Subsoil on a mobile device

Visualizing and estimating the distance and depth of underground infrastructure

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Abstract

Augmented reality adds extra visual information to the real world by superimposing computer generated graphics over real world images. The end result can be displayed on mediums such as computer monitors, head mounted displays or mobile devices.

Today, augmented reality is becoming more mobile because smart phones, tablets and other handheld devices are much more capable of presenting real time overlays on camera images than before. This increased mobility allows for new applications of augmented reality such as the visualization of underground infrastructures, like cables and pipelines. Visualizing these infrastructures on location offers the advantage of immediately knowing whether there are any cables and pipelines nearby. Which is a particularly useful tool for excavators, city planners, and emergency services personnel.

Creating an augmented reality 'app' suitable for such applications requires the ability to get an accurate location dependent view. It also requires the ability to correctly estimate the location of virtual objects displayed on the screen, as if they were part of the real world. These two requirements are the focus of this thesis.

The first aspect is to determine whether augmented reality is suitable for professional applications which require an accurate display of information. The second aspect focuses on the human factors, the perception of distances and depth of augmented reality, when displayed on the screen of a mobile device. Determining the distance and depth of virtual objects, superimposed on an image of the real world is not a straightforward task. Cues that normally aid humans in seeing depth need to be artificially added to the virtual objects. Most prior research on this area focuses on relative depth and distance cues using head mounted devices.

In this research, two experiments were conducted in order to evaluate which depth and distance cues and techniques enable the user to best determine depth and distances. The experiments build upon techniques from previous research on depth cues, and in some cases they are an adaption of them. In the two experiments, participants were asked to estimate the distance or depth of a virtual target object. The participants also had to specify how confident they were that their estimation was correct. In the distance experiment, an extra task was performed in which the participants had to measure distances using a paper map. A third experiment was conducted to find out how well the mobile device can determine its geographical location and orientation.

The results for the user study indicate that all of the presented techniques improve the accuracy estimation of distance and depth. The estimation of depth, especially without any help of cues, was considered to be significantly more difficult than the estimation of distance. The technique resulting in the most accurate distance estimations in the quickest time for the distance experiment was the 'range finder'. This technique estimates and presents the distance on the screen which gives a lot of confidence in the accuracy. A 2D depth cross section presented on the display resulted in the most accurate depth estimation and was the most preferred as well.

Based upon the third experiment, experiences during development and observations during the user study, it is evident that augmented reality on mobile devices still requires various improvements in order to be suitable for accurate professional use. Of which, most are hardware based. The accuracy of the orientation sensor, and especially the GPS sensor, are lacking the accuracy required and the readability of the screen becomes troublesome with sunlight.

Keywords

augmented reality, depth perception, depth cues, mobile devices, evaluation, map reading, mixed reality

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Contents

1 Introduction

1.1 Background

Excavation and urban planning operations depend on subsoil knowledge. Knowledge about the subsoil infrastructure is important before construction workers can begin excavating or (urban) architects can design and renew city areas. The ability to see underground infrastructure on location is advantageous for both fields of work, and is also useful in other fields, such as maintenance or emergency services [96][97].

Traditionally, paper maps are used in planning or excavation operations. However, paper maps are not very user-friendly for a number of reasons. First, they can easily be held in the wrong direction, they are not dynamic, they are difficult to read when they contain overlapping data layers, and lastly, they are difficult to keep up to date [99]. It is also easy to misinterpret the current location when no distinct features are in the area, and this can lead to incorrectly determining a position. Paper maps also have good qualities. First, they can offer an overview of the area. Secondly, where digital maps depend upon a power source, paper maps do not and can be used without any sources of electricity. Finally, determining distances is relatively straightforward if the maps contains a scale and if the user has a ruler.

Digital maps have also become popular in the last decade. They have become available through online web services, accessible from either standalone computers or as applications on mobile devices. Combined with satellite navigation, digital maps are often a common addition to activities like driving or hiking. They offer advantages over paper maps in the area of navigation such as automatic positioning when a GPS receiver is available, automatic orientation when a compass sensor is available and also a screen that can display real-time up to date information. The screen can display layers of information which can be switched on and off, or could zoom in on important locations to emphasize on future actions that will need to be taken by the user.

Top down digital maps also have drawbacks that could be improved upon, for example using augmented reality. Digital maps with a top down projection cannot display information in 3D, as they are only 2D. Layers of information all share the same horizontal plane and can only be stacked on top of each other by a certain order. Information will therefore always overlap, and this may be confusing for the user, leading again, to incorrectly determining a position or reading information incorrectly. While using 2D maps on location, a user would have to mentally transform the map to a 3D representation of the area [31]. Coloured contours of buildings would need to be matched with the real world around the user. Although digital maps can aid with automatic rotation and positioning of the map, knowing the exact world location requires mental transformations. Augmented reality can offer a 3D perspective view where it would be possible to display 3D models of the environment or of the data itself instead of abstract polygons or icons. This would require less mental transformation of data and information, and would likely result in more accurate perception of data [84].

Underground cables and pipelines, data critical for excavators, could also be displayed in 3D as an improvement over top down 2D paper and 2D digital maps. Augmented reality could enable one to see how deep the subsoil infrastructure lays under the ground, even when infrastructure is located on top of it [12]. Additionally, augmented reality facilitates visualization of physical features of the pipeline in relation to the real world, such as pipeline diameter, valves, and levers through the use of 3D models. The automatic generation of such 3D models [86] for use in augmented reality is being studied [75][85]. Such aspects of the underground infrastructure may not be as apparent on a paper or top-down digital map, but they could become clear to the viewer using augmented reality.

Augmented reality superimposes virtual models on image input acquired from a camera. A hardware platform to deploy such an application has already emerged, as mobile devices such as smartphones and tablets, are becoming increasingly popular and accessible. As technological improvements follow rapidly, hardware limitations become less of an issue and it is likely that ‘apps’ for mobile devices will soon become an important asset to engineers and experts.

2 Augmented reality

Augmented reality is a technology that allows the user to view things as they are in the real world along with additional data that my otherwise not be visible. The "reality" in this case is not completely replaced like in the case of "virtual reality" where the entire world is completely virtual [20]. Augmented reality is becoming a mainstream technology a mainstream technology, likely because of the increase in smartphone sales [63] and usage.

2.1 History

During a conference in 1965, Sutherland [35] mentioned the use of a visual display that would depend on the way someone would look, that could display images not bound to ordinary rules and would also be able to look through objects. Since then, this idea went from a concept to an actual product. As computer technology began to develop rapidly around 1980s, more research was performed on virtual reality and mixed worlds. At the start of the 1990s various augmented reality applications started to appear [66]. From the early 2000s either laptops, small computers or personal digital assistants (PDA's) were used in combination with various tracking sensors.

Augmented reality became widespread during various applications shown on television. At American football matches various virtual graphics were overlaid on the playing field showing additional information [82]. In soccer, sometimes advertisements appeared on the television screen that looked similar to normal banners around the soccer field, but were actually virtual.

In 1999 a software toolkit was released by Kato named ARToolkit [37] which provided programmers a library to create augmented reality applications with. From this moment development of augmented reality applications really started to lift off. Even though augmented reality becomes a more mature technology, the steps are small and it has not been until recent that more serious applications are considered, instead of seeing it as a gimmick for games and technological tests.

2.2 Applications

Research and applications using augmented reality have spread over a broad domain of categories. Azuma [01] has created a list of these categories and provides some examples. A short summary of this list:

- Medical, by providing 'X-Ray' vision abilities to medical staff
- Manufacturing and repair, presenting instructions and blueprints directly on machinery
- Annotation and visualisation, to display related information to the real environment
- Robot path planning to aid in robot motor control
- Entertainment which mixes virtual and real worlds for entertainment purposes
- Military which commonly use additional information displayed on Head Up Displays (HUDs) on helmets and screens

Free 'apps' like the augmented reality browser named Layar [05] make using augmented reality in our daily lives progressively more simple. Layar provides a directory of so called "layers" that augment an image recorded by a camera on the device with an additional layer of information. Some layers that can be found on Layar are for example:

- Real estate companies that inform you of houses that are for sale or rent in the area around you.
- Another example is the layer that displays air planes that are nearby including information about their departure, destination and velocity.

Augmented reality just went past the *peak of inflated expectations* [98] in the Gartner hype cycle of emerging technologies of 2011. This means that augmented reality will now slowly mature and become a serious and useful technology for the general public.

2.2.1 Taxonomy

Milgram and Kishino [20] proposed a taxonomy about the Virtuality Continuum. This taxonomy defines a range over reality (the real world) and complete virtual environments, that do not contain anything from the real world. Everything between these boundaries is called "Mixed Reality" (MR). Augmented reality's primary visuals come from reality. On these visuals, a computer generated image is super imposed, supplementing the reality with a virtual environment. In augmented virtuality (AV), the environment is mostly virtual, and the opposite of augmented reality, as extra information is added from the real world instead.

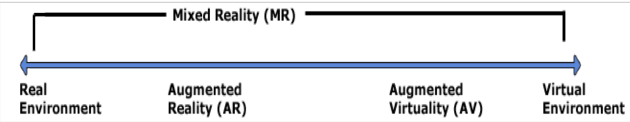


Figure 1. The virtuality continuum as defined by Milgram and Kishino [20].

Azuma [01] defines an augmented reality system to have the following three characteristics:

1. Combines real and virtual
2. Interactive in real-time
3. Registered in 3D

This definition ensures that augmented reality is technology independent, yet requires real-time interaction. Movies with special 3D effects like virtual characters are therefore not supported by this definition. Azuma also remarks that augmented reality is generally considered to only add information to reality. Augmented reality, however, can also be used to remove information, by removing an unwanted real object from the scene completely and replacing it with a virtual object.

Although augmented reality techniques are improved regularly, there is still a long way to go to integrate virtual models into the displayed image of reality. Reflections, complex light, radiosity (global illumination) effects, and shadows are still not possible to display in a convincing way. Collisions with the real world are becoming available through the use of various feature detection algorithms on images captured by the camera [76].

2.3 Augmenting the view

There are two methods of combining the virtual and real images, both of which have advantages and disadvantages.

2.3.1 Optical

Optical based augmented reality relies on a view created by mirrors (Figure 2) and computer graphics. Using this technique there are no cameras used to record the world environment. What is seen is directly based upon the real world, except it passes through a set of mirrors, similar to the optical view finder of a single lens reflex (SLR) camera. A virtual image is created by the hardware and then placed on the mirror surface of the device by a small light projector which is integrated in the head mounted display (HMD).

Currently the creation of augmented reality enabled contact lenses has been researched as well [74]. As these lenses are directly placed on the eyes of the viewers, there are many benefits. The most important of which being that no special equipment will be required to (such as glasses). The current systems only allow for a small amount of coloured pixels but the technique itself looks promising.

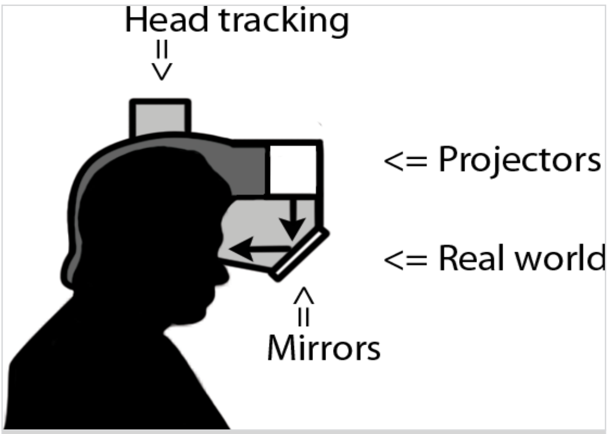


Figure 3. Optical see-through HMD.

Video

The second way of presenting augmented reality graphics is by using video. A camera records footage of the real world, preferably at a smooth frame rate of at least 25 frames per second. The frames of the video are then combined with the computer generated images. This combined view is the augmented reality view. Various methods to create such a system exist. For example, one could use a Head Mounted Display (HMD) in combination with a camera to record the frames and to place the augmented view in front of the user's eyes as seen in Figure 4.

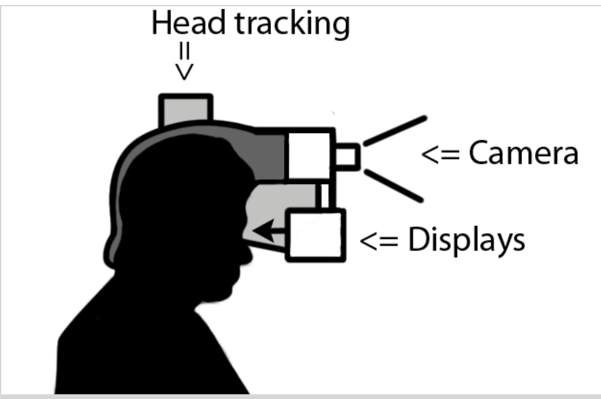


Figure 4. Video based augmented reality.

Using a mobile device like a smartphone or tablet is another medium to use an augmented reality-capable system. In this case, the camera on the rear side of the device records the video input for an application. This application will again super impose the computer generated images on the footage and then show it on the display.

Video-based augmented reality heavily depends upon the performance and resolution of the camera. When the camera produces poor footage, then this will have a direct effect on the quality of the presentation. Further, if the camera has a different field of view (FOV) than the human vision, a mismatch occurs in the actual perception.

2.4 Augmented reality positioning

There are two classes of augmented reality that directly influences the way it is used: vision based and sensor based. Each has its' own particular advantages and uses.

Sensor based

Sensor based augmented reality relies on other sensors to determine what to show, and where. In most cases there are two types of sensors used: a position sensor and a sensor that determines orientation. The position sensor is commonly a GPS sensor, which allows the device to know *where* it is. The orientation sensors are used to determine which direction (compass) the device looks at and how the device is held (orientation sensor). Modern smartphones are equipped with a vast amount of sensors The device used throughout this paper, a typical modern smartphone, built in 2011, contains:

- Accelerometer
- GPS
- Light sensor
- Compass

2.4.1 Vision based

Vision based augmented reality relies on the image acquired by a camera sensor, which is commonly part of the same device that displays the real-time camera image. The application analyses the incoming input stream of images for (known) patterns such as fiducial markers (Figure 5).

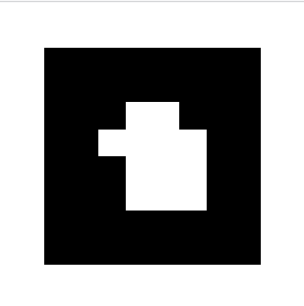


Figure 5. A fiducial marker

For such a given pattern, the application has been programmed to recognize these and to perform specific actions, such as placing a 3D object on the screen with a certain transformation (translation, rotation, scaling). When the pattern is moved or rotated, the program will also apply the transformation on the 3D object so that the 3D model remains "stuck" on the given pattern.

This type of augmented reality is commonly used indoors, as an alternative to sensor based augmented reality which often relies on GPS. GPS cannot be used inside buildings because the satellite reception is poor or not possible at all. The vision based approach also allows a more controlled dynamic environment because many markers can be used at the same time. For example, one could make a game of chess based on solely markers for the pawns and one marker for the board grid.

It is still possible to use this technique for outdoor purposes as well. Patterns can be placed on certain locations. Or, the location itself can be used as long as they contain patterns that can be recognized by image recognition. For example: paintings, posters, statues or buildings. When such a pattern has been recognized, some predefined action can be taken by the augmented reality application.

The prototype application build used in this study will solely rely on sensor based augmented reality. This is because what needs to be visualized by the application is underground and therefore not visible. Often the only way identify the location of nearby cables and wires is visually by the presence of maintenance holes and covers for electricity, sewer, or gas. Unfortunately these covers do not provide much more than a single location. If maintenance hole covers were unique, the usability would still be limited. The cover would have to be continuously in the field of view of the camera in order to determine the position of all the 3D geometry that need to be rendered. This would mean that the phone would always have to be held somewhat downwards and looking around would not be possible.

2.4.2 Registration

Putting virtual objects in the view of the real world through either optical or video based techniques is called *registration* [21]. This is the field of research that captures a lot of attention: The believability of the augmented reality application begins with a correct registration. Without proper registration the believability of the augmented view is reduced severely.

The term registration is also used in solely virtual environments where objects also need to be placed on locations that match with the viewer's location. In a virtual reality environment a user would expect that walking against a wall would result in a collision. If this does happen, it will lead to a registration error and create confusion. This is because, users in a virtual reality environment will try to apply normal physics laws to the virtual objects.

These registration mismatches can occur because of the following reasons:

- *Inaccurate positioning of virtual objects*

Virtual objects will need to be superimposed correctly on the input image (for both optical and video based systems). Mismatching may occur, however, because the positioning of the virtual objects can be inaccurate, or they may lag due to a delay in the software processing needed before superimposing the computer generated graphics on the optical or video surface.

» *Incorrect position determination*

Inaccurate position determination can also be a reason that causes objects in the virtual world to mismatch with the real world. When using sensor based augmented reality, the position of the viewer will constantly be updated. Therefore when the GPS accuracy changes, the viewer's location will 'jump' constantly to other locations. Fluctuations in the sensors of the devices can also cause the virtual objects to slightly move around the screen while standing still as well.

Because image based augmented reality relies on fiducial markers which are in most cases placed on a fixed location (they do not move out automatically), it suffers less from registration errors. The capturing frame rate of the camera device is the critical factor. While moving the device which displays the augmented reality, the super imposed virtual world should not lag behind. The ability to recognize fiducial markers is reduced when the distance increases between the camera and the marker. Eventually there will be a point where the software has problems determining the transformation of the marker or does not recognize the marker at all.

2.5 Human factors

Superimposing virtual objects onto a screen or optical display brings various human factor related issues. Some of these factors have already been mentioned, but [42] breaks these down in the following:

- Latency, where the delay of the registration updates will cause perceptive errors for the users
- Depth perception which is difficult, incorrect or both depending on the scene setup
- Adaption, as humans adapt to the augmented reality system when wearing a HMD. When they are finished they will need to adapt to the normal situation again. This does not apply to video based augmented reality applications on devices that are not immersive such as mobile devices.
- Fatigue and eye strain as some displays cause eye strain after prolonged use. Eye strain itself can lead to fatigue again.

2.6 Egocentric and exocentric

Augmented reality applications can use both egocentric and exocentric views, but this depends on the way in which augmented reality is used by the user.

In an egocentric environment the viewer his or herself is in the middle and the source of the view itself. This is the case with mobile augmented reality were a user looks 'through' the screen.

Alternatively, when using an exocentric view, the viewer is seen from an external point of view. Behind the viewer, for example. This is not possible in a typical augmented reality setting where a single camera is held by the user. It is possible to have an exocentric view if the user were not to use a first person view. For example, the user could look on a paper map using the mobile device. The paper map is recognized to be the map of the area and the application puts a virtual avatar of the user on the screen which is placed on the map where the user is currently located. The user now has an exocentric view of his or herself.

Exocentric views are more common in virtual environments where one would have a virtual avatar. This avatar can be viewed from any direction as the application would only need to change the virtual camera.

3 Research goal

As previously discussed, the way in which 2D maps present information about underground infrastructures could lead to confusion when a user attempts to locate a particular site. Where urban excavation is concerned, a users' misperception or misunderstanding of the subsoil could result in incorrectly determining a position, thereby digging in the wrong location, and causing significant damages which would result in greater costs and repair. Augmented reality could likely aid in understanding subsoil infrastructure, and as such could reduce potential human errors that cause damages [11][100].

It is important to determine whether the estimation of distance in augmented views could be improved by adding depth cues. Cues could be added in such a way that the distance measurement is comparable to the currently used top-down 2D paper maps, while of course providing the benefits of having a 3D view.

Developing an augmented reality application, however, is not free from problems of its own. Some of these problems have a technical origin like the accuracy of the device's gyroscopic sensors or the sensitivity of the internal GPS receiver. However there are generic concerns as well, which are not bound to the hardware, meaning that these issues affect more than just one certain brand or model of a mobile device. These issues can be related to the user's perception of the mixed environment created by superimposing the virtual rendered objects onto images of the real environment. Such issues include the mismatching of occlusion cues or virtual objects having an unrealistic exposure when compared to the real environment [40].

Cognitive and perceptual issues in the field of augmented reality are not straightforward to solve, because the human brain will need to be deceived to interpret virtual objects as they were part of the real world. When dealing with geographical positioned data, the proper estimation of vertical depth (in the ground) and horizontal distance by using a superimposed display of cables and pipelines is such an issue, and needs to be addressed. Where urban excavation is concerned, a users' misperception could result in incorrectly determining a position, thereby in digging in the wrong location, and causing significant damages which would result in greater costs and repair.

3.1 Project focus and research questions

With the primary goal in mind of developing a tool that allows visualization of subsoil cables and pipelines infrastructure, this project will focus on the perceptual and cognitive issues related to distance and depth perception of underground cables and pipelines in outdoor augmented reality on mobile devices.

The virtual objects are those that lie below the surface and are super imposed on video images of the real world. Objects are therefore always on top of the video images and the depth and distance cues are either mismatching or not existent. As discussed before, inaccurate depth and distance estimations could lead to costly repairs from excavating in the wrong areas. In order to improve these cues the following research questions will be addressed:

- How can artificial depth and distance cues be improved in the augmented reality visualization such that the overall result is a more accurate determination of absolute depth and distance than when using paper maps without cues?
- Could 3D augmented reality aid in understanding the subsoil infrastructure, by improving user accuracy and confidence, thereby resulting in less damage from excavating in the wrong places?
- Could a modern mobile device be used to create a professional augmented reality application to visualize subsoil infrastructure in a usable way?

The focus is primarily on absolute depths and distances. Instead of studying whether a user could determine if one object is in front of another other, the focus is whether the user can estimate the absolute distance in a unit system.

Although this thesis will use only visualization cables and pipelines, there are many other visualizations that can benefit from research about depth and distance visualization. For example the visualization of archeological findings or polluted soil on a site that is considered to be part of a new construction project are both areas where these findings could be relevant.

3.2 Objectives

To answer these research questions and to improve the distance and depth estimation in augmented reality setups, two objectives have been formulated. These objectives are used in a qualitative user study which was performed in a within subject design type experiment.

3.2.1 Cognitive and perceptual aspects for distance

By comparing methods of distance cues in distance perception of cables and pipelines using augmented reality, it is possible to determine which methods work well, and which do not. The cues for these comparisons have been acquired by a literature study or by an adaption of techniques when deemed to improve upon the original. The data used in the study was based upon real data from the Dutch cadastral office acquired online through a website. The comparison criteria for the distances cues are:

- » Accuracy of estimated distance compared to actual distance (centimeters)
- » Certainty (or confidence) of the user in his or her estimation (fixed scale)
- » Effort required by the user to determine distance (time, seconds)

3.2.2 Cognitive and perceptual aspects for depth

Similar to distance, comparing the differences in depth perception of the cables and pipelines using augmented reality, it is possible to determine which methods work well and which do not. The comparison criteria are:

- » Accuracy of estimated depth compared to actual distance (centimeters)
- » Certainty of given depth (fixed scale)
- » Effort required to determine depth(time, seconds)

3.2.3 Paper map compared to augmented reality

To determine whether the subjects in the experiment can measure distance better using either augmented reality or paper maps, an additional objective is to perform a comparison in distance measurement and confidence between these techniques.

- » Let the subjects perform distance measurement tasks using a paper map, using the same positions as the tasks performed in the augmented reality experiments. Compare how accurately the subjects measure distances and how certain they are of their estimations when using augmented reality visualizations.

3.2.4 Goal of this research project

The purpose of this research project is two fold. First, the goal is to determine if it is possible to use smart phone devices combined with augmented reality for creation of tools which can visualizing hidden objects with geographical coordinates, using the current state of technology. Second, it aims to answer the question if adding artificial depth and distance cues can improve the ability for users to determine depth and distance significant more accurately than without such cues. A prototype called 'CLARA' (Cables and pipelines augmented reality app) will be created in order to research the depth and distance cues.

4 Related work and theory

Hidden underground cables and pipes have been a problem for a long time, as early cables and pipelines were already being placed underground in the middle of 19th century [09]. There have been various solutions to aid in finding these underground infrastructure elements. Some of these solutions are rather practical and analog like the still commonly seen cable signs at the shores of small water ways (Figure 5). These signs indicate that a certain type of cable is located in a straight path to the other side of the water. Such signs function as a (last) warning to anyone that wants to perform any kind of excavation activity in the area. Using boat anchors is prohibited as well.

Figure 7. A sign indicates a gas pipeline is nearby.

Sometimes they are difficult to spot.

