C2B: AUGMENTED REALITY ON THE CONSTRUCTION SITE

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ABSTRACT: This paper describes the development of a system that brings augmented reality at the construction site. Due to the growing complexity of buildings, the growing number of actors on the construction site, and the increasing time pressure to construct a building it keeps getting harder to gain a clear overview of the work in progress. This leads to high costs due to construction failures and even security risks of the building and on the construction site. To cope with these problems it is necessary to develop a tool that helps construction workers to rapidly gain inside in the (intended) construction and construction site. The C2B (pronounced 'see to be') system combines the real world with the virtual design giving a mixed reality (augmented reality) view at the construction site. The C2B system combines technology from different industries to help the construction industry. This paper describes the development of a prototype of this system.

KEYWORDS: virtual, augmented, reality, world, construction.

1. INTRODUCTION

The C2B (pronounced 'see to be', future artists impression above) prototype system provides augmented reality on the construction site. It was designed and constructed during a project that ran within one of the research programs at TNO called 'Mixed Reality and Collaboration'. In this project TNO tried to establish how construction processes at a construction site could be improved by applying new and innovative technology in the area of mixed reality.

1.1 Need for augmented reality

As we have entered the 21st century buildings tend to become much more complex. Through the introduction of building management systems with electro-mechanical systems buildings seem to be almost changing into complex organisms. Due to specialization of the construction workers more and a diverse set of actors is walking around on the construction site. Add to that the increasing time pressure to construct a building and it becomes clear that it keeps getting more difficult to gain a clear overview of the work in progress for each of the actors involved. This in turn leads to higher costs due to construction failures. Also security risks of the building and on the construction site will increase.

To cope with these problems described above it is necessary to support construction workers by providing them with real-time and accurate information about their ever changing surroundings and the task at hand. We want to do so without overloading them with information, but helping them navigate through the complex environment they have to work in. This is were technology for augmented reality (sometimes also known as mixed reality) kicks in. By adding an extra information layer to the real physical world we can provide the right information *in situ* at the right time. There are many different ways of how to ‘augment’ reality. In this article we assume the use of ‘visual augmentation’. We add extra information into a persons visual view of the world. We see three major categories of applications using this kind of technology:

1. **In situ experience.** When a building is to be constructed it will alter the landscape. To experience this feeling people could walk around in that landscape and look at a virtually constructed building and see how it fits in with the surroundings. What is the impact of a new office building, house or bridge in the landscape? Early in a project an architect would want to show his views and ideas to other people. Also, by using environmental models it could be possible to add more abstract information into the augmented view, like environmental noise contours surrounding the building. The combination of a real-life environment with the virtual environment can be very enlightening.
2. **In situ verification.** In order to carry out inspections of the construction site a 3D construction map could be projected on top of a building situation. An inspector could then visually check if the intended design is in line with how the work was actually carried out. For example the correct placement of reference poles for brick-laying. This does require a great accuracy.
3. **In situ warning.** When unseen dangers are present, workers can be warned of these dangers in a more interruptive and attention demanding way than a sign on the wall (with probably outdated information).

In this project we wanted to find out to what extent we could engineer a system that would support those applications using on the market components (with some integration technology of our own). To that, we wanted to get an idea about the level of ‘applicability’: is it ready for the construction site, or is it an idea for the (near-by) future?

1.2 Existing approaches

In order to provide people with a view on an augmented reality, several ways already exist. One of the oldest ways is to draw a picture of reality as you perceive it and add the extra information. This method is time-consuming and requires a lot of human labor and a lot of craft when the viewers want a realistic view. This method is rather static too. Not surprisingly photo montage has entered the stage where artists blend in a building in front of other building. In the digital age a tool like Photoshop in combination with a CAD system is often used. With enough patience and skill a good impression can be delivered. However, this is not that immersive. You look at a picture which does not surround you. In order to get an immersive experience there is the Cave Automatic Virtual Environment (CAVE). It has been there for more than a decade by now. It is an immersive virtual reality environment where projectors are directed to three, four, five or six of the walls of a room-sized cube. The use of a CAVE requires that you – just as with the photo montage – first capture reality and bring it into to the cave. This is still a rather static experience. However, you can move around in a CAVE, by telling the system (using some kind of device) that you want to move around. The CAVE computes what you should see again and projects it on the screen. Although more real, you are not actually at the construction site. You do not hear it, feel it and smell it. And since you cannot bring a CAVE to the construction site, the possibilities end here.

Due to the arrival of portable wearable computational and display technology however there is another way of providing an immersive experience in situ. An important part of this technology is known as the hands-free Helmet (or sometimes Head) Mounted Display (HMD). It can project a 3D scenery on the retina of the viewer, combining this with a real-time view of the surroundings. It is a one-person device only and requires a computational device for computation. Together with today's portable computer power including powerful 3D graphic cards an in situ immersive image can be created