Further, the Dutch cadastral office (Het Kadaster) offers a service which returns images or digital documents upon request. It is by law [25] required to perform such a request when performing mechanical excavation activities. More about this process can be read later on in this paper (chapter 9.1), as this information is an important data source for this project.

With the availability of mobile computers, the increasing use of GIS applications and the availability of GIS data [83], some of the visualization and registration aspects of the underground infrastructure are transforming to the digital domain, instead of analog. Though some research is more advanced than others in this new field, the research altogether provides a general background on underground infrastructure visualization and techniques, as well as an idea of a the problems encountered and relevant solutions provided to date.

4.1 Related projects

The prototype application in this project is not unique in its goal to visualize subsoil information. However, it is unique in its attempt to solely rely on a mobile device like a smart phone.

Vidente [12] is a project for the creation of handheld augmented reality device called Vesp'R that allows its users to see underground infrastructure, make notes and edit it. The research project is executed at the Institute of Computer

Graphics and Vision of Graz University of Technology in Austria. The device is build using various separate devices which together form one single handheld device. All these devices that Vidente merges, like GPS, inertial sensor, UMTS wireless data adapter, camera, joystick handles and an Ultra Mobile PC (UMPC) are vastly covered in modern smartphones. Of course the joystick handles are rather different than the touchscreen or rocker button on smart phones.

Figure 8. Vidente AR displaying the underground infrastructure.

Vidente retrieves its 3D geometry from a conventional database which is then converted to a lean Geography Markup Language (GML), which is in the XML format with a certain schema applied. The GPS of Vidente allows the device to know its geographic location on Earth, and the inertial sensor is used to track the orientation of the device. The camera displays the video stream on the display with an overlay created by the Vidente software which is ran on the UMPC. Data can be exchanged using the UMTS module. One rather interesting feature of Vidente is the two grips on each side. These grips allow the device to be used for a longer time by its users than without [12]. The authors also state that the joystick input reduces error prone inputs using a stylus. Yet the equipment is specifically made for an augmented view of the underground. One of the aspects of this thesis is to see if similar functionality can be achieved with modern smart phones as such devices are more diverse in their applications.

Vidente's GPS provides accuracy to within one meter, which the receivers in modern smart phones *should* also be able to achieve an accuracy in that range. Other functions provided by Vidente are filtering the visualized data into categories (gas, water and so on) and providing an 'excavation tool' which resembles a hole in the ground. Figure 8 displays this tool. The latter was implemented in order to improve depth perception and was rendered using a magic lens technique [12]. It can also take a snapshot of the current image which can be viewed in a different moment. If the input data provides metadata, then this can be viewed as well. Further interaction is supplied by allowing the user to annotate onsite with special symbols (damage, maintenance areas). The radius of this annotation area is configurable by varying the direction of the device.

Another project, partially by the same authors as the Vidente project, demonstrates the use of vision based augmented reality to display underground infrastructure [75]. The information is super imposed on the table itself, which contains of a maquette. The fiducial markers are used for positioning the projection (Figure 9).

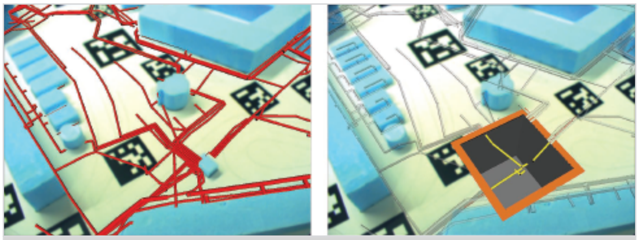


Figure 9. Visualizations of cables projected on a maquette image. The right image demonstrates magic lens functionality. Image courtesy of [75]

Cote [91] started a blog in December 2011 with various projects involving the display of underground infrastructures. The blog specifically focuses on the perception of depth when using hidden data such as cables and pipelines. The intentions of the author are similar to this thesis: Determining how distance and depth cues can be improved and if mobile devices are suitable for such applications.

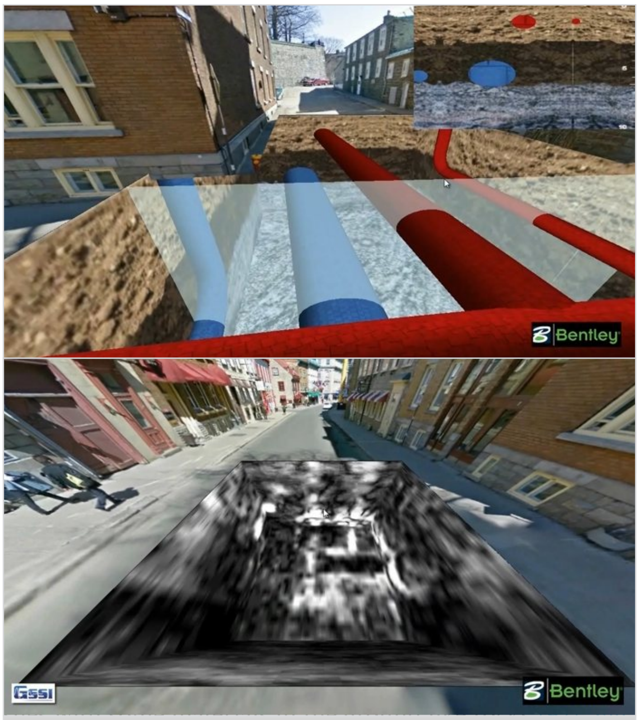


Figure 11. Ground Penetrating Radar data super imposed on camera images taken of the street. Image courtesy of [91]

4.2 Related work about depth and distance cues

Depth cues have been a matter of human interest for a long time, as drawings from ancient Egypt already show the use of some cues [54]. Famous artists like M. C. Escher[88] have been using depth cues to trick the human mind into seeing contraptions which are impossible to build. These depth cues have a powerful effect on the human vision and therefore also play an important role in digital computer graphics.

The surface of a modern computer screen is flat. By using various colours, shading and border combines the illusion of depth can be evoked. For example, when a toolbar button has been pressed the colours and borders change in such a way that it gives the illusion of being pressed (Figure 12). In 3D virtual reality environments these cues play a role in convincing the user to be part of the world [89]. This also applies to augmented reality where virtual objects are mixed with the world. Without a proper set of various cues the mixed reality will not be convincing to its users [90]. This is one of the main reasons why a lot of research has already been performed in this area.

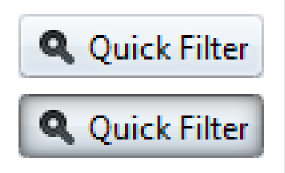


Figure 12. User interfaces depend heavily on depth cues

The research on depth cues in mixed reality settings is widespread, and there are many approaches to adding depth cues into a view. These approaches depend on the type of visualization that one tries to achieve. For example [03] overlay edges of virtual objects on top of the real world images to enhance the perception of depth. Various depth cues have been discussed and experimented with in [43]. In this paper the subjects of the experiment use head mounted displays instead of a mobile device. The subjects had to align a real pole on a virtual marker on the ground. The cues added to the augmented reality view were shadow, a circle which size depends on the closeness of the virtual marker to the ground, droplines and an absolute number. In this study augmented reality techniques perform better than non augmented reality techniques such as the absolute number.

Various elements are important in this study. One of such is the type of depth cue, as there are binocular depth cues and monocular depth cues. The chapter 4.3 contains more background information about these differences. In short, binocular cues rely on two eyes (or images) to create a sense of depth while monocular cues only use one image to do so. In previous studies head mounted displays are commonly used and these give the ability to present binocular cues. However, the target hardware in this research project exists of a mobile device which can only offer monocular cues.

The environment is also one of the elements to take into account. Various studies only perform experiments indoor and have a limited working range. While outdoor experiments offer a larger working range. Outdoor does provide a less controlled environment as the participants might get distracted or use natural distance cues.

Depth ambiguity is a topic that has been well researched and various solutions and guidelines have been proposed to overcome some of the perceptual issues, some of which have been by studied by Furmanski et al [51]. These guidelines can form an important base when designing augmented reality applications when displaying obscured information. Proper working depth cues are of large importance to create convincing augmented reality graphics.

Instead of just using the cues to determine the distance, there have also been various attempts to improve interactive tasks in augmented reality where the users would move and place objects at a distance. Wither [50] uses various techniques for interacting with virtual objects having a distance to the user. Such techniques include a top-down view with grid lines that indicate how far each object is from the user, coloured markers indicating distance and 'shadow planes' where a checkered plane on the left and top of the screen receive shadows from the objects, allowing the distance to be estimated through these planes (Figure 13).

Figure 13. Various distance measuring techniques.

In this case the distance was relatively short (close to the subject). A depth cue technique created by the authors of the paper was preferred over the other techniques. The technique displayed a circle that changed its radius depending on the vertical distance between the real pole and the virtual marker such that it became smaller when the distance decreased. Some of these techniques will serve a basis for the techniques used in this thesis.

4.3 Depth and distance cues

Humans use various cues to see depth. Binocular depth vision is achieved by using two eyes which are on two different positions (Figure 14). Each eye sees an image of the world that is slightly different than the other; this is called binocular disparity. The brain then takes both image inputs into account,

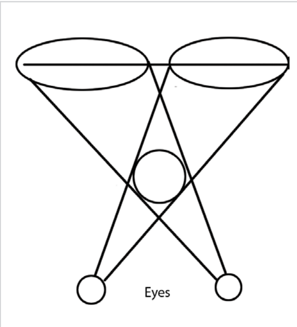


Figure 14. Binocular depth perception.

which results in a 3D view of the world. Some electronic displays try to mimic the binocular effects. For example, HMD's can show two different images, one for the left eye and one for the right eye, creating artificial binocular disparity and thus creating a sense of depth. This is also the reason why most research on mixed reality and depth or distance cues is performed with HMD setups [57]. Modern displays or 3D TV's can show two different images on one single screen by using a polarized screen. Both images are extruded by using polarized glasses which will both result in a different image for each eye.

Besides binocular depth cues, there are also monocular cues. Monocular cues do not rely on the disparity created by two eyes, and can be viewed by using just one eye. These cues rely on other factors such as [44] the change in texture detail over distance, haziness when objects are further away, and the change in size over the distance.

With electronic displays that do not support 3D functions, monocular cues play a major role in creating a feeling of depth. Many of these cues can be found in modern 3D games that use a perspective view of the world as seen in Figure 16. (distance fog, size scaling, shadows, occlusion, etc.). Monocular cues are also commonly used by artists such as painters and drawers to add a feeling of depth to their creation

Figure 16. Levee Patroller showing various depth cues. Image courtesy of Deltares [69].

Various models explain how humans perceive depth, given a number of different depth cues as defined by Howard and Rogers and cited in [49] The most commonly used or accepted model is called 'cue averaging'. This model relies on weights that are given for each cue. Summing the cues while being weighted will result in the perceptional outcome. Other models described by Howard and Rogers are: *cue dominance, cue specialization, range extension* and *probabilistic models.* These are shortly described by [49]:

- Cue dominance: when different depth cues conflict, one may cancel out the other
- Cue specialization: based on the idea that some cues may be used for other components of a stimulus than other different cues
- Range extension: uses the idea that the different depth cues each have a certain working range, some working better in a nearby situation, while other cues are more effective on large distances to the eyes
- Probabilistic model: cues work in a probabilistic way using prior assumptions and a Bayesian framework

Depth cues are important to augmented reality, specifically in both binocular (when using a HMD for example) and monocular setups (in the case of displays as found on mobile devices on computer screens). Depending on the setup, various solutions have been earlier proposed to improve the depth perception in augmented scene [51]:

- Additive transparency; The most common method of visualizing depth. Human perception becomes confused with too many transparent layers on top of each other.
- Size scaling of rendered surfaces; similar to perspective. Objects can be displayed smaller when they are displayed further away from the viewer. The viewer should be made aware that all objects would be the same size if they where all equally far away in order to judge depths correctly.
- Over-rendered transparency; by rendering a cut away in the real world object (like a wall) and replacing it by an image of what would be on the other side.
- Distance markers; Markers which display some kind of depth measurements or have a fixed distance between the markers. This allows the viewer to determine either absolute or relative distances.
- Temporal distance coding; Not all objects are presented at the same time. For example, they are presented as a function of distance. Objects on various distances would be presented on different times.
- Ground plane grids; displaying grids on the ground plane to aid in absolute or relative distance estimation.
- Marker fore-shortening; This technique would make lines connecting objects and labels together dependent on the distance. Objects closer to the viewer would have thicker lines than other objects further away.
- Alternate perspective; using different perspectives (views) to display the same information from a different angle.
- Symbolic representation; Using symbols and icons to communicate depths to the user.

Contrast can also be used as a depth cue [41]. Objects that have a high contrast to the background appear to be closer than objects that have a lower contrast instead.

When a virtual object has a real surface nearby, it influences the perception of the virtual object significantly. The depth cues of the virtual object are affected by the real surface, and the object appears to be closer to the viewer than it actually was [39].

Table 1 provides a list of pictorial depth cues which can help in determining distances or depths.

Table 1. Pictorial Depth Cues. Text and images as defined by [49].

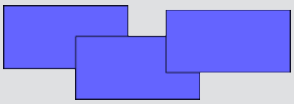
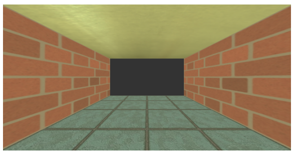
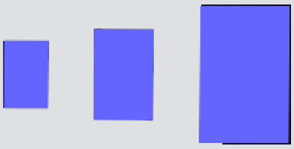
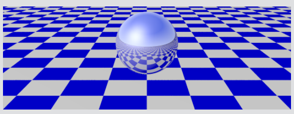
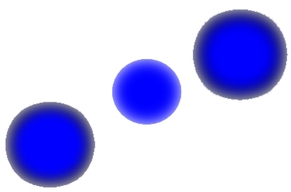
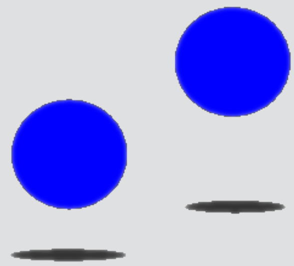
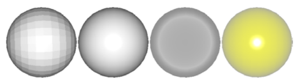
Depth cue	Details
	If an object overlaps some part of the other, it is known that the blocked object is further. It only gives information about the order of the objects
	In real life, parallel lines seem converging, as they move away, towards the horizon.
	The size of an object is inversely proportional to the distance from the viewer. Hence, larger objects seem closer to the viewer.
	When the world is divided by a horizon; the objects closer to the horizon seem further under the horizon, and seem closer above the horizon. (Painting: "The Coast of Protrieux" by Eugene Boudin.)
	In textured surfaces, when the surface gets further away, the texture becomes smoother and finer.
	The intensity level of an object varies with depth. Brighter objects are prone to be seen closer.
	Further objects seem hazy and bluish due to the scattering of the light in the atmosphere. Hence, aerial perspective increases the perceived distance. (Painting: "Near Salt Lake City" by Albert Bierstadt)
	Our eyes fixate on different objects in the world to bring them to sharp focus. The objects other than the object in the sharp focus seem blurry

Table 1. Pictorial Depth Cues. Text and images as defined by [49].

	If the object is in shadow, it is further from the light source. Shadows of the objects on the ground facilitate the perception of the objects' relative positions by connecting them to the ground plane.
	Shading provides important information about the surface shape by enabling the observer to distinguish between convexities and concavities.

Some cues like occlusion (will result in a binary condition: either object A is behind object B, or the other way around. The only other option is that they are not occluding. It is difficult to estimate absolute distance when only a single cue is present. Therefore additional cues are needed when absolute distance estimation is required. Such cues can be markers showing values indicating relative distance towards the user, or between objects. When one, or preferably more, of these cues are present, then it becomes possible to make estimations for absolute distance. The determination of absolute distance largely depends on the position of the eyes, such as where they converge [93][94].

As mentioned earlier, the effect of relative distance cues is subject to various ranges. The cues of occlusion, size and density are not attenuated by distance. Cutting & Vishton [54] explore the effect of distance on the cues extensively. They mention the just-discriminable depth thresholds (JDDT) of various cues. The JDDT indicate the sensitivity of discriminating the depth between objects. Occlusion is the most sensitive, meaning that it is almost always possible to determine a depth difference between occluding objects, yet it does depend on object size over distance. Height in the visual field as cue works up to a distance of a kilometer. The values are all rather approximates and idealize a perfect situation [54].

Alternatively, it is also possible to specify absolute distance markers. As an example, one could think of the hectare markers next to the Dutch highways. If the highways were to be placed in a simulation game, adding these markers would enhance the perceived distance travelled by the players. As the user drives over the road, the markers would let the user know that he travels 100 meters by just seeing the markers (relative) or by subtracting the value of the current marker to a marker seen earlier (for example: 147.3 to 146.6 would be 700 meters travelled).

4.3.1 Motion parallax cue

Motion parallax is a cue that works with relative distances between objects and velocity. Objects closer to the eye will appear to move faster than the objects which are further away. When the object does not have any (rotational) velocity, this cue is not visible.

4.3.2 Sound as a depth cue

Not all depth cues depend on visual stimuli. Sound can also play a role, as it travels slower than the speed of light. Given that sound travels roughly 340 meters per second, one can determine the distance by using the audible delay between *seeing* something happening, and *hearing* it happening, as it can help in tell that the source of the sound was a certain distance away. This technique is often used to determine the distance between a thunderstorm and a person. A simple division of the amount of seconds between the lighting flash and the sound of rumble by three (an easy to use approximate) will tell the person how many kilometers the storm is away. The prototype application for the cables and pipelines does not use audio, nor does the user work at a distance where a delay in visual and audio stimuli would occur.

4.3.3 Registration of distance

In research projects involving distance or depth measurements, there is a need to record the estimations of the subjects when performing experiments. This research project is not different in that concern. Many methods of registering the depth have been researched, some performing better than the other. Swan II et al [52] have performed a study dedicated to this subject. They state that there are three primary methods for judging and reporting the distance:

- **Verbal report:** The subjects will estimate and tell the distance in the units which they are comfortable with.
- **Perceptual matching:** Where the subjects will need to relocate a target object (which can be either physical or virtual) such that the distance matches, according to their perception, with another object used as reference.
- **Action based tasks: Which** can be divided in two groups, open-loop and closed-loop. The subjects do not receive any feedback while performing actions when performing and open-loop based tasks, while though they do in a closed-loop setting. [52] also stated that the most common open-loop task is called 'blind walking'. In such a setup, the subjects will get to look at an object placed at a certain distance. This is one of the most commonly used techniques because it has proven to be accurate to within a distance of 20 meters. Blind walking appears to have a better accuracy than verbal reporting, as the percentage as calculated by judged distance / actual distance) where over 85% for the blind walking experiments and for the verbal report it was 77%. These results also matched with studies which were similar of subject.

The same study also researched the underestimation of distance in virtual reality environments. This happens specifically when the objects are at or close to the ground plane and from close to the subject to medium distance. In VR worlds HMD's are commonly used and the relation between the underestimation and the HMD's have been researched. It might be possible that the underestimation is caused by the weight of the HMD and not by other factors such as graphics quality of the displays, or limited field of views.

5 Occlusion

When projecting information on top of camera footage, occlusion related issues are bound to occur. Basically, all the pipeline data is already underground and therefore should be occluded by the surface, which is identical to real life. As visualizing pipelines underground is the intended use of the augmented reality in this project, this is not considered a problem. What *does* look unnatural is that pipelines will appear to go through other objects placed on the ground (like constructions), as Figure 17 shows. Incorrect occlusion results in conflicting depth cues and could lead to confusion. Such occlusion problems are being studied in order to improve augmented reality visualizations [03].

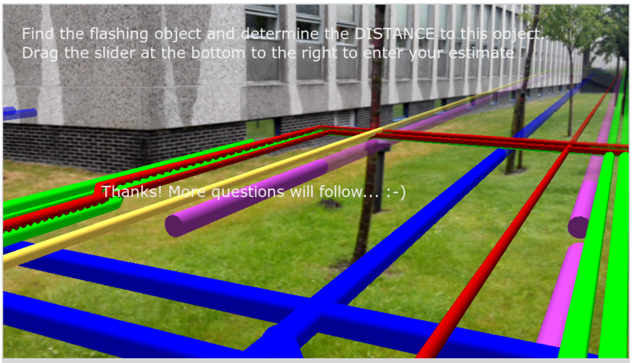


Figure 17. Occlusion problems. All the pipelines are rendered in front of the tree while some are behind.

One approach is to prepare a 3D model of the real environment beforehand. This model can be used to modify the rendered augmented reality display. The 3D model will have to be mapped accurately to the position and orientation in the real environment, and does not have to be visible. When the location of the virtual object is behind the hidden 3D model, it can be clipped accurately using the earlier prepared 3D geometry of the world. Another way of using a prepared scene is by using a depth map, which is an image where the colours indicate levels of depth from the camera to the environment viewed. Such a map can be used for depth testing. There are various research projects that try to emphasize the depth cues by using image enhancement features on real-time camera images such as edges [03].

Concerns with enhancing depth cues might be addressed in the future by integrating a depth camera inside the mobile device. An example is the Microsoft Kinect, although it is not a mobile device. The Kinect uses a depth camera of 11-bit depth and a resolution of 640x480 pixels. 11-bit depth results in a sensitivity of 2048 (2^{11}) different depth levels. The range of the camera is maximal 3.5 meters [38]. This range is likely to be more practical for indoor applications than outdoors. Consumer depth camera's are still in their infancy which might mean that improvements are expected.

6 Maps

6.1 Displaying map information on mobile displays

The subject of paper maps, digital maps and augmented reality have already been slightly touched in the introduction and background chapters before. This chapter tries to discover the advantages and disadvantages of those different means of displaying geographical information and covers various aspects: from cognitive and perception aspects to more technical elements.

When referring to mobile maps in this paper, digital maps on smartphone or tablet like devices are meant. This means that there are no other mapping techniques considered such as electronic paper, touch tables, and so on.

There are many different map projections for paper maps. Each with their own distinct representation of some geographical information. Projections can transform geographical map data to a flat 2D projection. An example of such a projection is the Earth projected as a Mercator projection.

Electronic maps offer various benefits to paper maps, such as the ability to:

- Zoom in and out to provide a dynamic level of detail
- No map borders, as there are no physical borders but only virtual (unlike paper, where the size of the paper limits the map)
- Either show or hide specific map layers or features

Some other concerns in relation to paper maps. Paper maps often come in a folded form and after unfolding are larger in size than a mobile digital map device. This is also why paper maps offer the ability to work collaborative [04], unlike digital maps which have a small display that also has a limited viewing angle which therefore is difficult to look at by multiple persons at the same time. Digital maps that support collaborative interaction do exist and often include touch support. Such digital map devices are more often than not the size of a small table, and at the height of a table such that multiple persons can stand around it. Such digital map tables are far from being mobile.

Mobile devices have a rather small display, which affect the ability to read maps or points of interest (POI's) on the map when there are too many [24]. Recent research has tried to find various solutions for these issues. A common map display technique is to display the user's position in the centre of the map display. Winter [04] states that it might be more efficient to display the user at the bottom of the screen instead. This allows the user to see more of the map information which lies in front instead of around.

The small screen size of the mobile device can lead quickly to unwanted cluttering of information on maps; like too many icons. This is the reason why map software often has various functions to reduce the information. Some common functions in 2D maps to reduce this are:

» Decluttering, only displaying the largest streets and a subset of the available information

» Zooming, to increase or decrease the amount of information presented on screen

» Detail level or layers of information which controls how much information is presented at any given time either automatic or by the user

Mobile devices and desktop computers increasingly become more like each other: The hardware improves such that it becomes possible to run more sophisticated programs, the resolution of the screen almost matches those of normal desktop monitors and so on. A good example of this is the Microsoft Windows 8 operating system, which runs both on new Windows Phones, but will also run on desktop machines. Nevertheless, there are still many differences between the different types of hardware to keep in mind. Chittaro [24] gives a list of the differences, of which the following is an excerpt:

» Displays have a small size, and also have a aspect radio that is quite different compared to desktop machines

» Concessions have to be made on computational performance, the performance is therefore a lot lower

» User input is handled in different ways (small keyboards, touchscreens)

» Large variations in form factors of the device

Kray et al [60] performed an experiment with various navigation methods. Using either (spoken) text, 2D sketches or maps and 3D maps. Their main purpose was to collect feedback from their participants about navigation through cities with 3D maps. There are various conclusions that are relevant for the research of this thesis:

» 3D maps were found to be slower than 2D maps

» The 3D world should be recognizable, in the study some of the buildings were difficult to distinguish

» The correspondence between 2D and 3D views might not be strong.

Although these are commonly seen in 2D digital maps, the risk of having an overwhelming amount of information on a 3D display are no less, and might actually have the potential of becoming cluttered even faster due to two reasons:

» Instead of having just one top-down view, the view has a depth. This means that it is possible to display information further from the user than other information resulting in (multiple) overlaps of information on the display as data will be behind each other

» Information will become closer together over distance when using a perspective view, as the perspective view moves the lines to the centre.

Such issues are there to be kept in mind when developing tools that display information in 3D (whether in augmented reality or in other mixed reality environments). Techniques like filtering using depth-sorting and reducing the visibility of objects further way can improve the readability on the display. Various of such studies have been performed which try to split the environment in two categories: focus and context. This can be achieved by rendering the augmented reality scene in multiple passes of objects related to each other and finally merging these together [80].

6.1.1 Frames of reference

When dealing with some kind of space, whether virtual or not, a coordinate system is required. Such a coordinate system will define how coordinates are specified for the objects, and what units they represent. In the standard Cartesian coordinate system two variations exist: Left-handed and right handed. In these systems some of the axes are different which can be seen in the explanatory Figure 18. It is important that the coordinate system is equal during communication between people, but also for software. Objects in virtual worlds will be on different locations than expected when the unit system or meaning of the axes are different.

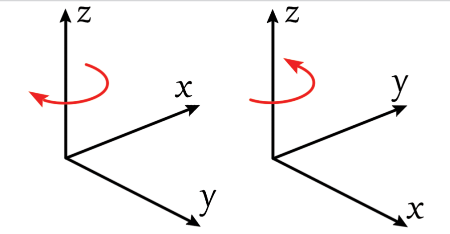


Figure 18. Left and right handed coordinate system.

The frame of reference in a map determines how objects are referred to the user. A coordinate system relies on a reference frame which defines what the subject of the system is. This could be for example the object itself, the world which the object is in, but also based upon another object. So, the frame of reference describes the location and rotational properties of a certain object.

Miyaki and Shah [29] mention some example reference frames in their research:

» A world frame with cardinal directions (N,S,E,W) and also up and down

» A head frame which takes the head orientation into account, which might be different to the body.

» Vehicle frame associated with the orientation of cars, planes and boats

» Display frame defining the orientation and movements of information on displays

These frames of reference are an important aspect in virtual worlds. An example is the virtual world represented by a computer screen. On Microsoft Windows based machines moving the scroll wheel of a mouse downwards will make documents in text editors or websites move down as well. In Apple based operating systems moving the scroll wheel downwards will make the documents move upwards instead. This is a simple issue of the frame of reference, which is here represented in two ways:

"*When you scroll the mouse, do you move the document inside the window or do you move the window over the document which holds its own position?*"

As augmented reality views are typical egocentric (the user sees the world almost if it were through his or hers own eyes), a common way to use a reference frame similar to the users head as the super imposed objects need to align correctly to the real world. If a different approach would be used it would undoubtedly lead to registration errors.

Navigating somewhere also requires a specific set of elements in order to successfully arrive at the destination. McCormick et al [30] defined a set of primitives that are the basics of navigation and movement and translation of reference frames:

» Where am I?

» Where do I want to go?

» How do I control?

» What is the array of space that I observe or operate on?

These primitives do not necessarily have to be used all at once. But in the case of navigating from one place to another all these primitives are required. In the case where the frame of reference directly applies to the user, or to something that is controlled by the user (like an avatar) then this is called the ego or icon frame of reference [29]. This is the common frame of reference in many navigational applications. Miyaki and Shah [29] also state that misalignment of the frame of reference for the controlled object and the displayed entities is an important human factor to keep into account. Sometimes in computer games the left and right keyboard controls are switched as a result of an action, and this results in penalty that makes control more difficult. In this case an misalignment occurs as the button for left would turn or move the object to the right, and vice versa. The amount of cognitive resources that are required to compensate for misalignment vary by the amount of misalignment. In studies about mental rotation [31] it became apparent that misalignments of 180 degrees are easier to rotate mentally (and therefore the mental costs being lower) than misalignments of other values like a misalignment of 90 degrees. This observation is interesting when it comes to maps which are either rotating with the direction of the user or always face with the north side up. With north being up, a user has to mentally translate the map to the egocentric frame of reference.

When using 2D maps the user still have to compare the map to their real view which is in 3D. This requires another additional mental rotation [29]. A 3D view could have less mental rotational costs but the selected view would have an important role in this.

A first person view like in augmented reality which matches with the perception of the user's eyes will require less mental resources than a view that offers a view from a different location or orientation like a 3D top down or side view [84]. In both cases the user will see an image which differs from their own image and will first need to translate the seen image to the egocentric reference frame.

6.2 Maps and mobile devices

Kray et al. formulate two types of resources which are important to the presentation of maps on mobile devices [19]:

» *Technical resources*

These resources include elements like speed, network bandwidth and the screen resolution. They influence the look and feel of the presentation.

» *Cognitive resources*

Which involve the way how the map information is presented to the user. By taking the cognitive resources into account the application can be optimised to make it easier to use.

There are other means of presenting map information to users. Often multimodal approaches are used in navigational software. In this software, a graphical map is combined with actions to take in the future. These actions are often directional actions and inform the user to turn somewhere or to keep following the current road. Navigation software in cars support in nearly all cases a computer voice for such instructions, such that the driver does not have to look as often to the screen showing the map. By not spending time looking on the map display, the driver should have more time to look at the road, and thereby should increase safety. This is also the reason why various equipment in cars sometimes have support to be controlled by voice commands [61]. Mobile devices often use a haptic modality to inform the user of an event, by vibrating shortly. In the prototype application this is not used as the focus is solely on the visual aspects.

6.2.1 Other factors in mobile devices

Other factors that influence the practicality of mobile devices in (semi-) professional use are directly related to the properties of the device itself. Most of these factors are related to the hardware itself, the materials used in the device.

Sunlight is often causing unwanted reflections on the glass covering the graphics display, such that the visibility of the display is severely reduced [19]. Raising the backlight intensity (increasing brightness and contrast of the screen) can reduce this effect to a certain extent but it does come with the cost increasing energy consumption and draining the battery faster.

The viewing angle of the mobile devices determines how well the display can be viewed from angles other than a direct perpendicular angle. Wider viewer angles could mean that other persons could also look on the same display instead of just having the mobile device for a single person. Cooperation is rather difficult on small displays as one needs to hold the display in front and rotate around the axis of the body. Which is rather impractical for the person(s) standing next to the person holding the device. A possible solution to this problem is by introducing multiple augmented reality performing devices and using these to collaborate on location as demonstrated in [46].

In dark locations the camera of the mobile device will most likely prove to have insufficient light sensitivity to be able to display anything but a dark screen. Sensor based augmented reality visualisation would still work, but without any visible context as the real world is not visible (Figure 19). This could potentially be solved by lighting the real world with an external light, or possible even using the flash light of the camera on the device.

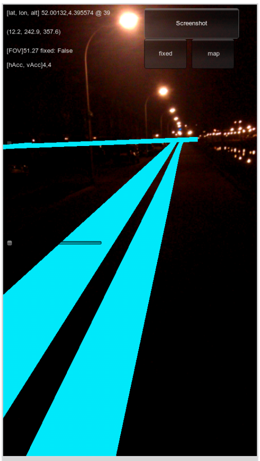


Figure 19. Augmented reality during night time.

Some of the factors such as the influence of sunlight and the lack of light sensitivity in the camera's are hardware issues which are likely to be solved in the near future. Various technologies are already under development to improve sunlight visibility [45].

Problems of precipitation and humidity and electric devices should not be forgotten, yet this can relatively easily be solved by using a form of protection such as a plastic sleeve. This might influence the touch sensitivity of the display, which can probably be solved by proper design of the user interface such that there is no interaction required through small buttons placed closed next to each other.

6.3 Screen sizes

The physical display size of mobile devices is a lot smaller than displays of normal desktop or laptop computers. This does not necessarily mean that there is significantly less room available to create an interface. The resolution and Dots Per Inch (DPI) of mobile device displays have been rapidly increasing over the last years [79]. This means that more information can be displayed on the screen, while keeping the physical size of the display the same. The main difference between tablets and smartphones is the size of the screen. Various studies have been in order to determine if there are differences (in usability and performance wise) between these two [78]. The study shows that larger displays do increase the speed of performing actions on a larger display, but that it also reduces the total awareness of what is presented on the display.

There have also been various prototypes of ideas that try to increase the amount of map data displayed. For example Harrie et al. [26] transform maps in "variable scale maps" such that the visual information in the centre matches the original map, while the outer part of the map is distorted to show more information of the area, instead of showing everything on the same scale.

6.4 2D and 3D maps

Because the hardware of mobile devices has become more sophisticated over time, 3D applications have started to appear. On modern devices it is possible to play full featured 3D games that exceed the graphics quality of the games that appeared on normal desktop computers around 2005. But the support for 3D graphics is not only interesting for games, but also for many other applications. Especially on mobile devices, which are carried in and outdoors. Navigation software are popular mobile applications [17] which also feature 3D navigation software. Some research has been conducted in this area to compare whether 3D maps have a significant value in terms of accuracy, performance and ease to use when comparing to 2D maps.

Most of the field experiments that have been performed are primarily about navigational tasks. The prototype in this project does not really focus on navigation, though. Yet, the results are interesting in terms of the comparison which is relevant to this project.

According to [06] 3D maps offer various qualities over 2D maps, such as:

» The ability to display volumetric concepts

» Multiple views of spatial data

» Models that are rich and realistic, supporting direct recognition of objects

» More degrees of freedom in movement

While 2D maps rely on the standard conventions to paper maps. Vainio and Kotala [13] concluded in a field experiment that users prefer a combination of both 3D and 2D maps, rather than using either one separate instead. The participants found it easier to find their own location in the world using the 3D maps as well. According to Crampton [14] the cognitive load is higher when using a 2D map as the user has to mentally visualize the map information and how it relates to the real world environment. When using a detailed 3D world, this cognitive load is lower as the user can compare the real world to the virtual world for objects that look familiar. This matches with the map reading process as described by Lobben [15] which states that the referential relationship between the map and the world lead to an understanding that is the basis for navigation by maps.

The rotation of 3D maps is generally directional, which means that the map rotation follows the direction of the user. For 2D maps this often not the case. Maps are often either "north up" and showing an icon at the map which indicates the current location of the user. Sometimes this icon is also an arrow indicating which direction the user is facing. A different 2D map view is where the map is oriented such that the top of the map is always the direction which the user faces (similar to 3D maps). Liben and Downs [16] give the suggestion that mental rotation is a harder process than rotation of the map it self. In the experiment of Oulasvirta et al [6] it became apparent that a street map can outperform a 3D map because of the ambiguity of the 3D street detail and the lack of information provided at the street level perspective as one could not look through the buildings.

Although 3D maps reduce *some* mental rotational costs, additional costs are created by two issues indicated by [29] based upon research of Gregory [32] and McGreevy[33]:

» Line of sight ambiguity which is related to the increasing difficulty of resolving differences in the perceived position along a viewing axis of a display

» Favoured orientation which is ambiguity (direction and speed) in the vector orientation caused by the line of sight ambiguity. It means that it is difficult to resolve positions of objects because the distance to the viewer is the same, but because of a lack of depth cues the exact position cannot be determined.

Wunderlich and Auer [18] state that many people are unfamiliar with complete 3D virtual environments and that 3D geometry is not as complex and complete as the real world, such that the perception is only based upon visual cues. And therefore it is more likely that mistakes will be made in complete virtual environments. Instead of using a pure virtual environment, a mixed augmented environment is used in this project's prototype and this might suffer less from this issue.

7 Coordinate systems

Coordinate systems are an important aspect of any system that relies on GIS data. The data can be supplied in any coordinate system and might have to be converted to a different coordinate system before it can be displayed. In this project three different coordinate systems have been studied.

7.4.1 Rijksdriehoek (RD)

The Netherlands has its own geographic coordinate system, called "Rijksdriehoek" which is commonly abbreviated to "RD". Each world wide registered coordinate system has an unique code, the European Petroleum Survey Group (ESPG) code. The code for the Rijksdriehoek coordinate system is ESPG:28992. Since the augmented reality application is created here in The Netherlands, and all the input data is from the Dutch cadastral office, the RD coordinate system is important to take into account. The Rijksdriehoek system is a Cartesian coordinate system and the units are in meters.

7.4.2 World Geodetic System revision 84 (WGS 84)

A globally used coordinate system is the World Geodetic System (WGS) revision 84, usually abbreviated as WGS84 (EPSG:4326). This system is not Cartesian and relies on an ellipsoid instead. The model behind the coordinate system is the EGM96 model, or Earth Gravitational Model 1996 which is based on three decades of various measures including surface gravity, and altimeter measurements of the oceans by various satellites [81].

7.4.3 Universal Transverse Mercator (UTM)

The Universal Transverse Mercator (UTM) coordinate system represents position on the world as 2D Cartesian coordinates. These coordinates have an x and y value which is independent from the other axis. This model divides Earth in 60 longitudinal zones and in each of these zones a traverse Mercator projection is used to reduce distortion which is common in Mercator based projections of the Earth. Coordinates are specified by providing the zone number and the coordinate pair representing an east and north value in meters. Because this projection uses meters as its units the coordinate values tend to be high numbers. UTM has multiple EPSG codes, one per zone.

7.4.4 Conversion of coordinates in the augmented reality application

3D engines generally have nothing to do with complex geodetic coordinate systems. The coordinate system in a 3D engine is always a Cartesian coordinate system with 3 axes (x, y, z). However, there are difference between 3D engines and their interpretation of these axes. The so called "handedness" of a 3D engine determines what the axes mean as previously seen in Figure 18. Even though the 3D engine works with a Cartesian coordinate system, some transformation has to be done on our input data's coordinates. We cannot directly use the other systems because of the following reasons:

Table 2. Coordinate systems

Coordinate system	Reason
Rijksdriehoek (RD)	The range is too large as it goes from (0,0) to approximate (300.000, 629.000) which exceeds the range that the 3D engine which is used for the prototype (see 9.3.3) supports, although it is within 32-bit floating point range.
WGS84	Not a Cartesian system. When used in applications it would required the "double" variable type to provide enough accuracy. 3D engines are always using the floating point type generally (which lacks the amount of precision needed).
UTM	The range is too large as it goes from (0,0) to approximate (833.000, 9.300.000) depending on the zone. These values exceed the range what Unity supports, although it is within floating point range when using 32 bit floating point values.

This problem is solved by making our own coordinate system based upon one of the Cartesian coordinate systems (UTM, RD). All the received data is in RD coordinates. To convert these to a more suitable coordinate system all objects will be moved to a new origin. This origin is determined by finding the smallest x and y value (both on the horizontal planes) in the scene. These two variables combined form the new origin. Then all the objects will have their current position subtracted with the new position, effectively moving it in the new coordinate world coordinates. This algorithm for this procedure is shown at Code 1.

Note that if the objects have large distances between each other, for example, covering the whole of The Netherlands, then this algorithm will not help as the objects will still keep their large numbers for their coordinates.

Code 1. Coordinate transformation algorithm

```
MinX = float.Max
MinY = float.Max

ForEach RegisteredObject in World
        If (RegisteredObject.X < MinX) Then
         MinX = RegisteredObject.X
        End if

        If (RegisteredObject.Y < MinY) Then
         MinY = RegisteredObject.Y
        End if

Next

Now that we have the minimum X,Y position found in the world, a sec-
ond loop calculates the new coordinates for all objects

ForEach RegisteredObject in World
        RegisteredObject.RenderX = RegisteredObject.X - MinX
        RegisteredObject.RenderY = RegisteredObject.Y MinY
Next
```

After this code, all objects can be placed in the scene at the calculated *x, z* coordinates. The *y* coordinate is not calculated, as it is altitude which we determine differently.

7.4.5 Terrain height

Although GPS provides the ability to return altitude value, this value is often quite far from the correct altitude value. This is also caused by the datum (WGS84) used by the GPS receiver. This datum assume that the ellipsoid that represents the earth is all smooth, while Earth has a large variety in height over the surface instead. An additional correction has been devised to reduce the effects of the offsets which are between the real surface of the Earth and the reference ellipsoid. This model is called "Geoid" and defines heights for the surface of the entire Earth. The software of some GPS devices already use the Geoid corrections in the altitude output, but they can be quite coarse [77]. For some models these corrections will need to be performed manually on the altitude.

To solve this issue, a different approach has been used using a technique that requires measuring the height of the user, which will be explained in the next chapter.

7.4.6 Eye height

To solve the eye height in a practical and reliable way, the virtual camera in the augmented reality world will be configured to have a certain *y* value. This will automatically create a proper elevation of the virtual objects as all other objects related to the ground are either at an altitude of zero or lower (like the cables and pipelines). Eye height needs to be measured in advance prior starting the experiments though. Figure 20 displays how this method works.

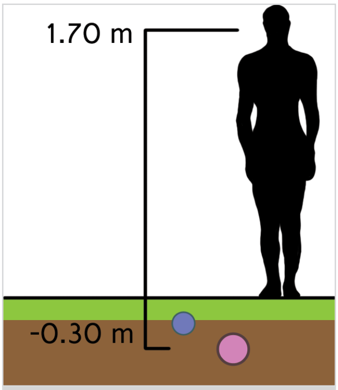


Figure 20. Heightmeasurement in the prototype

The pipelines and objects in the augmented reality are positioned at a fixed depth in the prototype application. The following example illustrates the problem:

Imagine pipelines laying at a depth of 30 cm deep below ground level and the virtual camera to be configured to a fixed height such that is 100 cm above ground. This is a difference of 130 cm in height. A user of 180 cm in length holds the mobile device in front of his eyes, at about a height of 170 cm. This now means that the rendered pipelines are not at 30 cm depth of the ground, but rather at 170 cm 130 cm = 40 cm above the ground.

Therefore the camera requires to be configured at height which is near the average device 'holding' height of the user. By configuring the camera position to be at 170 cm in this example, the difference would be 200 cm which is correct: 170 cm above ground, and 30 cm below ground for the pipelines.

At first thought another solution could have been the AHN2 data set ("Actual Heightmap of The Netherlands"), which provides accurate height values up to a 0.5x0.5m resolution. But this would only determine the ground level and its relation to the sea level. It does not help in any way to solve the eye height problem. When working with a combination of relative and absolute depths, and with a known height of the device such as if the device were on a tripod, then this could be a good solution.

7.1 Prototype world coordinate system

In the prototype application all objects related to cables and pipelines have world coordinates which match with the Rijksdriehoek coordinate system. These objects all have a position and orientation relative to the pivot point of the world and are independent from the position and rotation of the user. The location of the camera object is also specified in world coordinates such that both the world and the viewer share the same coordinate system. As the user moves around, the other objects will change their orientation *on* *the screen* because of the transformations that take place to move the user around. Which can be seen in Figure 21.

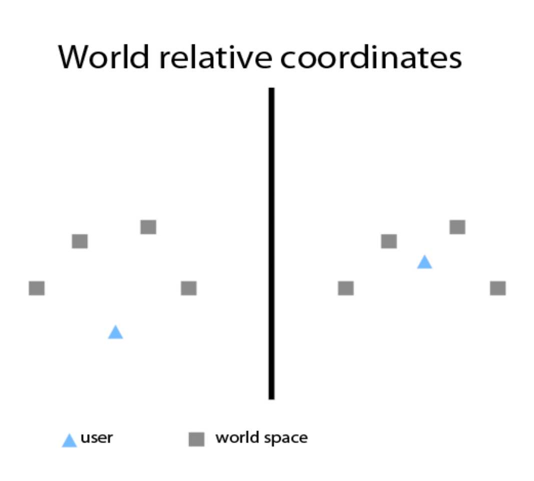


Figure 21. World relative coordinates, the user moves relative to the objects.

Some objects in the prototype have coordinates relative to the location or orientation, or even both of the user. This means that these objects will always have the same distance towards the user, even during movement (Figure 22).

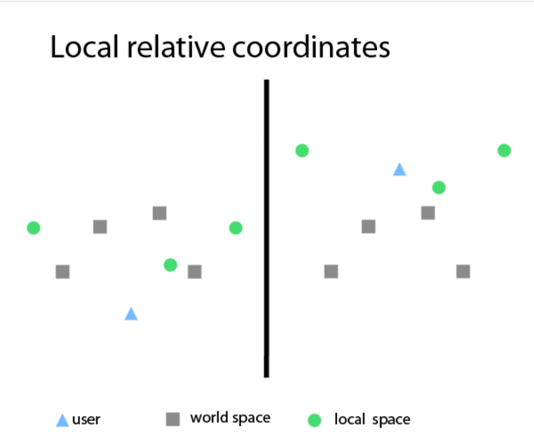


Figure 22. The user relative coordinates where the distance between the objects stay the same.

Objects which are relative to the user are: the radial distance cue, and the grid line depth cue. The magic lens exists in normal world space and the top-down view is part of the user interface. When the user rotates the smartphone, the view rotates egocentric.

8 GPS accuracy

8.1 A brief history

Global Positioning System, or commonly abbreviated as GPS, is a technical solution to a problem which has existed for many hundreds of years in the existence of mankind. In the past there was no way for anyone to determine the current location, except for reference points (like landmarks) which might have been seen earlier. This could be done when on land, but when a ship was moving over the ocean, there were no reference points, let alone maps. By creating maps this somewhat changed. Yet, it was still difficult to pin point one's exact location on either land or sea. The development of various tools like the compass and sextant changed this problem as it became possible to get an idea of the current position.

Yet, the positioning was an analog process and still inaccurate. To solve this problem reliably, the United States Department of Defense created a space satellite based system in the 1960s to 1970s [22]. This system is still used today and has become an important tool to the daily lives of many people

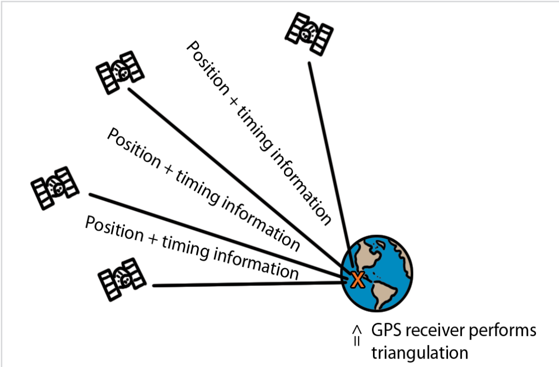


Figure 23. Schematic functioning of GPS.

8.2 A short explanation of the GPS

Earth is surrounded by many satellites. From all these satellites, there are 27 that are used for the American GPS system. Three of these are backup satellites, and 24 are actually active. GPS receivers use information sent from the satellites and the known location of these satellites called the almanac. Using two or more satellites the GPS receiver can calculate the differences in time that it takes for the radio signals to arrive (Figure 23). By taking these time signals into account, the GPS receiver can determine its geographical location on Earth by the process of triangulation [22].

8.3 Location finding in smart phones

The GPS sensor is in this application as important as the eyes and ears to a human being. It allows the application to determine where on the world it currently is. The application depends heavily on the GPS sensor (as well as the other sensors) of its host device. Unfortunately GPS is not as accurate as desired.

GPS is only suitable for outdoor position determination. Indoor the reception of satellite signals is either poor or non-existent at all. Even with poor reception, a lot of the radio signals have gone through several materials or have been reflected from other walls. This means the signals follow a different path, but their content with the timing information does not. The difference between the expected timing, and the actual time causes unreliable readings and easily have inaccuracies of more than 40 meters.

In a field experiment conducted by Oulasvirta et al [06] GPS was specifically not used, due to two reasons:

» Most phones did not have support for GPS

» The GPS errors in urban areas were unacceptable and undermine the achieved

While performing the experiment using the prototype application in this augmented reality project GPS will also be disabled. Even if the user would be asked to stay on a fixed location, the GPS receiver would still update the position on regular intervals. This would mean that all the subjects would see the virtual objects on different locations, which can lead to different results.

Gethin et al [11] provides a table what kind of accuracy is roughly required for the use of various tasks. Location and buried utilities need a accuracy of 10 cm, which unfortunately cannot be acquired using standard GPS solutions. Solutions that increase this accuracy of GPS are available but more often than not require external devices.

Table 3. Applications and their required accuracies and working range. Adopted from [11].

Application	Required accuracy (m)	Anticipated working range (m)
Ore-body exploration	2	20
Contaminated site investigation	1	20
Visualizing Geology	10	100
Mine data visualisation	0.5-2	5 20
Flood emergency	0.5	100

Table 3. Applications and their required accuracies and working range. Adopted from [11].

Application	Required accuracy (m)	Anticipated working range (m)
Subsurface rescue scenarios	1	50
Location of buried utility services	0.10	5
Visualizing and operations civil engineering	0.10	10
Planning	1	20
Archaeology	10	10

When dealing with cables and pipelines, having inaccuracy is an important problem which cannot be fixed easily, if at all when continuing to use normal GPS. It could be possible that the GPS chipset of the telephone lacks accuracy because of the small form factor, and that it has only an internal antenna. In a study performed by Klimaszewski-Patterson [68], a comparison is made between two GPS devices: A dedicated GPS receiver and a mobile phone with a GPS sensor. The conclusion is that there is not a significant difference in the positional accuracy obtained between these devices. This could mean that external antennas provide a better signal than what most receivers with internal antennas can acquire.

8.4 Increasing accuracy by averaged measurements

To increase the likeliness for a better measurement, it is possible to average the position for a given time period. After acquiring a sample set of latitude and longitude coordinates, the average of the coordinates should result in a more accurate position. Some GPS devices support this function directly, for example when creating a waypoint in the device. There are not many articles that discuss the averaging technique. The articles that do, show that averaging GPS signals over time will lead to increased accuracy [72]. Unfortunately taking samples means having to wait for a period, which does not work very well when the user is in the field, finding the cables and pipelines.

8.5 Urban canyons

Urban canyon is the name for a typical city landscape, in which there are many tall buildings surrounding the GPS receiver. In such conditions the GPS is likely to report more inaccurate positions as the incoming radio waves from the satellites reflect on the buildings. These reflections cause a delay in the timing and causes the GPS to get disoriented. Tall buildings also withhold the GPS receiver from having a so called “clear horizon” which means that it will find fewer satellites. Fewer satellites means less accurate positions.

8.6 Other improvements

Various projects have been started to improve the GPS system. Russia and China are working on their own variation of a satellite based positioning system called GLONASS and Compass respectively. Russia has promoted civilian use of the GLONASS system in the last decade and some mobile devices start to support both GPS and GLONASS systems now. Compass is still under development and the target is to have a coverage of China in 2012, and global satellite coverage in 2020 [36].

Meanwhile, the European Union is working on the Galileo system. This system is meant to be a "free for everyone" system and also aims to provide better positioning accuracy than the GPS system. The system is expected to be completed and have worldwide coverage in 2019 [73].

There are other approaches already available in order to improve the GPS signal and to provide sub meter accuracy. These approaches use land based methods instead. Currently the following techniques can be used to enhance the GPS accuracy:

» Real Time Kinematic (RTK). In the RTK system a single reference station will provide corrections to the received signal from the satellites. The reference system itself relies on the carrier signal of the satellites L1 data frequency. RTK can provide up to 1 cm accurate location. To use such a system a special device is required to receive the information from the RTK signal transmitter which is out of the scope of this project.

» Differential GPS (DGPS). DGPS relies on a network of fixed ground stations which transmit their locations and the difference compared to location determined by GPS signals. This system was created to reduce the effects caused by the artificial random location offset given to the civilian GPS signal which was created by the US military to reduce the chance of their own navigational system being used for guiding enemy missiles into the US. In The Netherlands a service is provided to use DGPS signals [65].

» Inertial Navigation System (INS). An INS integrates a starting position and velocity over time to provide new locations based on various motion sensors Using these motion sensors (like accelerometer, gyroscopes, and so on) the application can still determine its position without any need for extra satellite updates. This system will suffer from numerical drift from the integrations, and therefore should actually have occasional updates. This is why it is more common to use it to acquire extra precision instead. For example: A device in someone's hand could actually update the location based upon the hand movement. Although mobile devices often have various kinds of motion sensors, it is not implemented in the operating systems.

9 Implementation

The data, the virtual world application and a system to perform various experiments in a user study make up the prototype for this thesis. One requirement for implementing the prototype application, is a source of data. Real data is critical for this thesis given the intent to explore a real tool for visualizing underground infrastructure in a real-life application. As such, data from the Dutch cadastral office will be used. Other requirements for the prototype are the implementation of 3D models in a virtual world that can be integrated with real-time camera images from a mobile device is also required.

9.1 KLIC data

Dutch law requires permission from the Kabels en Leidingingen Informatie Centrum (KLIC)[95] for any and all digging into the ground using mechanical means. The one exception to this is in the case of agricultural work where if a request has already been performed before and the underground infrastructure has not changed, then new permission is not needed. The procedure is as follows:

The person that wants to perform the requesting permission can either use earlier registered account at the KLIC online website [95], This website is maintained by the Dutch cadastral office. Or alternatively, the person can download a form from the website, enter his personal information and the area of interested and submit that by e-mail.
After submitting the form, the Cadastral office forwarded the request to those operators that work in the location associated with the request. Then the grid operators then returns a number of digital images (in the PNG image format) that displays where they are and other extra images inform the viewer which where in the digging location there cables and pipelines are high voltage or high pressure for example.

All grid operators will send their information to the Cadastral office which will combine all files together and send this to the person that requested the information. This person will receive the following data:

» Separate PNG's displaying the various types of cables and pipelines in the specified location. Some include only the location, others include more specific type information such as of high voltage and or high/low pressure

» PDF's with extra information and terms of usage, how long the information is considered valid, contact information in case something goes wrong, etc.

» Side views if available

» An XML file which contains a list of files and the bounding box rectangle coordinates for the PNG's

This data is compressed in a ZIP file and can then be accessed from the KLIC online website.

9.1.1 Data format

Cadastral data is in raster format because of license technical reasons. A raster format means that the data is represented by pixels. Each pixel represents a certain type of data and there is no extra meta-data available for each of these pixels. This makes the process of creating 3D models less straightforward then when a vector format was used. Vector data can easily converted to other forms of 3D geometry. When converting raster data (back) to a vector representation, it is always an approximation and accuracy can be lost.

The data is received in PNG files, which are separated by type and category. The filename indicates that the image contains either dimensions, locations, or other annotations of the infrastructure. Then for each of these categories there is a file per organisation that maintains the cable or pipeline of a given type. That can lead to many PNG files for one location, as there are images from various sewer infrastructures, various types of electricity grids (high, medium and standard voltage) and data communication. Figure 25 displays how these files look like when combined to a single map. Next to the PNG files various PDF's are also supplied per organisation, which inform the reader with specification conditions and contact information in the case if a cable or pipeline of a certain type is hit during an excavation.

Cadastral data is in raster format. This means that data is generated from files where the data is represented by pixels. These maps have a pixel of 14 pixels to one meter. This translates roughly to 1 pixel being 7 cm which is therefore also the maximum resolution that can be handled by tools using KLIC data. There is no extra metadata available for each of these pixels. This makes the process of creating 3D models more complicated than when a vector format is use because vector data can easily be converted to other forms of 3D geometry. Some plugins have been written for various technical drawing tools such as Autocad, to convert the raster to vector format[47] so they can be copied on technical drawings. However, these are only approximations and raster-to-vector conversions are often subject to errors. When converting raster data (back) to a vector representation, it i always an approximation and accuracy can be lost.

Another concern is that the cadastral data does not provide any depth information ('z-values'). This is because the agencies that provide the data do not send this information as it might have changed due to soil settlement from natural processes, or due to salt or gas production [48]. In some cases, companies do not registers depths of their infrastructure to begin with. However, others specifically mention that they did not include it. When using the 2D, maps this information is not used, as it is not displayed. Yet in the case of 3D visualization, it becomes a necessity. When drawing all lines on the same *z* value, all cables and pipelines would appear to intersect. Therefore, all values are within a 0 to 1 meter depth range in the prototype application that covers most of the standard infrastructure depths [09]. The cables and pipelines will manually have their depth in the ground changed, such that it reflects these guidelines. None of the various types of pipelines will be on the same z value (depth in the ground), otherwise the pipelines would potentially intersect with other underground infrastructure which leads to an undesired visualization issues.

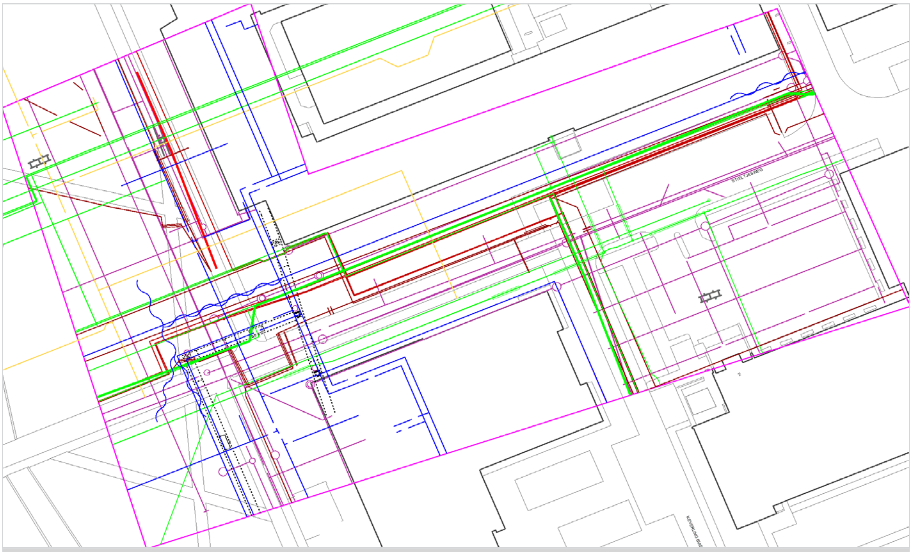


Figure 25. All pipelines and cables combined in one image.

9.2 Colours

Colours are an important medium to communicate with, which is for example clearly visible in traffic signs [28]. Colours can be perceived differently because of cultural background or because of other factors such as colour blindness. Roughly 8% Percent of the male population have a form of colour blindness, and 0.5% of the female population[59]. This implies that there is chance that red and green like colours are colours which can be seen difficult by some part of the population. Colour related research is a whole subject of its own [28].

In this project pipelines and cables will need to have certain distinct colours to keep them from looking all the same. One should be able to determine the type and function of a cable or pipeline by looking at the colour. The cadastral data is already supplied with specific theme colours per pipe or cable type. In the application for the experiment the same colours will be used; as the visualized information is based upon this real data. This gives various benefits:

» The colours match with actual paper cables and pipeline maps used normally, and therefore well suitable for this experiment

» The defined colours are bright, with exception of the 'other' category that is represented by black

The exact specifications can be found in the report that documents the exchange specifications [27], of which some are visible in Table 4

Table 4. Colours as defined in the specifications

Theme	RGB	Colour
Data transport	0,255,0	
Gas low pressure	255,215,80	
Gas high pressure	255,175,60	
Pipe with dangerous content	255,127,0	
National electricity grid	255,0,0	
High voltage	255,0,0	
Middle voltage	200,0,0	
Low voltage	150,0,0	
(Petro) chemistry	182,74,0	
Sewer	186,56,168	
Sewer pressured	128,0,128	
Warmth	0,128,128	
Water	0,0,255	
Orphaned	0,0,0	
Other	0,0,0	

In the application that will be used for the experiment, a selection of pipes will be presented that match these different types of themes. The colours are used as diffuse materials, and do not include extra effects like specular or emissive properties.

9.3 Hardware and software

The device used in this thesis is the smartphone called HTC Sensation. This is a model brought on the market in 2011 and features the following specifications which are relevant to the development of the application:

Table 5. Specifications of smartphone in this research project

What	Specification
Operating system	Android OS, v4.0.3 (Ice Cream Sandwich)
CPU	1 GHz Scorpion processor, Adreno 200 GPU, Qualcomm QSD8250 Snapdragon chipset
Sensors	Accelerometer sensor
GPS	Chipset SiRF Star III
Camera	8MP, 3264x2448 pixels, autofocus, LED flash which allows video recording of: 1080p@30fps

9.3.1 Development environment

The software is developed using Unity 3.5 [07] with Android support and an additional package called GyroDroid [08] which allows application development using the sensors of the device. The Qualcomm "Vuforia" library [53] is used in Unity to get camera images from the host device's camera. Although the Vuforia library is meant for vision based augmented reality, it works very well to get real-time camera images. Camera brightness is automatically controlled by the host platform, the Android operating system.

9.3.2 Android

The prototype has been developed for the Android operating system (OS). This platform has been selected because it is supported by Unity and because of the availability of various Android compatible devices during development. The most recent version of the OS has been used, Ice Cream Sandwich:

9.3.3 Unity

Unity is a game engine that allows the developer to build one application and then compile it to various platforms. Standard platforms like Microsoft Windows and Apple's Mac OS. But also other platforms like Google's Android, Apple's iOS and gaming consoles like the Microsoft XBox360, Nintendo Wii and Sony Playstation 3. Microsoft Visual Studio 2010 was used to write programming code in the C# programming language which Unity uses. Note that in the virtual world build in Unity, that y equals height. In Cadastral data this is commonly z. In the experiment section the y axis will be used a number of times.

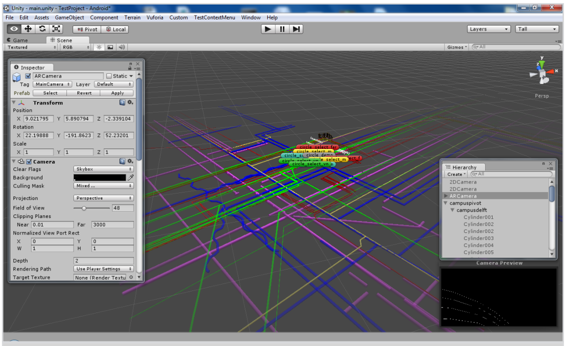


Figure 26. The Unity Editor with all pipelines placed inside the virtual world

Unity does not have direct access to the camera device(s) on the host platform, unfortunately. Therefore an additional component has to be used in order to acquire live video images. Qualcomm has developed a Software Development Kit (SDK) called Vuforia [53] which enables access to camera's on mobile devices and also has the ability to track 2D or 3D marker objects. Only vision based augmented reality is supported by this toolkit, which means that more is needed for the prototype application to function as desired. The camera functionality is suitable for the prototype.
Another essential feature which Unity does not provide either is the ability to access the sensors of the host device, with exception of the GPS sensor. Fortunately a developer has created an additional plug-in for Unity which enumerates all the sensors on the host device and provides access to them. The plug-in, called GyroDroid only functions when projects are compiled for the Android platform which is exactly what happens in the case of the prototype.

Qualcomm's Vuforia and GyroDroid are the eyes and ears of the prototype application, and no other additional sensory information is required because:

» Vuforia provides the programming interface to the camera functionality, and the ability to superimpose computer generated graphics onto a standard Unity camera object

» GyroDroid provides the ability to access the magneto sensor and gyroscope sensor, providing us with a compass and an ability to know what orientation the device has

9.3.4 Sensors

Using the sensors of the mobile devices, it is possible to create an application which is aware of the direction that it is facing. This means that the fixed screen space as seen in laptop and desktop computers can be extended to a dynamic environment instead. In the 3D augmented view all values of the magnetosensor will be used. Using these values it is possible to create an application that can change its view depending on how the device is held, no matter how the device is rotated. Figure 27 demonstrates this feature. The mobile device acts like if it were a camera which can be rotated over arbitrary axes, and translated on the horizontal plane. The virtual objects only take their configured height in world space units into account, while the camera view depends on the height of the device, as configured before the experiment starts.

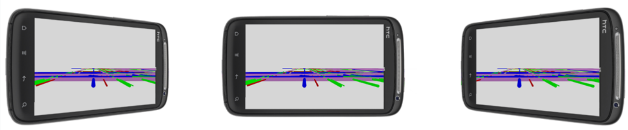


Figure 27. View of the virtual world changes on rotation of the horizontal axis

Figure 28 shows that rotating the device over the z axis does not make the world rotate. This is the desired effect, as the recorded image does by the camera does not change either. If the virtual world would rotate as well, it would lead to registration errors.

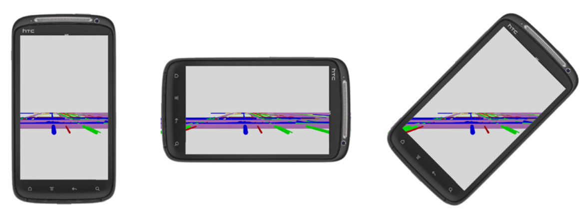


Figure 28. Rotation of vertical axis does not influence the world view, similar to normal camera's

9.3.5 Camera

The camera object in Unity has been set to the same field of view (FOV) as the camera of the phone such that the virtual objects will have their perspective properties aligned to the camera images which are used as a background. Unity automatically culls objects which are outside the frustum of this camera.

9.3.6 The virtual environment in Unity

Various 3D models have been made using AutoDesk's 3ds Max 2012 Student Version. These models are the heart of the visualization in this project. Some examples:

» All pipelines are 3D models

» All depth cue models that have some kind of 3D representation have been modelled and textured inside 3ds Max

These models have all been placed in a Unity scene file and various scripts (in Unity also called 'behaviours') have been added to make sure objects translated to the right world space coordinates. The world space has been configured to work in meters.

Unity has camera objects which represent the eyes in the world. In short, It determines what becomes visible on the screen. A script has been added to the camera that takes the mobile device's rotation through GyroDroid and subsequently sets the rotation of the camera to this rotation.

The camera position determines where the participant is in the virtual world. A fixed real world location has been chosen for the experiment. As a result the location of the virtual camera will also need to be fixed and configured to be equal to the real world coordinates. If the virtual camera location is not near equal, registration errors will normally occur.

The result of setting the position and rotation of the camera, and by making sure all objects adhere the same coordinate system is a working augmented reality system (Figure 29).

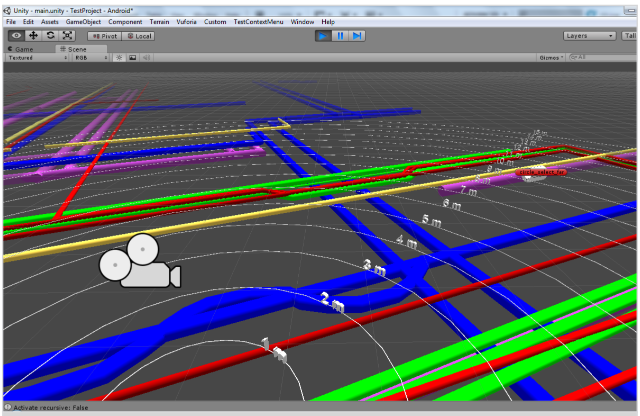


Figure 29. View of the virtual camera, one of the distance cues and the target object.

9.4 GPS Accuracy

In order to verify whether the GPS signal is usable or not, a short experiment has been performed. This experiment consists of having the mobile device log GPS positions for five minutes on various moments of the day. Each second a position would be retrieved from the GPS sensor. The Unity programming interface provides the ability to get the *horizontalAccuracy* variable from the GPS programming interface. This accuracy was compared with a previous position's horizontal accuracy value. If the accuracy was better or equal, the position and accuracy value would be saved so that it could be compared to the next position and the accompanying accuracy value. This procedure is shown at Code 2.

Code 2. GPS update code

```
boolean isBetterLocation(LocationInfo location, LocationInfo current-
BestLocation)
{

 if (firstupdate = false)
 {
  firstupdate = true
  // A new location is always better than no location
 return true
 }


 // Check whether the new location fix is more or less accurate
 if (location.accuracy <= currentBestLocation.accuracy)
 {
  return true
  }

  return false
}


// Called every second:
void Update()
{
 if (isBetterLocation(newGPSPosition, currentBestPosition) == true)
 {
  currentBestPosition = newGPSPosition
 }
}
```

This procedure makes sure that the GPS locations written to the file will have improved accuracy, making it easier to see how well GPS performs in the area around the user.

All logged GPS locations were in the WGS84 format. These have been converted to the Rijksdriehoek format and plotted on the earlier shown map with all the pipelines. The result of this operation can be seen in Figure 22.

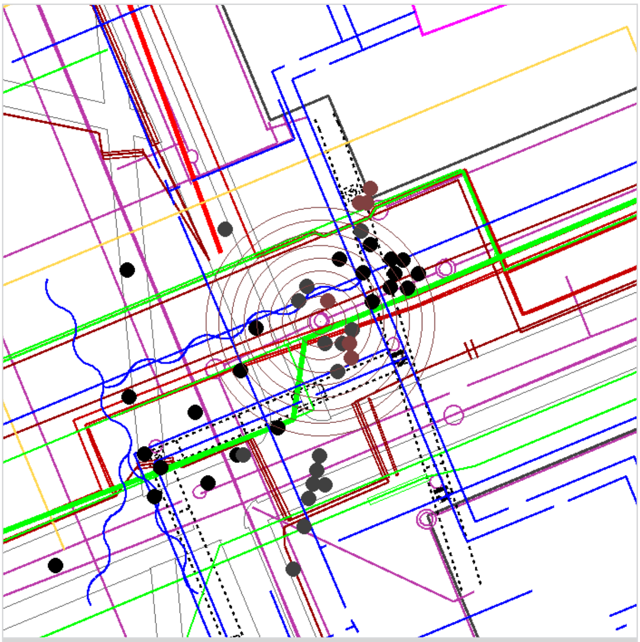


Figure 30. GPS locations as received by the smart phone. The image represents 50x50 meter and the circle in the centre has a diameter of 10 meter. Each circle is 1 meter.

It is clearly visible that the GPS signal is far from reliable and has a rather large inaccuracy. The accuracy never gets lower than a 3 meter error, which is undesired in the prototype application. Because of this, the GPS will be disabled in the experiments such that all participants will see the augmented reality rendering on the same location.

One important note to add to this experiment is that it is sampled on just one day. GPS signals tend to fluctuate because of atmospheric conditions

9.4.1 Gyroscope experiment

In order to determine how stable the gyroscope performs, a small experiment has been performed as well. In this experiment the smartphone is laying outside on a flat surface. For a duration of five minutes the phone will record its orientation represented as Euler angles (*x*,*y*,*z* in degrees). As the phone has been laying flat and has not been touched whatsoever, the Euler angles should not change However, sensors like the magneto sensor and gyroscope sensors are very sensitive and therefore easily generate noise. Unfortunately this is also the case with the sensor is this mobile device, as the angles fluctuate. This can be seen in Figure 31.

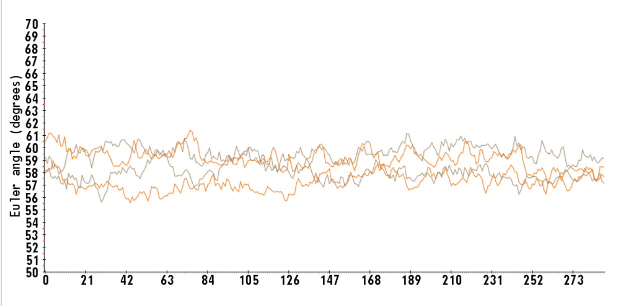


Figure 31. Angles of the device as reported by the gyroscope. The graph only displays the *y* axis, for clarity reasons.

Table 6 displays the minimum and maximum angle of the device while it was outside, laying flat on a concrete wall and with no other devices nearby within a radius of at least 15 meters. The absolute difference is calculated from these minimum and maximum values. Note that values that wrapped around the 360 degrees circle, have been mapped to values above 360. This explains angular values above 360. Otherwise, calculating the difference would not work

Table 6. Results of 4 gyroscope experiments. All angles are Euler angles.

Axis	Min. angle (degrees)	Max. angle (degrees)	Difference (degrees)
x	86.7	87.32	0.62
y	57.9	61.13	3.24
z	357.73	361.04	3.31
x	86.77	87.2	0.43
y	55.6	58.97	3.37
z	355.36	358.59	3.24
x	86.78	87.19	0.41
y	55.65	60.08	4.42
z	354.96	359.28	4.32
x	86.67	90	3.33
y	57.19	61.43	4.24
z	356.35	360.39	4.05

The axes have a spread of about 3-4 degrees. The *x* axis fluctuates less than the other axes, but there is no clear explanation for that behaviour. On screen this means that the pipelines will slowly fluctuate on the screen, even while the device is not being touched at all.

3-4 degrees of idle drift is not a lot. When a user will hold the mobile device, there will be a natural vibration or shaking caused by the individual holding it. This will make the drift of the gyroscope values less visible.

In this project, the gyroscope is a fundamental element of the application. One could configure a fixed location in the scene, but not for the orientation as it would limit the app only to be used from one single direction.

10 Experiment setup

10.1 Experiment setup

This experiment was separated into two parts. One group of 28 human participants performed the distance experiment and the other group of 20 performed the depth experiment.

10.1.1 Participants

All participants for the study worked at Deltares [69] in the Delft offices, and an email was sent to the entire company requesting their participation. Deltares is a knowledge institute that focuses on delta technology, primarily working in water and soil. Exclusively Deltares employees were invited to participate in this experiment. Since a major goal of this thesis was to enhance an augmented reality application that would be useful to those in the field, an appropriate professional background was a necessary criterion in selecting participants. At Deltares, the background and work experience of the employees is more suited to the using and providing feedback on the augmented reality prototype than would be the background of a random selection of students or the general public. Further, having all participants from one organization made planning the experiments more straightforward. Some of the participants had geotechnical knowledge, but considering the nature of the experiment, this should not have affected the results. The details of these the participants are presented separately in the results (11.1 and 11.2).

All experiments were performed on the same location, and the tasks in the experiments were ordered beforehand such that learning effects could be kept to a minimum. As the order of the distances would be the same for a single subject for all cues, the order would shift by half the row to make the positions of the targets feel less ordered and to reduce learning effects for follow up cues. To reduce this effect, all locations for both distance and depth cues were ordered by a balanced Latin square approach, and the cues as well were put in balanced Latin square order.

10.2 Materials

The hardware in the experiment was the HTC Sensation smartphone as discussed in chapter 9.3. The device was configured *not* to sleep or reduce display brightness after inactivity. The brightness of the screen was set to the maximum value such that it provided the highest contrast available on the device.

The prototype application worked as follows: During all experiments, the device was held in the landscape orientation, as seen in Figure 33. This allowed for more horizontal room than in a vertical position, therefore it also provided more space for horizontal oriented GUI elements like sliders and buttons. At the top of the screen there was a text message in English informing the subject of the current task :

“*Find the flashing object and determine the DISTANCE to this object. Drag the slider at the bottom to the right to enter your estimate*” for the distance task.

For the depth task this was: “*Find the flashing object and determine the DEPTH of this object. Drag the slider at the bottom to the right to enter your estimate*”.

Figure 32. Displaying one of the cues, the perspective height lines, on a mobile device.

In case of the distance or depth task, the subject had to find a flashing 3D object. This object was the “target object” for which the user needs estimate the distance or depth. The object was flashing so that subjects could distinguish it more easily from other objects on the screen like the static cables and pipelines infrastructure model. The target object changed from grey to white every second, to capture the attention of the participants while they are looking for the object.

After the object had been found the user could perform the task. After the subject felt that he or she determined the right distance or depth, he or she would move the slider at the bottom of the screen to the right, indicating “I am ready” to the program. The program will then present a screen (Figure 33) that allows the subject to enter the estimate and confidence.

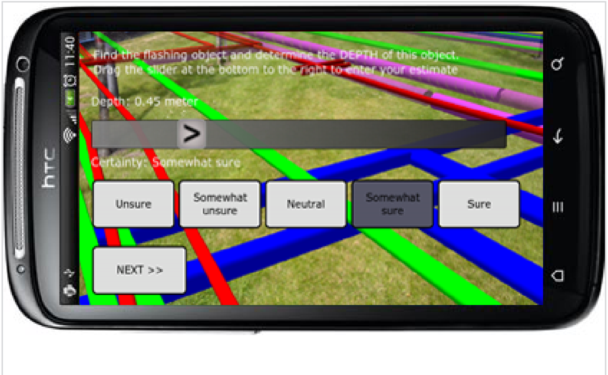


Figure 33. An example of the entry form in the augmented reality app.

For the distance task, the range was 0 to 15 meters (none of the target objects were farther than 11 meters). For depth this was 0 to 2 meters. None of the targets objects were deeper than 1.0 meter.

The second question in each task was about user confidence or certainty. The subject had to select one of these buttons to indicate how certain he or she was about the estimation he or she entered. Possible choices for this question were:

“*Unsure*”, “*Somewhat unsure*”, “*Neutral*”, “*Somewhat sure*”, “*Sure*”

The subject would select one of these by pressing the button bearing the captions of those values.

After selecting a distance, and pressing a button to indicate certainty, another button appeared. This was the “Next >>” button. By pressing this button the subject indicated that this task was complete and the next task could be shown. This entire process of showing objects and asking for distance or depth and certainty would repeat until all tasks were performed. Upon completing all tasks a final message would be displayed saying: “*Thanks for your assistance!*”.

10.2.1 Mip-mapping

In the prototype, various textures had mip-mapping disabled, as these lower the resolution of the textures over distance. Mip-mapping is a common technique in game engines to reduce moiré effects, which are undesired patterns where multiple textures might overlap each other. Particularly when the textures contain lines or points, this effect can occur. Mip-mapping generally lowers the resolution through a number of steps by the power of two. By actually lowering the resolution of the textures over distance, the graphical quality of these will be better if it were not.

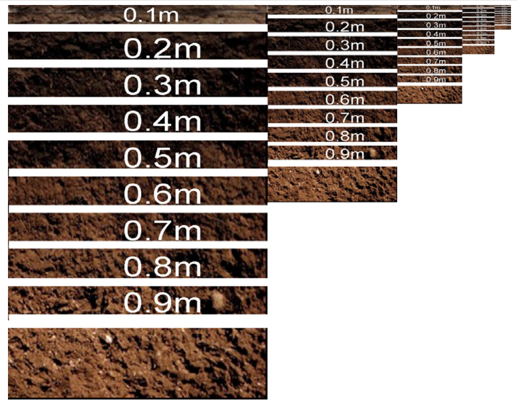


Figure 34. Various mip map levels.

A large texture of 1024x1024 pixels might have many mip-map textures (512x512, 256x256, 128x128, .., 16x16). Figure 34 is a texture that is 1024 pixels in height. In just four mip-maps the height has become 64 pixels. In the prototype some textures are used that have text.

Unity automatically applies mip-mapping as default to all the textures that are imported in the game engine. This would mean that the text would become unreadable, as Unity believes the textures are far enough away to use one of the lower resolution mip-maps even while they are not. Fortunately the mip-mapping can be disabled, such that the readability is not affected.

10.2.2 Data files

During the experiment, participants generated data which was stored in one plain text-file for each experiment. Each of these files contained important information about the participant like the experiment number, the starting time, eye height, and so on. The application also maintained placeholders for the information written on the paper forms to assist in streamlining the processing of all data after the experiment. The data file also contained the results as entered by the subject for each task. Each line in the data file noted the results of one full run-through and contained the following information: task type (distance or depth estimation), which distance target was used (eg: near_2), the user-estimated distance or depth, and the user confidence. To make processing easier, the line also contained the real 2D and 3D Euclidean distance as calculated by the application and the *y* (depth) value of the object as well. An example of the file format can be found in the appendix “15.8 Experiment file format”.

The prototype also recorded sensor information (GPS loca tion, rotation of the camera, etcetera) to a log file at two second intervals. This information was not needed in the data analysis, but was recorded to debug the application in the case of visual mismatches between the actual augmented view and the expected view. Unfortunately it is not possible to store the video footage from the camera as this process causes too much load on the processor of the device such that the performance of the augmented reality view is reduced as it becomes unresponsive and updates slowly.

10.3 Procedure

This chapter describes the procedures and variables of the experiment.

10.3.1 Independent variables

Independent variables in this experiment are (see also Table 7 and Table 8):

» Location of the target

» Type of depth or distance cue presented by the program

Table 7. Independent variables for distance

Name	# of variables	Description
Distance cue	4	None, Distance circle, Top down, Range finder
Distances	4*2 (8)	Near1, Near2, Middle1, Middle2, Far1, Far2

Table 8. Independent variables for depth

Name	# of variables	Description
Depth cue	4	None, Magic lens, Depth planes, Side view
Distances	2*2 (4)	VeryNear1, VeryNear2, Near1, Near2

10.3.2 Dependent variables

The following dependent variables are used in this research. These are based upon the data created by running the experiments

The dependent variables are:

» A subject estimated depth or distance towards the target

» Participant-expressed confidence score in his or her correct depth or distance estimation

» Time taken for the subject to determine the depth or distance

» Accuracy calculation (Formula 1), similar to the one which is defined by [52]:

While some may argue that distance estimation should be done by blind walking instead of using vision (see “Registration of distance” on page 12), blind walking will not be used in professional situations. The purpose of the cables and pipelines prototype is to be eventually used in such environments and therefore a vision based approach is used instead.

$$accuracy = 1 - \left(\left| \frac{estimated\ distance - real\ distance}{real\ distance} \right| \right) \times 100\%$$

Formula 1. Accuracy calculation

Furthermore the time taken to estimate the distance or depth is also stored in a floating point value representing seconds. A signed distance error is also calculated. This value indicates whether the estimated distance is under, over, or correctly estimated. After the experiment, subjects filled out a post experiment form expressing qualitative feedback about their preferred technique and any additional comments.

The target object where the participants had to report the distance or depth for, looked like Figure 35. This object was basically a small piece of pipe that could fit around other objects if needed. The four lines at the sides are placed to help the participants determine the centre location of the target. For both distance and depth experiments, the participants were instructed to use the centre (or ‘heart’) of the pipeline for their estimations. The target object changed from grey to white every second, to capture the attention of the participants when they are searching for the object.

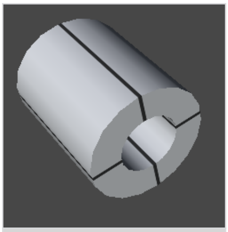


Figure 35. Target object which the participants had to report either the distance or depth for.

Participants would use a prototype of the augmented reality application on a smart phone to estimate depth and distance using the cues discussed previously. To begin, all participants were asked to fill in a form which asked for name, gender, age, previous experience with augmented reality and if they own table device, or a smart phone. This form can be found in the appendix of this document (“15.6 Pre experiment” on page 61). Next to this form, the subjects were also given an explanation of the experiment on paper, which can be found in the appendix as well (15.2 on page 55).

It was also clearly explained to the subjects that the augmented reality visualization is *always* overlapping the camera view, even if the objects are further away than the real world objects. This to make them aware that underground objects are still displayed as if they were above the ground.

10.3.3 Experiment conditions

The experiments were performed on a single location at the campus of the Technical University of Delft in The Netherlands. Because fluctuations in GPS would likely cause location inaccuracies between the subjects, a different approach was used in order to ensure the participants would see identical views of the pipelines. The location selected was a maintenance hole cover for the sewer system because it was an easy location for directing participants. To use this position inside the prototype, the geographical coordinates were calculated from the cadastral map and finally, the virtual camera object in Unity was configured to use those coordinates as a fixed location. The 2D Map (Figure 37, larger in the appendix at 15.10 on page 65) gives an impression of the underground data. The coordinates of this location are WGS84: lat 52.00006, lon 4.3745 and in Rijksdriehoek coordinates: x = 85457 m, y = 446227 m.

An outdoor location provided a less controlled environment than indoor. The reasons for choosing for outdoors were:

- » An outdoor environment is more appropriate for goals of this thesis, given that the function of this application (urban excavation) will always be performed in the outdoors.
- » It was interesting to observe if, and how, participants utilized features of the environment such as the nearby trees or buildings in their tasks.
- » Indoor there are no sunlight reflections nor is there wind. Sunlight in particular can be perceived as problematic when using mobile displays, and precipitation would have actually stopped the experiment. These natural elements would likely occur when the prototype application was used in a professional setting.

Each of the subjects had to take place on the maintenance hole cover which was the center position and were not allowed to move. The only movement that was allowed was rotation around their own axis, while staying on the marked position.

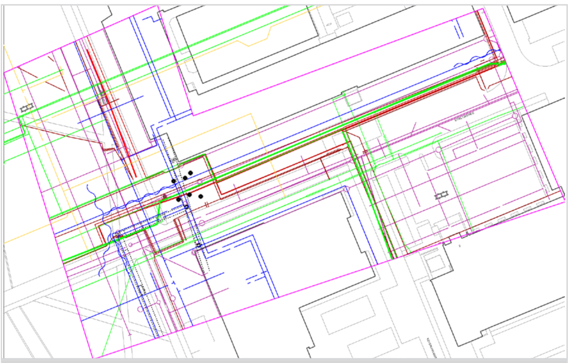


Figure 37. A paper map displaying the cables and pipelines of the area. All the distances are also displayed (black circles).

The subject was allowed to practice with the mobile device for a maximum of one minute. In this practice display, the cables and pipelines were visible as well as one demonstration target object. The target object was positioned so the user would immediately see it looking straight in the direction of the start position. The object was only used for the demonstration purpose and not reused in the actual experiment. No distance or depth aids were visible in the practice view.

Before the experiment started, the elevation above the ground of the mobile device was measured by a large ruler. This camera eye height was configured in the application so visualizations would be accurately displayed on the ground level. The eye height was one of two dependent variables that had to be set in the application prior starting the experiment. This had to be done manually as the device cannot accurately determine the altitude it is being held at itself. The eye height configured the height of the virtual camera in the scene, in order to position objects at the correct depth for all subjects as described in “7.4.6 Eye height” on page 19. The other variable that has to be set was the experiment identifier for the Latin square order.

10.3.4 Post experiment procedure

After finishing an experiment task, the participants were asked questions according to a post experiment form (see appendix “15.7 POST Experiment”). These questions were asked to determine which method of visualisation the subjects preferred and if they had other additional comments or remarks. The answers on both the PRE and POST experiment forms were merged with the result log files generated by the mobile device.

Figure 38. The location of the experiment.

Figure 38 displays a photo of the experiment location.

Figure 39 shows a how a subject would perform the experiment, standing on a fixed location and looking into a certain direction. All participants would be placed on this location.

Figure 39. A person performing the experiment

10.4 Distance experiments

For the distance experiments the target was consistently at the ground level (*y = 0, in meters, in the game engine*). The other pipelines were still underground at their configured depths (between 0 and 1 meter deep).

10.4.1 Distance estimation without cues

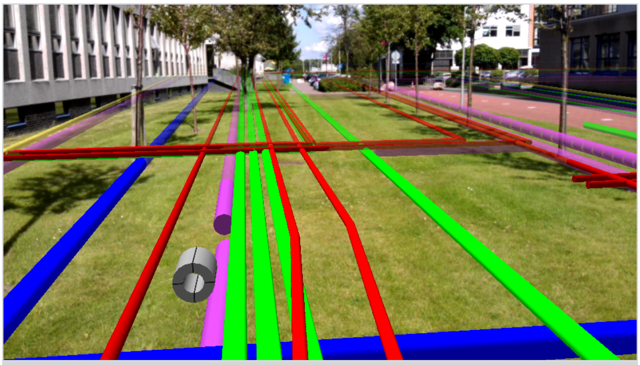


Figure 40. Distance estimation without any help.

In this experiment the subjects do not get any assistance. Only the target object is visible and the cables and pipelines are visible, as seen in Figure 40. This was to determine how the subjects estimated the distance on their own and then to use these values as a baseline to compare against the distance estimations in the other required tasks

10.4.2 Distance circle

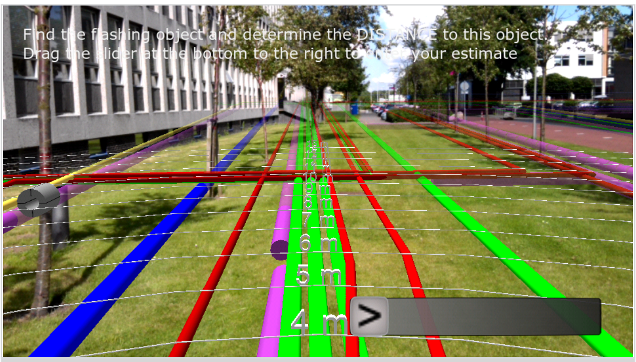


Figure 41. Distance circle cue.

In this experiment, a radial grid displays a grid line marked at one-meter increments from the user. This implementation was not found in background literature and was created under the assumption that it will perform well as it provides the user with a distance measuring tool for multiple locations in one sight. The idea behind this grid is that it is egocentric. Thus, the user will always be in the centre of the grid (user relative coordinates).

Numbers are placed on each grid line (Figure 41), which indicate the distance of each line to the centre. These numbers rotate with the view over the horizontal axis to be always in the middle of the user's view, as though they were attached to the device. This technique combines a grid on a ground plane and distance markers which are both methods to improve depth perception [51]. In this application the lines indicate distance increments up to 15 meters. This technique is subject to perspective effects, however, and therefore the lines become visually closer to each other when the distance increases. The maximum range of this technique, therefore, is likely limited and depends on other factors like the FOV of the camera and the screen resolution. This techniques combines a grid on a ground plane and distance markers which are both methods to improve depth perception.

A radial grid was chosen over a square grid, as a square grid will have a longer distance to its' four corners than to its' sides, while a radial grid has both equidistant lines and represents Euclidean distance. Figure 42 illustrates this effect.

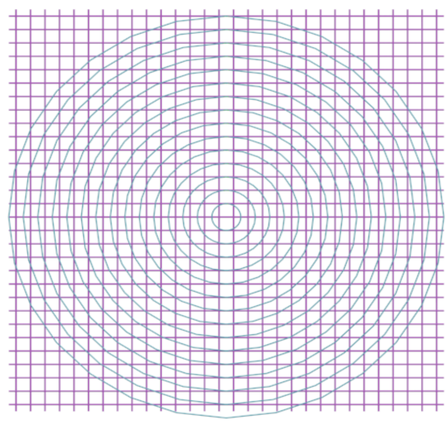


Figure 42. Square grid and a radial grid.

If a normal square grid were used, only the values at the exact four compass (0, 90, 180, 270) directions would match the correct distance. At all other angle there is a difference between the actual (Euclidean) distance and the distance displayed in the grid.

10.4.3 Top down distance view

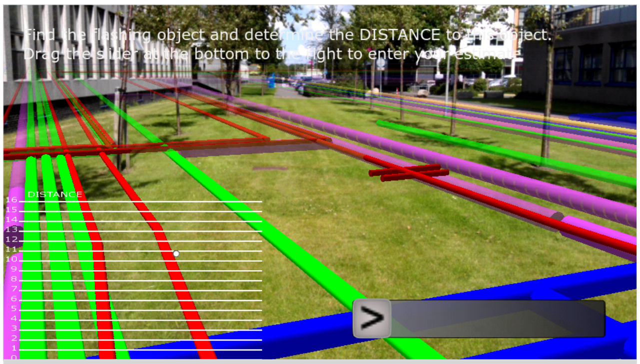


Figure 43. Top down distance helper.

A top-down distance indicator, which works like a radar view, was used in a similar way as the technique introduced by [03]. This helper is a graphical user interface element and does not integrate in the augmented reality view like the radial grid cue. A dot indicates the distance between the target object and the user as if it were a birds eye view. Each horizontal line represents a distance of one meter away from the user. When the object is the furthest away, it would be at the top line. In the prototype application, only one target object was used at all times as the distance to the single object needed to be determined. This technique is an "alternative perspective" [51].

In [03], multiple objects were visible at the same time using a similar top-down view. In this view the dot moved on the horizontal axis when the user rotated the camera horizontally (when turning around, for example). When the object was in the middle of the view, the dot would be at the horizontal lines. In theory, the dot would move vertically when the distance between the user and target changed. In this experiment, however this was not the case, as both the target and the user will be on a fixed location.

10.4.4 Range finder

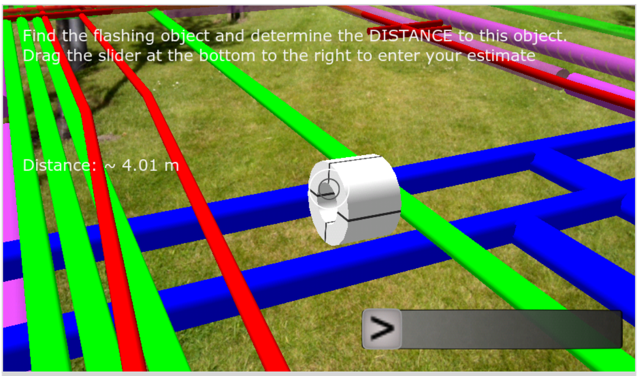


Figure 44. Range finder cue.

The range finder cue determined the distance based upon intersection with objects underneath the cursor in the exact centre of the display. This value is displayed at the left side of the screen.

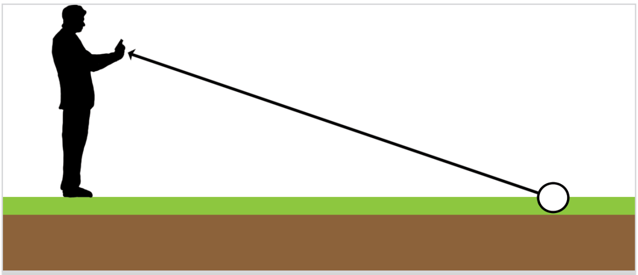


Figure 45. Measuring distance between camera and target object.

This technique relied upon the use of Unity's physics intersection function. A ray was cast from the virtual camera in the scene in the direction the device was being held. Any intersection would result in a ray length. Units inside the virtual world were in meters and this value was simply displayed on the screen. As in the distance estimation experiment, all objects were located at ground level ($y = 0$). There is a invisible ground plane in the augmented reality scene which makes sure that there will always be a distance provided the user keeps the mobile device at a angle to maintain an intersection with the ground at some point. If this is not the case, no distance will be reported. This range finder technique used the location of the device as its origin. A potential disadvantage of this method is that it only reports a single distance. When multiple objects are involved the user would have to point at these objects to determine the distance.

10.4.5 Paper map task

After finishing all distance tasks, the participant was asked to go inside the office and perform a final task for the distance experiment.

There were six different printed maps each on A3 paper, one for each distance in the experiment. Figure 46 displays one of the six maps. These maps had been created using a PHP script that took the coordinates from all the target objects in the Unity project (9.3.3). These coordinates were converted to a pixel location on the pipeline map where a circle was drawn to indicate the position. Each map also contained the location of the user. Both these circles contained another small 1 mm wide circle that indicated the exact centre of the circle.

The generated image file was saved as a PNG image and manually placed into a layout which contained a scale and ruler scale.

Figure 46. One of the maps presented to the participants in the experiment.

In this experiment the user was to measure the distance between the red coloured circle (user) and the black circle (target). Various tools were provided: a standard ruler, a calculator and a piece of paper. The participants were instructed to verbally give their result for the distance measurement, upon which the next map was handed to the user. Both their estimated distance as well as the time it took to estimate the distance were recorded.

The approach of putting this task always at the end of all other experiments posed the risk of learning effects. But as all the paper maps had different target locations, (each of which appeared only once), this effect is likely nonexistent or very small. The other way around the risk might be larger: Participants might remember some of the values and it might bias the estimations in the experiment.

10.4.6 General distance comments

There are some comments to the distance estimation experiment that should be given some thought.

The mobile device is held away from the eyes of the user. It is likely that the user estimates the distance from their own location instead of the mobile device and this might cause a small offset between the perceived distance and the actual distance. In an interview with a geotechnical company (15.9), it became clear that such distance offsets are a potential problem as the location of underground objects is generally measured with precision to less than 10 cm. When using augmented reality with accurate positioning sensors (1 cm resolution), these should be as close to the eyes as possible to reduce this offset. As a consequence, the augmented reality visualization will likely have an increased registration offset because the location of the device is not equal to the location where the device thinks it is.

Another important point is how distances are measured by people. Is distance measured in 2D or in 1D? The distance to target objects can be either considered from the measured mobile device height or from the ground as displayed in Figure 47.

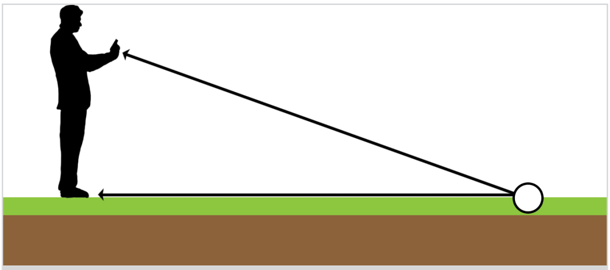


Figure 47. Distance measuring: 2D and 1D.

To determine how the participants in the experiment measure distances both the ground distance and the diagonal distance are saved in the result file. Having both distances makes it possible to calculate the accuracy of the estimated distance to the 1D distance and the 2D distance. After performing all experiments it would be possible to tell which of these two are more accurate

The 1D distances to the target objects will all be equal to the participants as the target locations and the location of the participants are all on the same place. The 2D distance is not as, it is determined by the Pythagorean distance as it takes the devices 'eye height' into account, so the camera object in Unity will have a different height, and therefore a different outcome of the Pythagorean distance per participant.

10.5 Depth cues

The second experiment explored cues to enhance depth estimation on a mobile device. Participants followed basically same procedure as for distance estimation.

10.5.1 Depth estimation without cues

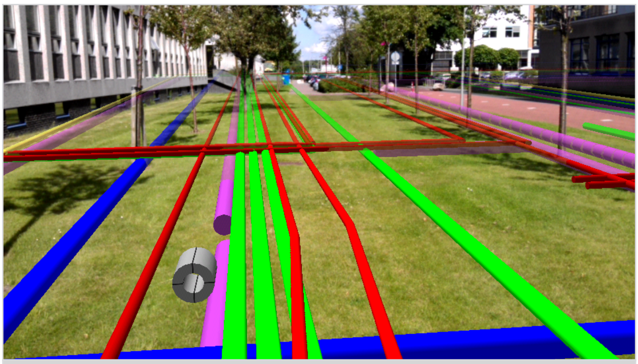


Figure 48. Depth estimation without any help.

As in the distance experiment, to acquire a baseline estimation, participants estimated depth without cues. The results of this experiment would be used to compare again depth estimation cues and assess whether other techniques improved upon the baseline situation.

10.5.2 Depth rows

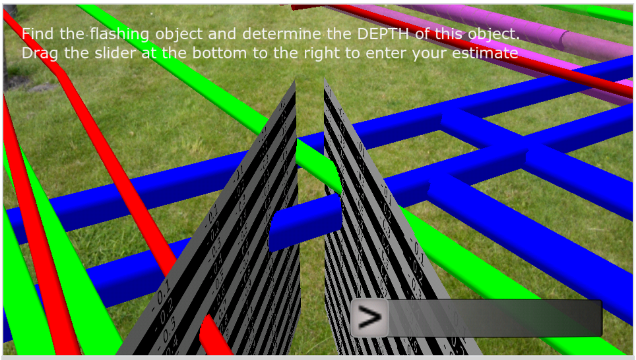


Figure 49. Perspective height lines.

This technique displays two vertical planes slightly rotated to almost intersect one another. The planes contain horizontal lines that alternate colours between black and white. Each line represents a depth value (in 10 cm increments) which is also shown on each row as a number. In the implementation of this prototype the lines are not fixed in world space. The planes rotate with the device as though they were attached to the head of the user. Therefore the position is fixed, but the orientation is not, similar to the radial grid distance technique. This technique was intended to improve accuracy in depth estimation [51] by adding a grid (although they are vertical instead of a ground plane) and showing distance markers as well. As a result, it allows the user to intersect any of the virtual objects presented in the augmented reality display. By intersecting the lines and looking at the target location, it is possible to determine the depth of objects as the user would only need to read the depth value from the coloured lines. Each bar represents a depth increase of 10 centimeters meaning users might need to interpolate a depth if the values are in the middle of a line Moving also allows for motion parallax effects.

10.5.3 Depth 'magic lens'

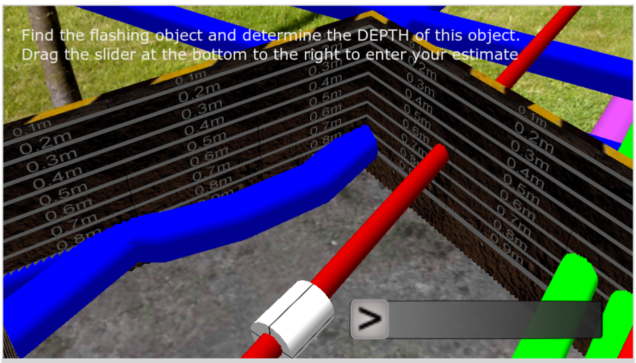


Figure 50. The magic lens cue.

The magiclens technique displays a fixed box around the target with horizontal lines indicating depth using absolute numbers. Each horizontal line at the sides of the box indicate a 10 cm distance and each vertical line represents 10 cm change in the depth. In essence, this technique is similar as the top-down distance measuring technique with a changed scale. The view is like if it were seen from the side, like a cross cut. This technique was added to experiment in the assumption that a 2D view should be able to provide an accurate estimation and also be easy understandable by the subjects.

This visualisation is also used in the Vidente project [12]. It was included in this experiment to determine usability and readability of the technique. In the Vidente project the subjects could walk around the object giving the extra cue of motion parallax. In this experiment, however the users were asked to stay fixed on their location which only provided only one point of view. As a result, the results of this technique cannot be copied over 1:1 to the Vidente project.

Another difference is that in a true magiclens, everything outside the box would be hidden or partially visible. In the prototype this did not happen and all the objects were equally visible outside the box as inside. The bottom of the box is covered with a concrete looking texture. The outsides of the box facing the user are always semi-transparent (Figure 51). Otherwise it can be difficult to look into the box from certain angles. This technique is similar to the "over rendered transparency" technique of [51].

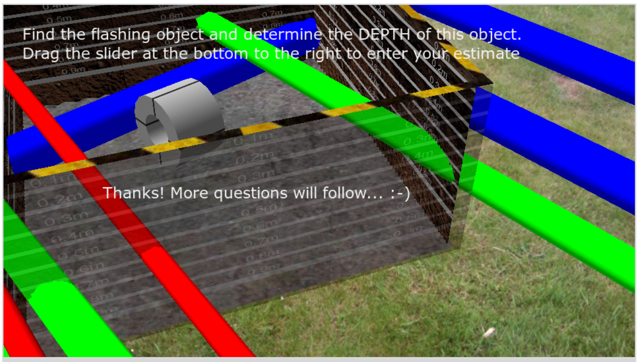


Figure 51. Transparent sides at the magic lens.

10.5.4 Side view depth lines

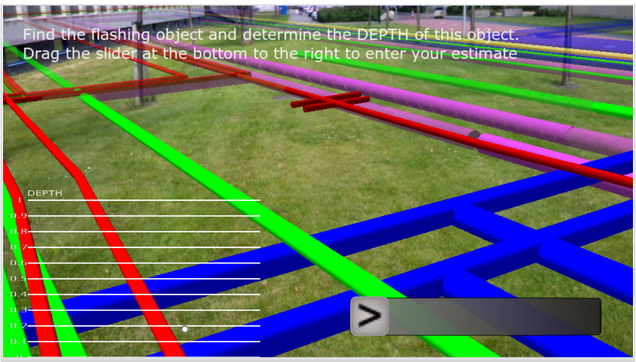


Figure 52. Side view of the depth.

In essence, this technique is similar as the top-down distance measuring technique with a changed scale. Each line represents 10 cm change in the depth. The view is like if it were seen from the side, like a cross cut. This technique was added to experiment in the assumption that a 2D view should be able to provide an accurate estimation and also be easy understandable by the subjects.

10.5.5 General depth remarks

All objects in the depth experiments were below the ground level. However, because of how the augmented reality in this project works, all objects appeared to be above the ground. In the distance experiments the objects were up to 10 meters away. In the depth experiment all objects were at most 1 meter deep, and therefore it was less evident that some objects were lower than others. Depth estimation was therefore more difficult than the distance estimation.

11 Experiment results

The results from the distance and depth experiments were analysed and are presented separately in two chapters.

The data that has been acquired through the experiments has been merged together using PHP which is a programming language primarily used for web development and tools. One PHP read all output files, sorted the order of the experiments, and then created Comma Separated Values (CSV) and HTML files containing aggregated data for both the distance and depth experiments. These files were imported in Microsoft Excel where further data analysis was performed. ANOVA operations have been performed using IBM SPSS. The graphs have been produced using PHP scripts and a charting library called pChart2 [62].

11.1 Distance experiment

11.1.1 Summary of statistics

28 subjects participated in this experiment, but one of the data files missed the result of the last task and one participant experienced problems because the gyroscope displayed erratic behaviour. The results from these two participants where therefore rejected leaving 26 samples to be used. 21 (80.77%) remaining participants were male, and the average age was 42.04 years. The experiments took place over five days. With 26 participants, a total number of 624 distance data values have been created. One experiment had to be restarted after one entry had been entered due rain. After the As only one result was entered before the restart, this experiment is still considered valid.

The mean time to perform all distance cue experiments was 850 seconds (14m 10s) with a standard deviation of 246 seconds (4m 06s). Of the participants, 15 (57%) owned a smartphone and 6 (23%) had used some kind of augmented reality before.

The purpose of distance-cue data analysis was to explore whether the additional cues provided a significant improvement in accuracy, in the time required to estimate distance, and in user confidence, compared to when not using any distance cues, or in distance measurement on a paper map.

Table 9 displays the short names for the various distance experiments.

Table 9. Codes for distance experiments

Code	Represents
di_nocues	No cues
di_radial	Radial grid
di_topdown	Top down view
di_range	Range finder

11.1.2 General observations

The author observed participants from two meters away during the study not only to ensure consistency in the procedure across participants, but also to note trends, mistakes, and user behaviour. Occasionally a participant would forget the estimated distance, after moving the "I am ready" slider to the right. After a short thought the value was often remembered.

Another observation was whether a participant was right or left-handed. Although not particularly relevant to the research question, it is interesting from a usability viewpoint. Right handed participants held the mobile device in their left hand, such that they could use the touchscreen with the right hand, while left handed participants held it in their right hand. This might be considered when building an application targeted to be held in a landscape orientation such that the chance of pressing buttons by accident can be reduced, as the majority of humans are right handed [71].

11.1.3 1D and 2D distance measurement

There was some concern about which distance measurement to use as previously discussed ("General distance comments" on page 34). Based upon the mean accuracy (1D: 85.92%, 2D: 86.77%) and an ANOVA significance test where $F(1246,1) = 0.914$ $(p < 0.339)$, it can be concluded that the are no significant difference between the report distances to the 2D distance than the 1D distance. Therefore, in this following analysis of the data only the 2D distance accuracy will be used.

Participants were required to estimate distances classified as *near*, *middle* and *far*. For each of these classes, there were two distances. Both distances were presented and therefore making it 6 locations per cue as displayed in Table 10.

Table 10. Distances in experiment

Type	Distance (meters)
Far_1	10.0
Far_2	10.0
Middle_1	7.0
Middle_2	8.0
Near_1	4.0
Near_2	5.5

11.1.4 Accuracy

Figure 53 shows the mean accuracy of the different distance estimation tasks. The accuracy was calculated as a percentage of the actual distance to the target objects by the earlier described Formula 1:

$$accuracy = 1 - \left(\left| \frac{estimated\ distance - real\ distance}{real\ distance} \right| \right) \times 100\%$$

In this graph a higher bar means that the participants were able to make more accurate estimations.

This graph also shows how participants estimated the distance the least correct without any cues to assist them. A one way ANOVA analysis showed a significant difference between the accuracy of the three different cues and the control condition with $F(3, 620) = 157{,}033$, $p < 0.001$. To further determine which cues have significant differences a Tukey HSD post hoc analysis was performed.

This showed that ***di_nocues*** performs less accurately ($p < 0.001$) than all other cues. ***Di_range*** performs significantly better than any of the other cues($p < 0.001$). The ***Di_radial*** is not significantly more accurate than ***di_topdown*** ($p = 0.149$)

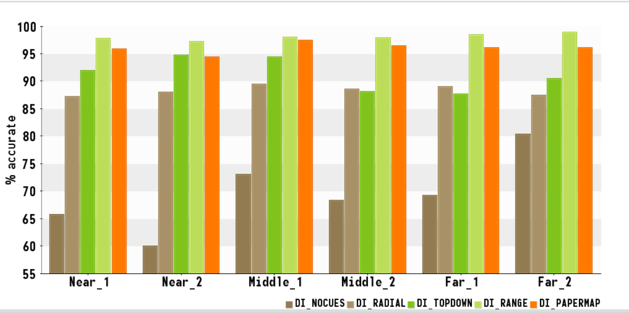


Figure 53. Percent accuracy of the cues in distance estimation.

The 'range finder' cue resulted in the smallest error in distance estimation compared to the actual real world distance with a mean accuracy of 98.09% (SD: 4.15%) %). The other two cues, the radial grid and the topdown lines also provided an improvement over the baseline condition. The topdown cue had a mean average of 91.24% (SD: 9.74%) and the radial has 88.32% (SD: 7.23%) Mean accuracy without cues was 69.46% (SD: 20,77%).

The participants also had to perform a small task of measuring distances on a paper map. This task was always performed as the last experiment and took place indoors. Surprisingly only two participants realised halfway the task that the locations shown were likely to be the same as used in the outdoor experiment. The paper map distance measurement technique worked out well (mean accuracy 96,3%, and the standard deviation was 6,0%. The results of the paper map measurements are significantly different to all cues with the exception of ***di_range*** (*p = 0.66)*. Which was 98.09% accurate (SD = 4.15%). This makes the ***di_range*** cue perform slightly (but not significantly) better than the paper map.

Most participants wanted to use the ruler to measure the distance between the two given locations and only one participant tried to do it visually only. People were less interested in using the calculator, which resulted in slightly longer measurement times.

11.1.5 Confidence in distance estimation

When estimating distance, participants were also asked to express their own level of confidence indicating how much they considered their entered value as correct. The results are shown in Figure 54. The vertical axis of the figure show the type of distance cue and the bars across the horizontal axis shows the level of confidence expressed by the users.

Under baseline conditions (***di_nocues***), the subjects felt the least confident in their estimation compared to all other conditions. Many participants still were 'Somewhat sure' in this, which leads to believe that the augmented reality visualisation integrates well with the environment, but does not expose enough cues on its own to make distance estimation easy.

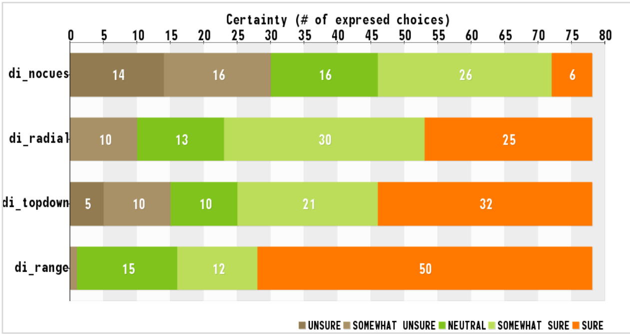


Figure 54. Certainty per distance cue.

Participants felt the most comfortable using the ***di_range*** technique, which reported the distance as a floating point number. One common comment was that this technique did not provide any additional depth cues (similar to ***di_nocues***) and that it was only possible to learn the distances by looking around, as the displayed distance is related to the way the phone is held. So a *blind trust* in the reported number is required according to many of the participants. Participants did like that the technique was dynamic and could be influenced by their own actions, giving them a form of control, unlike ***di_topdown*** which did not give such a feeling. ***Di_radial*** worked better on near distances than far distances as the radial lines become more closer to each other and less visible when further away. In the "*neutral*", "*somewhat sure*" and "*sure*" categories both the ***di_radial*** and ***di_topdown*** technique approximately share the same percentages. ***di_topdown*** does have more "unsure" votes which might be because some participants did not fully understand what the top-down distance meant.

Figure 55 displays the mean confidence calculated over all distances as expressed by the participants as well as the mean accuracy. This provides the ability to see if a user confidence was at all correlated with user accuracy This figure shows the integer values of the Likert scale (0 being unsure and 4 being sure) as if it were a linear scale. The position of the indicator on the graph shows the mean score. There does seem to be a relationship between the confidence and the accuracy. ***di_range*** has the highest confidence, and the highest mean accuracy. The confidence with ***di_radial*** and ***di_topdown*** are quite close to each other and so is their mean accuracy. As stated before, the accuracy was the lowest under baseline conditions, and the participants also felt the least confident in their estimations.

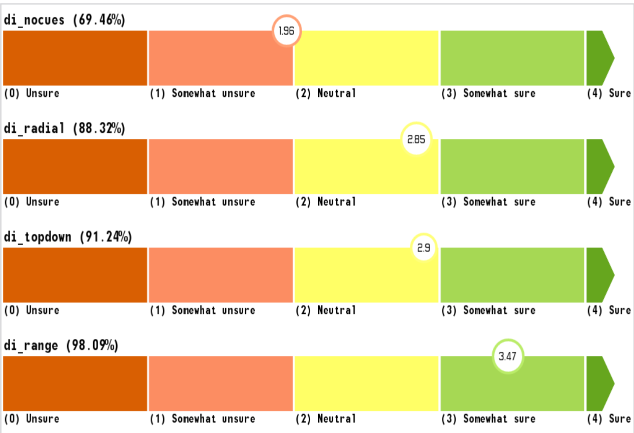


Figure 55. The mean confidence in the cue.

Although confidence was not explicitly measured in the paper maps experiment, participants verbally expressed that they were completely sure of their measurements,. This can likely be explained as the reading of distances is a task which relies less on mental and cognitive abilities as the paper map task relies on a 2D map and not on 3D perspective view.

On hindsight, it might have been interesting to have all the participants perform this experiment and express confidence without using any tool such as a ruler or calculator.

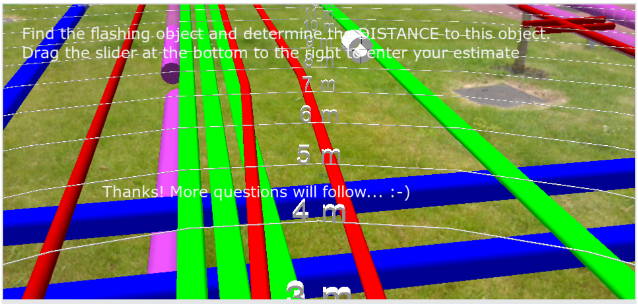


Figure 56. Readability of distances becomes more difficult and more ambiguous over distance.

11.1.6 Over and under estimating

Table 11 displays whether participants have been under-, over, or correctly estimating the distance while using a certain cue. The absolute error (| estimated distance real distance|) and error (estimated distance real distance). If the absolute error has a maximum error of less or equal to 1% of the actual distance it is considered equal. If the absolute error is larger than this, it is considered either an over estimate (error > 1%) or an underestimation (error < -1%).

Table 11. Under, over and correctly estimated distances

Type	F1	F2	M1	M2	N1	N2
di_nocues						
Overestimate	7	16	5	4	1	3
Underestimate	18	7	20	22	23	23
Equal	1	3	1	0	2	0
di_radial						
Overestimate	11	10	14	10	11	11
Underestimate	14	16	12	15	15	15
Equal	1	0	0	1	0	0
di_topdown						
Overestimate	21	24	21	20	6	8
Underestimate	5	2	3	5	18	10
Equal	0	0	2	1	2	8
di_range						
Overestimate	1	6	6	3	7	3
Underestimate	4	1	1	4	5	7
Equal	21	19	19	19	14	16

Estimating distances without any cues (***di_nocues***) shows that underestimation occurs more frequently than overestimation. In the Far_2 situation the overestimation is higher than in the other cases. The cause of this is not sure, except some people have reported the use of the environment to aid them in the determination of the *far* distances such as the trees. This might explain the difference as the trees were not centred to the participants. The trees at the Far_2 side were further away from the actual target than from the Far_1 object. The ***di_radial*** cue displays a more equal spread of over or underestimation. Although various participants mentioned that the perspective element of the radial circles made it more difficult to judge the objects further away (the *far* locations), this cannot be seen from the table. Underestimation is an commonly reoccurring error in the perception which frequently occurs in virtual or mixed environments [58].

Participants tended to overestimate both the far and medium distances using the ***Di_topdown*** cue displays, while they underestimated the near distance. There is no clear explanation for this effect. Possibly the dot indicating the distance might have been considered to be just below the line indicating the distance instead of on top of the line for both of the near cases Another potential reason could be that the participants did not fully trust the presented distance and decided to enter a lower value

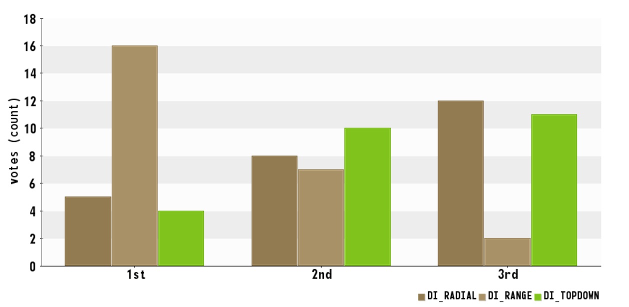


Figure 57. Preferences as given by the participants in the post-experiment form.

At the end of the experiments the participants were asked to rank their preferred methods of depth and distance estimation (Figure 57). As there were three cues to rank, a weight has been used to create a total score. This score is defined by the following formula:

$$totalscore = (3 \times 1^{st}\ score) + (2 \times 2^{nd}\ score) + 3^{rd}\ score$$

This formula gives larger weights to the order of choice, the first item having the largest weight and then the second and third respectively.

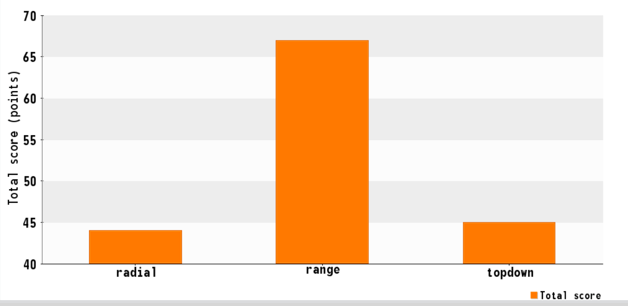


Figure 59. The total scores for distances cues as calculated by the weighting function.

The range finder technique was the preferred technique by most participants, which can be seen from both the number of votes on the 1st score and in the total score. Participant feedback indicates this might be due to the ease of use. ***Di_radial*** and ***di_topdown*** both have almost the same place in the total score. Both these techniques did not have a significant difference in distance estimation which could be the reason behind this result.

One would only need to pinpoint the centre of the device on a location and it would tell the distance based upon the angle of the device as mentioned in "Range finder" on page 33. In the post experiment evaluation most of the participants indicated that the displayed number gives a sense of accuracy. The other techniques do not offer values as concrete. They also realized that this could be a false sense of accuracy as there were no other means of establishing a distance estimate, although the majority reported that they were "*sure*" when filling in their values.

11.1.7 Time required to estimate distances

The time between the visibility of the target object on the display, and the moment the participant moved the "I am ready" slider to the right, has been recorded. The durations for each cue and distance can be seen in Figure 60.

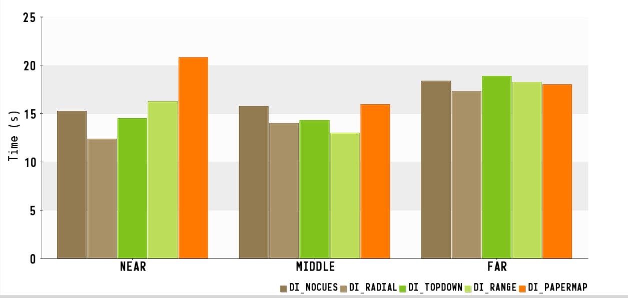


Figure 60. Time spent on the estimation of the distance. The values shown are the average of the two distance types.

The ***di_radial*** technique (light brown) required the lowest time for estimation (mean: 16.18s SD: 14.15s). An ANOVA analysis on the time spent per distance and per cue revealed that there were no significant differences in the time spent for the different cues as $F(3, 100) > 0.31$ and $p > 0.44$ for the entire analysis. That the radial technique required the lowest mean time likely means it provided a more natural representation of distance than the other techniques, and also that the participants do not have to look anywhere other than the target object in order to determine the distance.

When looking at the average time it took to estimate distance, an increasing trend is visible with exception of the paper maps. The greater the distance to the target object, the more time it took to estimate it. It is not clear why this happened as there were no particular anomalies visible during the experiments itself. Possibly the participants tried to estimate how much time it would take to walk to a certain distance which would explain the increase over distance. Dey et al.[57] also found an increase of time with increasing distance, but did not discuss an explanation either.

The time spent on distance measurement using the paper maps was quite similar in each task. The maximum mean difference is 0.9 seconds, which is fairly equal considering the nature of the task and overall time required on to complete it. The difference in time between the paper maps task and the other cues is quite small.

11.2 Depth experiment

For depth estimations, the target object was always “placed” between 0 and 1 meter below ground level. The information that the subjects had to enter was similar to the distance measurement tasks with the only exception being the slider, which has a different range due to the smaller depth range than distance.

Table 12 displays the short codes for the various experiments instead of using their complete name all the time.

Depth experiments have been performed on two distances: very near, and near. Distances further away are considered impractical as it will be very likely that future users are only interested in depth when they are nearby pipelines. Similar to the distance experiment, each had two different locations resulting in a total of 4 locations per cue. The depths of these locations can be seen in Table 13.

Table 12. Codes for depth experiments

Code	Represents
de_nocues	No cues
de_magiclens	Magic lens
de_planes	Diagonal planes
de_side	Side depth lines

There were 20 participants in the depth cues experiment with a mean age of 42.2 and a standard deviation of 9.91 years. 11 (55%) participants had a smartphone and 5 (25%) has used augmented reality before.

Table 13. Actual depths for the experiment

Type	Depth (m)	Distance (m)
Near_1	0.75	4.0
Near_2	0.9	5.5
VeryNear_1	0.2	2.7
VeryNear_2	0.6	2

During the experiments it was already becoming apparent that performing depth estimation is more difficult than estimating distances. Almost all participants mentioned that estimating depth without any help (***de_nocues***) was practically impossible.

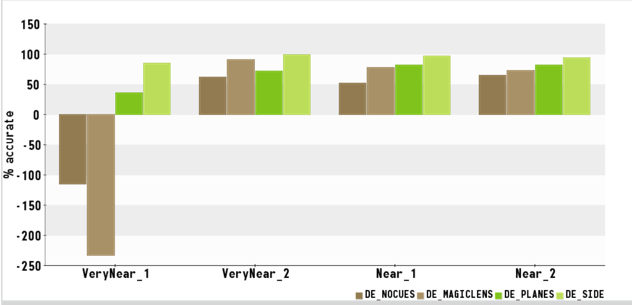


Figure 61. Accuracy of depth estimation per target location.

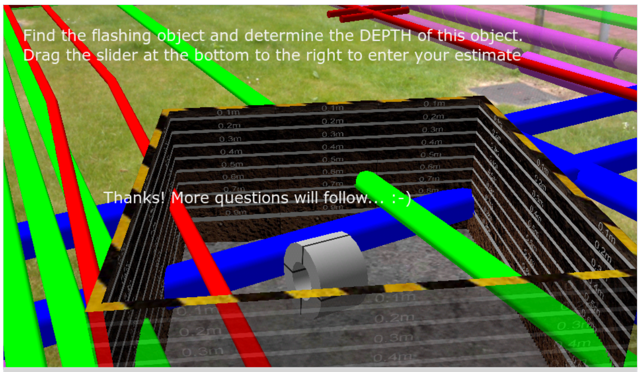


Figure 62. Depth cue issue.

The mean accuracy when no cues are displayed was 15.58%, with the standard deviation of 101.60%. An ANOVA analysis shows that there are significant differences in all distance groups ($p < 0.001$). Therefore an Tukey HSD post hoc analysis has been carried out to determine where the significant changes specifically are.

In the VeryNear_1 case, both ***de_nocues*** and ***de_magiclens*** have $p < 0.004$ to other cues. Only ***de_planes*** and ***de_side*** seem to have a difference which is insignificant as $p < 0.460$, this means that they do not have a significant difference to each other.

With the VeryNear_2 distance accuracy, both ***de_magiclens*** ($p < 0.007$) and depth 5 ($p < 0.001$) have a significant improvement of accuracy over ***de_nocues***. ***de_planes*** does not with ($p < 0.658$).

de_magiclens, ***de_planes*** and ***de_side*** all have a significant improvement over ***de_nocues*** ($p < 0.001$) in the Near_1 case. Additionally, ***de_side*** has a significant accuracy improvement over ***de_magiclens*** ($p < 0.003$) and ***de_planes*** ($p < 0.025$).

At Near_2 ***de_planes***($p < 0.47$) and ***de_side*** ($p < 0.001$) offer a significant improvement over the accuracy of depth 1, while de_magiclens does not ($p < 0.619$). ***de_side*** also offers an improvement over ***de_magiclens*** ($p < 0.009$) but does not over ***de_planes*** ($p < 0.278$).

De_side was the most accurate, even though it showed an anomaly at the VeryNear_1 condition where it was less accurate (mean accuracy of 84%, SD = 27.04). This standard deviation is higher than in the other distances of ***de_side***. ANOVA shows that these differences are not significant ($F(3,76) = 1.673$. $p = 0.180$). ***De_planes*** has a mean accuracy of 67.68%.

Figure 61 shows outliers in the data of the depth estimation experiment. There was one distance with a different outcome for all. It is the VeryNear_1 distance which has been placed somewhat less deep in the ground ($y = 0.20$ meter deep) instead of all other targets which have been between 0.6 to 0.90 meter deep. The target object does not have any contact (intersections) with other pipelines nearby. This means that it is more difficult to determine the proper depth using the ***de_magiclens*** technique, as it does not provide any additional depth cues to the user (see Figure 62) when there are no clear intersections with any of the pipelines nearby. If the target object is positioned around one of the pipelines that intersect the edges of the box, the depth can be estimated quite well, as visible in Figure 62. However a lack of such an intersection results in an inability to determine the depth. The mean depth estimation using the magic lens cue is less accurate (1.88% accurate, SD: 146.89%) than the estimation without any cues (15.58%, SD: 101.60%) which might be caused by participants choosing a 'safe' value when it is practically impossible to determine the depth. Only two of all candidates estimated a depth with an accuracy of 90%.

The other cues also perform less well in this situation. ***De_side*** has a mean accuracy of 84.00% and ***de_planes*** has a mean accuracy of 35.73%. Why this happens is not exactly clear, as the mismatch in the depth cue primarily exists for the ***de_magiclens*** situation as the lack of intersections does not apply for the other techniques.

In the case of the vertical planes, participants might think that the target object is on the same depth as the pipelines and use these instead to intersect with the planes. The side depth lines should not suffer from any incorrectly perceived cues as it is a 2D cross section representation. This technique does still have the highest accuracy with a mean accuracy of 93.15% accurate with a SD of 16.35%.

Depth cues preference

Similar to the distance technique ranking, the participants of the depth experiments were also asked to express their preference for techniques. These values are weighted using the same formula as in the distance situation. The formula is repeated for ease of use:

$$totalscore = (3 \times 1^{st}\ score) + (2 \times 2^{nd}\ score) + 3^{rd}\ score$$

which results in the following figure:

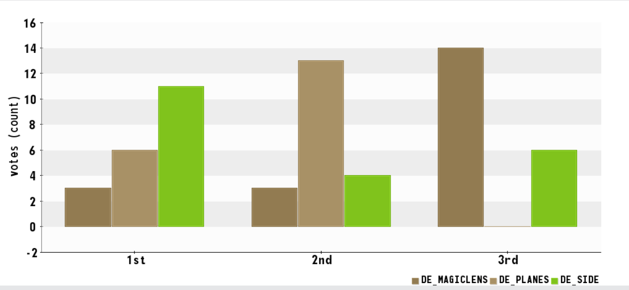


Figure 63. Depth cues as ranked by the participants.

The participants preferred the ***de_side*** technique the most (Figure 64), as it received the most votes as the first choice. This technique does not require difficult perspective intersections of the target with the helper objects or other pipelines. In the second place is the vertical planes technique. Many participants preferred this technique over the magic lens because it could be moved around by the participant, based upon the reactions from the participants. The side depth does not depend on perspective rules and provides an orthogonal view from the side. Such a view requires less mental effort than using any of the perspective views. Unfortunately it is also the technique that integrates the least with the augmented reality view as it is a GUI element.

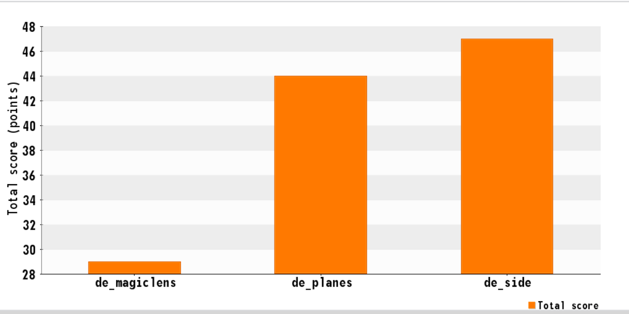


Figure 64. Total scores.

11.2.1 Confidence in depth estimation

It is evident from Figure 65 that the subjects did not feel confident in the values they entered in the cue less situation. ***De_magiclens*** did not convey enough depth to have the subjects specify 'sure'. The ***de_planes*** and ***de_side*** cue both have many votes for 'sure'. For ***de_planes*** this is likely caused by the ability to intersect the target object using the geometry of the cue. After discovering the ability to perform these intersections, the subjects felt quite comfortable using this technique, which is also why it was ranked 2nd by the participants.

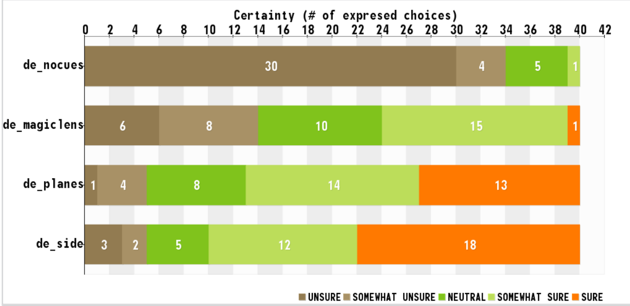


Figure 65. Certainty per cue as specified by the participants. when filling in their depth estimation

De_side allowed the participants to see the depth as a side view (as seen in Figure 52), like an excavation. Some reported that they considered this view not as an extension to an augmented reality view. This is for the similar reason as the technique for distance displaying a top down view: ***De_side*** does not become an element of the 'virtual world' but rather a GUI element above everything. Despite this, ***de_side*** was chosen as the most preferred depth cue, had the highest accuracy in depth estimation and the participants felt the most confident in the values they entered.

Figure 66 shows the mean accuracy and the confidence participants had in their estimation. A relationship between the confidence of the participants and their estimation is clearly visible in this graph.

The VeryNear_1 situation reduces the mean accuracy of the ***de_magiclens*** technique to 1.88%. If this situation were not to be considered, the mean accuracy would be (80.83%) which also explain why the confidence is quite high. But the VeryNear_1 case does not reduce the confidence by a large amount: Without VeryNear_1 and the associated entered confidence levels, the confidence value would be 2.38 (0.09 difference).

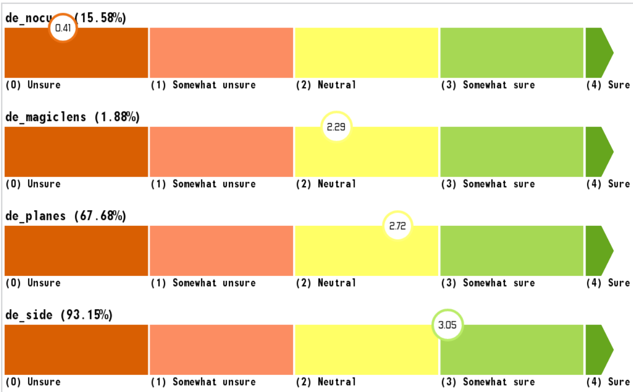


Figure 66. Confidence per cue.

11.2.2 Depth estimation analysis

Over and underestimation was determined by comparing the participant estimated depths with the known depths of the target objects as previously seen in Table 13.

Table 14. Over, under and equal estimations for depth.

type	N1	N2	VN1	VN2
de_nocues				
Overestimate	0	2	19	5
Underestimate	20	18	1	14
Equal	0	0	0	1
de_magiclens				
Overestimate	13	2	20	6
Underestimate	7	16	0	11
Equal	0	2	0	3
de_planes				
Overestimate	2	0	16	8
Underestimate	17	18	4	10
Equal	1	2	0	2
de_side				
Overestimate	7	7	9	7
Underestimate	6	3	11	4
Equal	7	10	0	9

Table 14 provides information how participants performed in their estimation of depth. It shows if they either over estimated the depth (too deep in the ground), underestimated it or if they managed to determine the depth accurately such that the depth was equal to the actual value. Similar to Table 11 which displays performance for distances, the threshold for values to be equal is 1%. If the value is outside this threshold, it will fall in one of the two other categories. When the participants reported values to be deeper underground than the target, it is considered an overestimate. If less than the target, then it is considered an underestimate.

In the baseline condition (***de_nocues***) underestimation is common with the exception being the VeryNear_1 target. This exception was probably caused by the participants making a 'safe' assumption of depth., Where the Near_1 and Near_2 targets were too deep into the ground to fall in the overestimation category. The depth of the VeryNear_1 target was too close to the surface and therefore fell outside the underestimation category. The mean value for baseline (***de_nocues***) was 0.52 meters deep. This matches with all the estimations in Table 11. 0.52 meters is an overestimate for VeryNear_1, and underestimate for all other depths.

In the ***de_magiclens*** case there is more ambiguity. The location of the target influences the result as it determines whether an intersection with the sides of the box can be made or not. In the VeryNear_1 situation the target was not near any pipelines which increased the difficulty of making a proper depth judgement. None of the participants reported a value which was equal or less deep than the target.

11.2.3 Time required to estimate depths

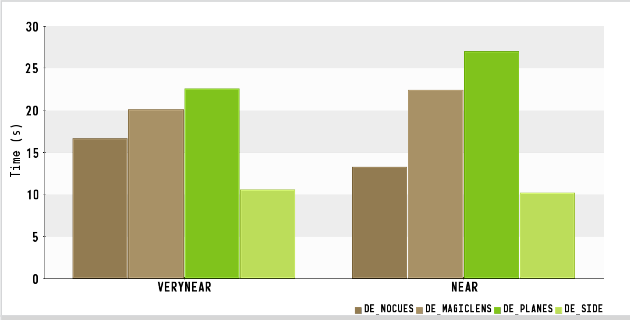


Figure 67. Time spent on the estimation of the depth.

The time measurement started after the object had been (partially) visible for 0.2 seconds. The time represents the moment between seeing and a "estimation done" slider move at the bottom right of the screen. There is a high standard deviation (15.70s) in the time required to estimate the depth. The ***de_magiclens*** (20.43s) and ***de_planes*** (24.80s) technique required the longest mean time. This could indicate that the participants had trouble estimating the depth or reading the perspective lines. ***De_nocues*** required less time (13.77s) which is likely caused by the fact that determining the depth was considered impossible and there was no cue. Without cues there is no additional time spent on the 'reading' of a separate cue. Both these two reasons will likely cause the participant to make a decision quicker than with cues. Four participants discovered that there was no need to actually see the object to determine its depth when using ***de_side***. This also explains the lower mean values, as these have times of 0 seconds (they never searched for the target object). After filtering these items, a different table is produced, as seen Table 15. The mean values are now more similar to ***de_magiclens*** and ***de_planes***. (See table at appendix, 15.3 on page 56)

Table 15. Mean time and standard deviation after filtering zero times.

What	N1	N2	VN1	VN2
de_side				
Mean time (s)	12.34	10.68	19.46	11.25
Std dev time (s)	9.78	9.16	18.83	13.07

11.2.4 Summary

The next table, summarizes the results from both the distance and depth experiments. ***Di_nocues*** and ***de_nocues*** are not considered here, as all other techniques provide a significant improvement. The only exception to this is the ***de_magiclens*** which is caused by the high quantity of estimation errors in the VeryNear_1 case. Paper maps have a lower mean time to measure the distance (17.24 seconds) than ***di_topdown*** (19.18 seconds***).***

Table 16. ***Summary of all results by means***

What	*Best cue*	*Worst cue*
Distance		
Accuracy	*di_range*	*di_radial*
Time	*di_radial*	*di_topdown*
Confidence	*di_range*	*di_radial*
Depth		
Accuracy	*de_side*	*de_magiclens*
Time	*de_side*	*de_planes*
Confidence	*de_side*	*de_magiclens*

11.3 Participant comments

All participants were asked for general comments or feedback about the experiment, the cues they had seen, etcetera. Many participants comments were similarly.

General

It was interesting to see that some participants did not really trust the distance cues at first, but did so after a few tasks.

Although ***di_topdown*** was considered one of the easiest to read, some found that it did not integrate well with the augmented reality scene and that it was equal to reading a map in an office, instead of being on location.

One unexpected question has been asked many times by the participants, after completing an experiment: If it were possible to have some form of a 'scoreboard' to see who had the highest overall accuracy.

Cues

The radial grid was considered a technique that worked well, until about a distance of 8 to 9 meters at which point the grid lines started to get too close to determine distance. This is not visible from the results as shown by the graph in Figure 53, however.

One participant suggested a combination of the radial grid and the top down lines as a way to improve accuracy of distance estimation. The radial grid would only display the two closest circles around the target object (eg: if the object would be at 6.3 meters, it would only show the 6 meters and 7 meters line) and then use the ***di_topdown*** view for the values between.

Some found that the perspective height lines allowed to 'cut' or intersect through the virtual objects, such that it was easier to determine the depth of objects, unlike the magic lens technique where this was not possible.

The fixed depth box was considered a nice approach by various subjects, with the additional comment that it became more difficult to read with increased distance. It did provide a better view of depth itself, because of the excavated presentation it provides.

The range finder technique was considered the most accurate by the participants. According to many of the participants they blindly took the values for granted and did not think whether the values were correct or not. Participants did not like it for exactly that reason: It was hard to tell if the values are actually correct if there were no additional cues. A few participants found it slightly difficult to keep the phone steadily pointed at the target objects while reading the distance at the left side of the screen.

The ***di_topdown*** and ***de_side*** was considered the most believable cue by some of the participants although the rangefinder (***di_range)*** was favoured mostly because of its perceived accuracy. Some participants reported that the distance of targets located on the near distance were more difficult to estimate than objects further away.

Participants did mention that ***di_radial*** result in a better general awareness of distances throughout the augmented reality scene as multiple distances were visible at the same time.

Procedure

One participant kept his hand in front of the camera as it did not matter for this participant whether the real world was visible. Only during the cases where there were no cues, his hand was removed from the camera, apparently to try to use environmental features. Nearly all participants performing the depth estimation tasks without any help said it was practically impossible to do it correctly. This was not the case with the distance experiments, where the participants did try to measure distance without much comments.

In the case of the top down view (distance) and side view (depth) some discovered that there was no need to find the target object at all. Some decided to skip locating the target, while others continued to see if the indicated distance or depth was matching their own interpretation.

Interface and controls

Various comments were made about the readability of the screen and the visibility of numbers. Especially with sunlight the screen was more difficult to read. Most participants managed to read everything fine eventually. Not all participants were completely satisfied with the slider to enter their estimated distance. They considered it too accurate (floating point, two digits of precision).

A few participants also reported that the ***di_topdowns*** view's scale was considered too high level (1 meter resolution). Some also found this technique difficult to understand.

It also became apparent that many participants did like to be in control of the depth cue. Being able to move the radial grid, the range finder and the side depth planes was considered a great help. Two participants mentioned that using a tablet size device might be better for augmented reality applications, as the screen is larger and therefore the font size can also be increased. Some mentioned that holding the phone for a while became a little bit heavy.

12 Conclusion

The purpose of this project was to design and explore various visual cues to enhance the estimation of depth and distance in an augmented reality environment on a mobile device, and to evaluate the performance of these cues. Further, the project was also about assessing whether it is possible to create a smart phone application that would assist in locating underground cables and pipelines.

12.1 Estimation of depth and distance in augmented reality

Proper estimation of virtual objects in either depth or distance, whether absolute or relative, is crucial for the proper understanding of the virtual objects and how they relate to the real world. In this research project both the perception of depth and distance have been measured by a user study that implored a variety of visual cues on the mobile device to present either depth or distances on the screen. The first research question stated the following:

" How can artificial depth and distance cues be improved in the augmented reality visualization such that it results in a more accurate determination of absolute depth and distance than without any additional cues? "

Based upon the data analysis it becomes clear that letting the software show the distance towards the users is considered the most reliable and the most accurate, and the difference was found to be significant when compared to other techniques. The ***di_range*** and the paper map technique perform the best and are surprisingly equal in their distance measurement performance. It is worth mentioning that some of the participants did feel that visualizations such as ***di_radial*** and ***de_magiclens*** provided more of a integrated feeling with the world, than those that did not include any 3D geometry in the augmented view. However, in this experiment the tasks asked for distance estimation and showing real numbers is more convincing for the users than if they have to do the estimating themselves.

The depth experiments have shown that depth estimation is harder than distance estimation as the mean accuracy between the worst performing experiment (***de_nocues*** and ***di_nocues***) is quite different: 69.46% percent accuracy for distance and 15.58% for depth. There is a (***de_side*** and ***di_range***) 4.94% difference in accuracy between the best performing techniques. This is likely because the targets and visuals are all displayed on top of the real-time camera images. This is also likely the reason why some participants (15.00%) preferred ***de_magiclens*** as it gives a better indication of the actual depth of the infrastructure compared to the ground level.

The one 2D view cue resulted in high accuracy in both depth and distance estimations.

Altogether, any of the presented cues for the distance improve the accuracy significantly when compared to estimation without cues. In the distance case, the participants preferred to see absolute numbers (***di_range***) as it gave confidence of precision and was easy to use. The other techniques were rated lower by the participants and were less accurate. They allowed more room for interpretation and therefore also increase the chance of perceptual errors. Yet, they also provide the ability to determine multiple distances in one eye sight. This is something that should be researched in the future.

Depth estimation is more difficult than distance because of conflicting cues: the pipelines are underground but because of the nature of augmented reality, they are projected above the ground. Still most of the presented techniques show a stable and significant improvement in depth estimation. When adding cues to the perspective view, it is important that the user can move or rotate the device to be able to cause different view points or intersection. With a single point of view it becomes more difficult to assess depth.

"Does 3D augmented reality aid in understanding the subsoil infrastructure, by improving the accuracy and confidence such that it could result in less damage caused by excavating on the wrong places when using a paper map?"

The distance estimation accuracy using paper maps and that of the best performing augmented reality technique (***di_range***) are very close to each other. (2.02% difference in favour of ***di_range***) This is both with the assistance using extra help: In the augmented reality case the display of the approximate distance and in the paper maps case using a ruler and calculator. When standing on a potential excavation site, augmented reality has the advantage of immediately displaying the location of the underground infrastructure. This immediate factor is likely to be the true advantage of the augmented reality visualisation as compared to paper maps. The user will immediately see if there are many cables and pipelines at the current location while the paper map first requires the user to find the current location, and interpret the scale of the map correctly.

Still, there are other factors at hand, which *might* result in reduced accuracy as discussed in the interview with two geotechnical experts (15.9 on page 64). If you introduce technology that helps its users in such a way that there is no need to 'think' anymore, then it might make the users *depend* on it. This means that there is a risk that users will always rely on the presented information, even if the information is incorrect. In The Netherlands, many cables and pipelines are not correctly documented because of varying reasons: they might have never been updated after their paths changed after construction work, or were maybe never documented at all. Incorrect information will still be presented by the device as if it were true, with all the associated consequences.

Overall, augmented reality offers benefits over the paper map, yet it likely does not offer significant improvements in accuracy and confidence to the paper map. It might result in less damage because one could take a look around the area before starting to excavate, and decide that some of the underground infrastructure is too close such that a careful approach needs to be considered.

12.2 Professional applications with augmented reality on mobile devices

The usability of outdoor augmented reality applications on smartphones depends on various uncontrollable conditions.

"Could a modern mobile device be used to create a professional application to visualize subsoil infrastructure in a usable way?"

In short: No, the technology is not yet far enough to solely rely on the hardware that mobile devices have to offer. There are two important elements that need to improve before augmented reality can be used on mobile devices to visualize subsoil information:

» Improved sensors. The GPS sensor is not accurate enough in the positioning determination. As long as it does not reach accuracy of less than a meter it should not be used for excavation purposes. It can still be used to visualize the underground to provide an impression but one should not use it for more than this. The orientation sensors of the device should also be more accurate and less subject to drifting.

» Improved display. It should not become difficult to read the display when the sun is shining bright. With current mobile devices this is practically always the case.

» Support cooperative working in some way. Cooperating together with multiple persons on a single smartphone device is difficult and not practical because of the insufficient readability of the displays when viewing from the side, the size of the display being too small and because the augmented reality view uses the location and direction of the device as it's pivotal point. This is already visible when demonstrating an augmented reality prototype to multiple people. Viewing from a different angle than straight behind the device does not make much sense. To support cooperation a different approach will need to be sought.

These considerations aside, sensor based augmented reality is still usable in situations that does not require accurate positioning to the decimeter, such as visualization of landmarks, guided tours, and so on. This is also likely why most of the augmented reality 'apps' on mobile devices are related to such applications. Instead of primarily aiming at a professional application, the focus could also be changed to create an application which can be downloaded by individuals such that it becomes easier to quickly determine, for example, when performing gardening work, if there is underground infrastructure near by.

13 Future work

In this thesis various cues have been implemented to increase the accuracy of absolute distance and depth estimations when using a mobile device. While working on the implementations more ideas came to mind to include in further studies.

13.1.1 Distance measurement between objects

The prototype application in this research primarily focused on stationary targets. Future studies can also be performed that measure the distance between two stationary points and learn which techniques can aid here. Subjects would measure lengths of objects (or between two specified points) instead of estimating the distance to a single object. In such situations, there might be a need for additional cues like texture gradients or colour changes

13.1.2 Depth perception with the freedom of moving

To extend the research presented in this paper, one could opt to allow the subjects to walk in the depth experiments. This might provide the subjects with additional cues such as motion parallax and the ability to view intersections with geometry from a different angle. When the subjects can walk around the targets while performing a depth analysis. This could help significantly in the case of non-screenspace based visualizations such as the magic lens or the depth lines.

13.1.3 Combining techniques

More research is required on how to incorporate augmented reality visualizations on mobile devices which only have limited hardware support and do not have the ability to provide an immersive environment using a head mounted display. The lack hereof means a lack of depth cues. Alternative solutions should be developed to provide the users' a better feeling of depth and distance. Some research is already focusing on image based analysis techniques to determine an artificial depth that could occlude virtual objects. An application could combine multiple techniques such as screen-space and perspective elements to increase the of a users' distance estimation. Another idea could be similar to the ***di_range*** (showing a distance value on the screen) but instead used for depth. This might be a good method in combination with ***de_magiclens***.

13.1.4 Mobile devices with 3D screens

Recently multiple phones have been released that support 3D stereo graphics. These devices have two camera lenses and can therefore acquire two images to create binocular disparity. As explained earlier in 4.3, binocular disparity is created by presenting two different images; one for each eye. The mobile device has only a single screen. To solve this problem, the screen is capable of presenting two different images per frame using autostereoscopy [70].

Using such a mobile device for an augmented reality distance and depth study might lead to many more inspiring techniques to 'trick' the mind in perceiving 3D more accurately.

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15 Appendix

This appendix contains the following items

- 15.1 tables with certainties
- 15.2 Results table for distance
- 15.3 Results for depth experiments
- 15.4 Subject introduction form Distance
- 15.5 Subject introduction form Depth
- 15.6 Pre experiment
- 15.7 POST Experiment
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- 15.9 Expert meeting geotechnical company
- 15.10 Experiment map

15.1 Tables of certainties

Table 17. Distance certainties as specified by the participants

What	di_nocues		di_radial		di_topdown		di_range	
Unsure	25	71.43%	1	2.86%	9	25.71%	0	0%
Somewhat unsure	33	50%	20	30.30%	12	18.18%	1	1.52%
Neutral	31	28.70%	27	25%	23	21.30%	27	25%
Somewhat sure	57	28.93%	61	30.96%	53	26.90%	26	13.20%
Sure	10	4.59%	47	21.56%	59	27.06%	102	46.79%

Table 18. Depth certainties as specified by the participants

What	de_nocues		de_magiclens		de_planes		de_side	
Unsure	59	77.63%	7	9.21%	3	3.95%	7	9.21%
Somewhat unsure	10	27.03%	15	40.54%	9	24.32%	3	8.11%
Neutral	10	20%	14	28%	17	34%	9	18%
Somewhat sure	1	1.15%	36	41.38%	29	33.33%	21	24.14%
Sure	0	0.00%	8	11.43%	22	31.43%	40	57.14%

15.2 Results table for distance

di_nocues							**di_radial**						
	Far_1	Far_2	Mid-dle_1	Mid-dle_2	Near_1	Near_2		Far_1	Far_2	Mid-dle_1	Mid-dle_2	Near_1	Near_2
Mean time(s)	18.68	17.96	16.73	14.68	17.69	12.79	Mean time(s)	19.4	15.14	16.03	11.86	13.12	11.62
SD Time (s)	15.19	20.8	14.12	11.46	19.3	9.06	SD Time (s)	13.35	12.33	16.38	7.47	12.25	9.06
accuracy3d	69.24	80.42	73.09	68.34	65.69	60.01	accuracy3d	89.08	87.5	89.49	88.56	87.28	87.99
accuracy_std-dev	20.15	16.62	19.46	16.35	22.7	24.17	accuracy_stddev	7.28	8.02	6.04	7.65	5.18	8.99
estimate_over	7	16	5	4	1	3	estimate_over	11	10	14	10	11	11
estimate_under	18	7	20	22	23	23	estimate_under	14	16	12	15	15	15
estimate_equal	1	3	1	0	2	0	estimate_equal	1	0	0	1	0	0
di_topdown							**di_range**						
	Far_1	Far_2	Mid-dle_1	Mid-dle_2	Near_1	Near_2		Far_1	Far_2	Mid-dle_1	Mid-dle_2	Near_1	Near_2
Mean time(s)	23.28	14.4	18.43	10.19	15.82	13.15	Mean time(s)	22.61	13.88	13.17	12.72	16.26	16.23
SD Time (s)	34.07	19.43	21.29	12.49	21.93	15.82	SD Time (s)	14.64	8	10.65	7.69	14.24	11.87
accuracy3d	87.66	90.55	94.41	88.13	91.96	94.74	accuracy3d	98.51	98.93	98.03	97.92	97.85	97.29
ac stddev	8.32	3.72	6.66	14.94	9.33	10.16	ac stddev	4.49	2.18	4.26	5.08	4.01	4.52
estimate_over	21	24	21	20	6	8	estimate_over	1	6	6	3	7	3
estimate_under	5	2	3	5	18	10	estimate_under	4	1	1	4	5	7
estimate_equal	0	0	2	1	2	8	estimate_equal	21	19	19	19	14	16

15.3 Results for depth experiments

de_nocues	Near_1	Near_2	Very-Near_1	Very-Near_2
Mean time(s)	10.79	15.74	16.75	16.48
SD Time (s)	6.89	18.2	15.38	19.49
accuracy	51.01	64.7	-115.34	61.96
ac_std	20.59	23.55	130.83	25.75
overestimate	0	2	19	5
underestimate	20	18	1	14
equalestimate	0	0	0	1

de_magiclens	Near_1	Near_2	Very-Near_1	Very-Near_2
Mean time(s)	22.15	22.67	18.71	21.42
SD Time (s)	15.38	11.27	12.69	15.27
accuracy	77.6	72.49	-233.2	90.64
ac_std	19.83	24.78	103.69	14.62
overestimate	13	2	20	6
underestimate	7	16	0	11
equal-estimate	0	2	0	3

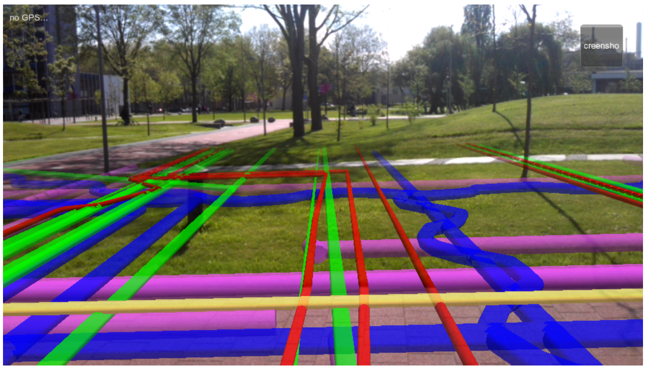
de_planes	Near_1	Near_2	Very-Near_1	Very-Near_2
Mean time(s)	24.92	29.07	24.67	20.36
SD Time (s)	18.83	15.33	19.3	13.66
accuracy	81.45	81.67	35.74	71.87
acstd dev	17.42	15.61	120.22	45.54
overestimate	2	0	16	8
underestimate	17	18	4	10
equalestimate	1	2	0	2

de_side	Near_1	Near_2	Very-Near_1	Very-Near_2
Mean time(s)	11.73	8.54	12.65	8.44
SD Time (s)	9.92	9.25	17.74	12.29
accuracy	96.9	93.26	84.01	98.46
acstd dev	3.76	15.21	27.04	1.61
overestimate	7	7	9	7
underestimate	6	3	11	4
equal-estimate	7	10	0	9

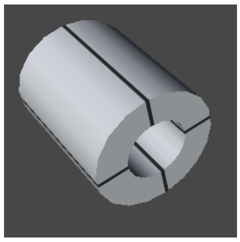
15.4 Subject introduction form Distance

15.4.1 Distance and depth perception in augmented reality

Thanks for participating in this experiment about distance and depth perception in augmented reality! In this experiment you will perform a number of short tasks which will be used to determine which technique provides the most accurate depth and distance.

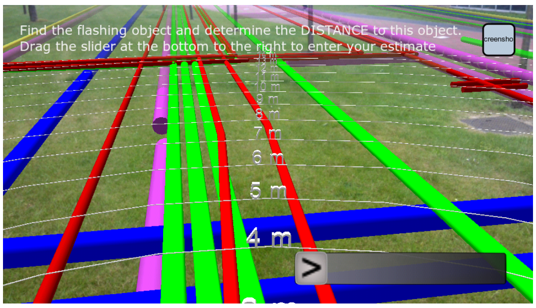


What you will need to do
You will soon be handed a mobile phone. This mobile phone is running an 'app' which visualizes the cables and pipelines that lay underground at the TU Delft campus. These cables and pipelines are projected on top of a live video camera image which comes from the camera on the phone.

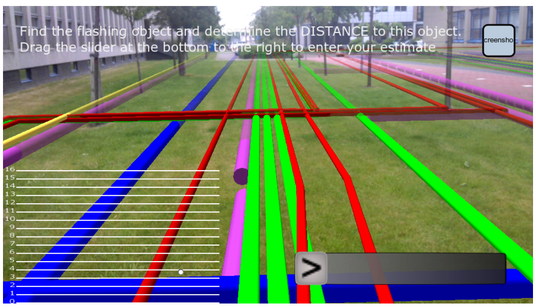


This app will place a cylinder like target object (see image) automatically in the augmented reality world, and you will have to **determine the distance between you and the target cylinder** ('how many meters is it away from you?'). After all these tasks have been performed you will get also a task based on a paper map.

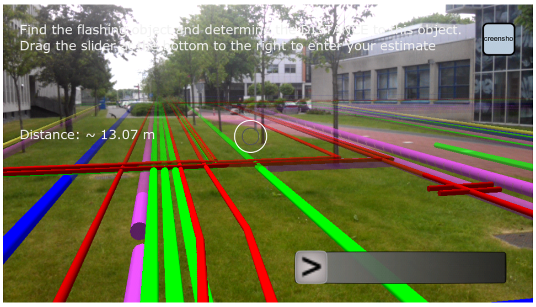
15.4.2 Examples of used techniques



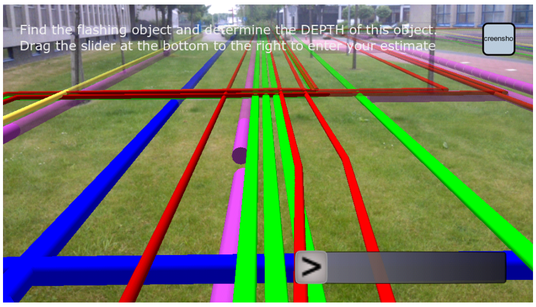
The circles indicate meters of distance starting at your position. Each circle represents one meter



At the bottom left, the distance is indicated by a small white circle. The lines indicate the distance starting from you, and are accompanied by a value indicating the distance.



An approximate distance (the best as is possible) is displayed with the centre 'crosshair' as the focus point.



And there is also a situation where there are no special cues to assist you.

As the location of the target object changes after each completed task, you will first have to find it again. You can search for it by looking through the device while you rotate around your axis, look around your feet or more towards the horizon. When you have found it, and are ready to answer the task (determining the distance to the target object) you can move the slider at the bottom of the screen to the right with a finger, and fill in a short questionnaire on the screen.

After finishing this questionnaire, the next tasks will automatically appear until you have finished the experiment.

After finishing all tasks (24) the app will tell that you are finished! All together, this should take you a maximum of 30 minutes.

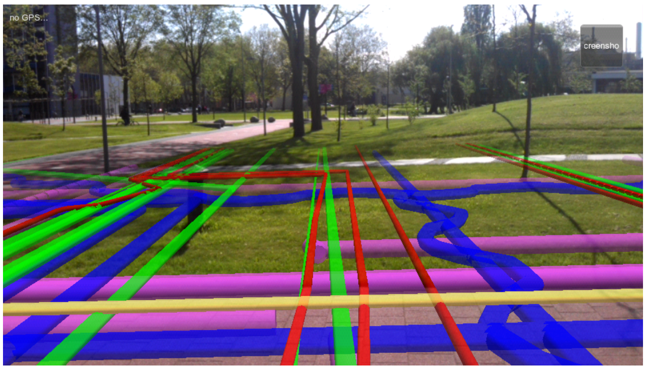
NOTE: One important element in this experiment is that you are **not** allowed to walk! Please only rotate around your axis and stay on the manhole (or in Dutch: 'put') which will be assigned to you.

Once again, thanks for your help! If you have any questions, do not hesitate to ask.

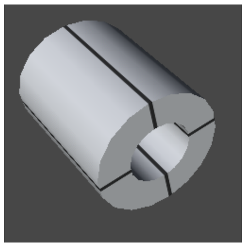
15.5 Subject introduction form Depth

15.5.1 Distance and depth perception in augmented reality

Thanks for participating in this experiment about distance and depth perception in augmented reality! In this experiment you will perform a number of short tasks which will be used to determine which technique provides the most accurate depth and distance.

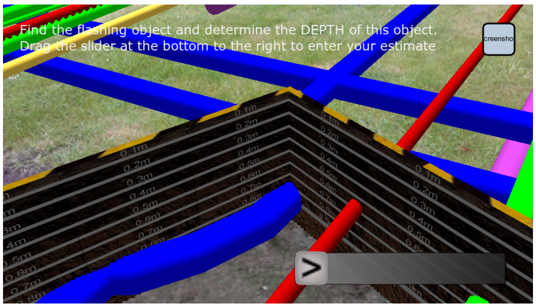


What you will need to do
You will soon be handed a mobile phone. This mobile phone is running an 'app' which visualizes the cables and pipelines that lay underground at the TU Delft campus. These cables and pipelines are projected on top of a live video camera image which comes from the camera on the phone.

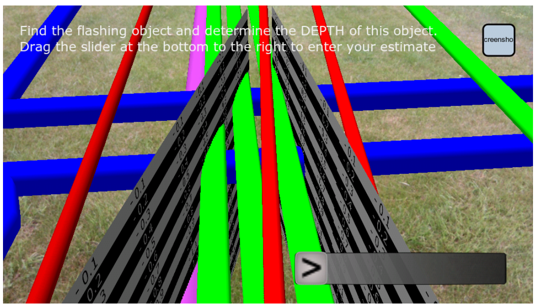


This app will place a cylinder like target cylinder (see image) automatically in the augmented reality world, and it is your task to **determine the depth (vertical) of the target object** ('how deep is it under the ground?').

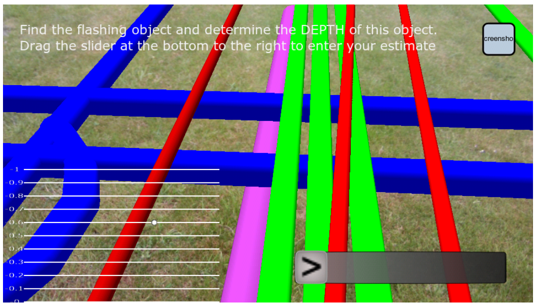
15.5.2 Examples of used techniques



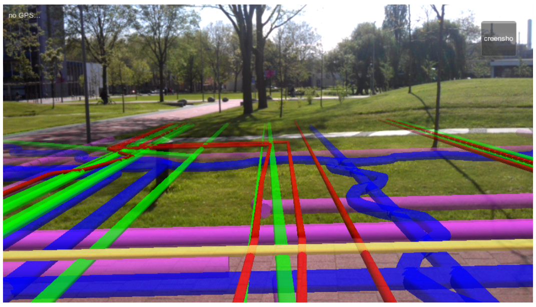
The 'magic lens' will be on a fixed position and the lines at the inside of the square will determine the depth. Each line is 10cm



These lines will move with the camera view, and indicate the depth as indicated per horizontal line. The lines alternate per 10 cm. The actual value indicated on the line is **at the bottom of that line**



The depth is indicated as a 'side view'. Each horizontal line displays a certain depth value, starting at 0.0 at the bottom. Each line is 10cm



And there is also a situation where there are no special cues to assist you.

As the location of the target object changes after each completed task, you will first have to find it again. You can search for it by looking through the device while you rotate around your axis, look around your feet or more towards the horizon. When you have found it, and are ready to answer the task (determining depth to the target object) you can move the slider at the bottom of the screen to the right with a finger, and fill in a short questionnaire on the screen. After finishing this questionnaire, the next tasks will automatically appear until you have finished the experiment.

After finishing all tasks (16) the app will tell that you are finished! All together, this should take you a maximum of 30 minutes.

NOTE: One important element in this experiment is that you are **not** allowed to walk! Please only rotate around your axis and stay on the manhole (or in Dutch: 'put') which will be assigned to you.

Once again, thanks for your help! If you have any questions, do not hesitate to ask.

15.6 Pre experiment

Experiment ID	Latin ID [ ] Distance [ ] Depth
Date	
Name	
Age	
Eye height?	.. cm
Sex	[ ] Male [ ] Female

Do you have normal eye sight, or corrected to normal eyesight?

[ ] Normal [ ] Contact lenses [ ] Glasses Other, ….

Do you own a smartphone or tablet device? [ ] yes [ ] no

Do you know what augmented reality is? [ ] yes [ ] no

Have you used augmented reality before? [ ] yes [ ] no [ ] I don't know

How well do you consider yourself to be able to estimate distances?

[ ] very bad [ ] bad [ ] normal [ ] good [ ] very good

How well do you consider yourself to be able to read maps?

[ ] very bad [ ] bad [ ] normal [ ] good [ ] very good

15.7 POST Experiment

Experiment ID

15.7.1 Distance

You have used three techniques that display distance cues. Please rank these techniques (from 1-3, use each value only once)

[ ] Distance radial grid

[ ] Top down height lines

[ ] Range finder

Do you have comments about the above techniques? If so, please take a short moment to fill in your comments here. Consider ease of use, time taken,

15.7.2 Depth

You have used three techniques that display depth cues. Please rank these techniques (from 1-3, use each value only once)

[ ] Fixed depth box

[ ] Perspective height lines at sides

[ ] Side depth map

Do you have comments about the above techniques? If so, please take a short moment to fill in your comments here. Consider ease of use, time taken,

15.7.3 Paper map

Do you have comments about the paper map? If so, please take a short moment to fill in your comments here:

15.8 Experiment file format

```
Experiment started: 06/08/2012 11:18:15
Experiment id: 47
Latin square: 4
Experiment type: distance
Eye height: -1.55
Light sensor value:10240
Name:.
Age: 40
Sex: F
Eye correction: Normal
Length:
Used AR before: N
Do you own a smartphone: N
Distance estimation: Normal
Map reading: Good
Favorite1:range
Favorite2:topdown
Favorite3:radial
Map_N1: 4,12
Map_N2: 4.8,16
Map_M1: 6.8,24
Map_M2: 8,8
Map_F1: 10,8
Map_F2: 10.6,14

result,di_nocues,Middle_1,8.072611,0,6.796291,6.970802, certainty,4,Sure,36.9978
result,di_nocues,Far_1,5.079178,0,9.863572,9.984616, certainty,4,Sure,36.53284
result,di_nocues,Near_1,1.989181,0,3.628575,3.945765, certainty,4,Sure,14.37563
result,di_nocues,Near_2,1.969875,0,5.234609,5.45927, certainty,4,Sure,6.649506
result,di_nocues,Far_2,14.79334,0,9.856716,9.977843, certainty,3,Somewhat sure,11.37506
result,di_nocues,Middle_2,5.928931,0,7.824377,7.976426, certainty,3,Somewhat sure,8.270935
result,di_Radial,Near_2,5.021224,0,5.234609,5.45927, certainty,4,Sure,10.15036
result,di_Radial,Far_2,9.018909,0,9.856716,9.977843, certainty,4,Sure,11.30701
result,di_Radial,Middle_2,6.952471,0,7.824377,7.976426, certainty,4,Sure,4.725708
result,di_Radial,Middle_1,7.087664,0,6.796291,6.970802, certainty,4,Sure,7.545288
result,di_Radial,Far_1,9.096169,0,9.863572,9.984616, certainty,4,Sure,7.524963
result,di_Radial,Near_1,3.476235,0,3.628575,3.945765, certainty,4,Sure,5.949707
result,di_range,Middle_1,7.087682,0,6.796291,6.970802, certainty,4,Sure,7.700562
result,di_range,Far_1,10.04247,0,9.863572,9.984616, certainty,4,Sure,9.7229
result,di_range,Near_1,3.93975,0,3.628575,3.945765, certainty,4,Sure,5.24054
result,di_range,Near_2,5.542656,0,5.234609,5.45927, certainty,4,Sure,8.272095
result,di_range,Far_2,10.04247,0,9.856716,9.977843, certainty,4,Sure,6.600281
result,di_range,Middle_2,7.956723,0,7.824377,7.976426, certainty,4,Sure,5.775696
result,di_topdown,Near_2,5.504064,0,5.234609,5.45927, certainty,4,Sure,53.17517
result,di_topdown,Far_2,11.08535,0,9.856716,9.977843, certainty,4,Sure,7.025513
result,di_topdown,Middle_2,8.497478,0,7.824377,7.976426, certainty,4,Sure,9.158936
result,di_topdown,Middle_1,7.126293,0,6.796291,6.970802, certainty,4,Sure,7.5755
result,di_topdown,Far_1,10.93085,0,9.863572,9.984616, certainty,4,Sure,11.27533
result,di_topdown,Near_1,4.094249,0,3.628575,3.945765, certainty,4,Sure,15.06689
Experiment finished: 06/08/2012 11:31:37
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15.9 Expert meeting geotechnical company

In a meeting with two geotechnical experts at a large international geotechnical organisation* various aspects of the augmented reality application were assessed. One improvement deemed necessary and to boost the accuracy is to combine the smartphone performing the visualizations with a highly accurate GPS receiver, such as the ones provided by the company Trimble. The smartphone would be placed on the same pole as the antenna and therefore accurately display the visualization based upon the coordinates from the external antenna. An expert also comes with the idea that next to this, an extra display facing downwards could display information of what will be directly underneath the antenna using a 2D map representation (see mockup, Figure 68).

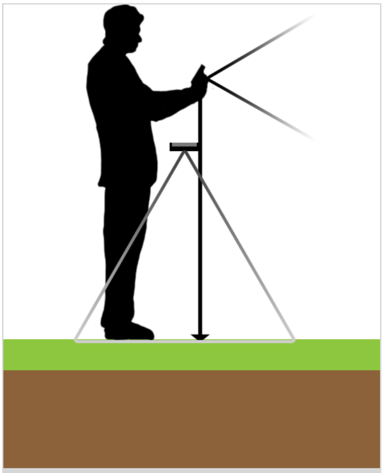

Figure 68. Proposed augmented reality view. One for the bottom, and one for the area view.

Another aspect is that they are only interested in the area where they have to perform a measurement on, with a radius of two meters. They are not interested in the visualization of all the cable and pipeline infrastructure, just if it is save to excavate a small hole in the ground. They mention that the tool might be useful for city planners as they are interested in the location to determine if there are problems to be expected when building a construction, which for example requires a foundation on a certain location.

One of the experts is concerned that technical improvements and displays like these might make the people performing the field work outside think less and therefore also potentially increase the risk of errors as the field workers might take all displayed information for granted.

During normal excavation or CPT's the location will commonly be determined by a GPS which provides accuracy < 1 meter, preferably < 10 cm accuracy. When the inaccuracy is too high some of the used models will refuse to say anything just to make sure that the field workers will resort to other methods of position determination such as using papermaps. This might for example happen while in a city with a lot of buildings surrounding the spot of the task.

After the position has been determined, and there are no cables or pipelines within a circle of five meters, then the operation will proceed. If the distance is between 1.5 to 5 meters, then a hand drill will be used to determine if there are cables or pipelines up to a depth of two meters deep. Of course, when some kind of underground pipeline shows up, then the operation is stopped. If nothing is found, then the operation will resume as normal. With the exception that pipelines that have been placed using horizontal directional drilling' (HDD) are often much deeper. If such a type of pipeline is nearby, this will be taken into account.

When looking for cables and pipelines, a one meter radius is considered as possible inaccuracy in the data.

To prepare for an assignment, the KLIC melding of the Cadastral office is first converted to an Autodesk Autocad file which then is used as overlay on Google Maps. If there are no cables and pipelines in the nearby area (> 5 meter) the only device used will be the GPS device.

* Name known by super visors.

15.10 Experiment map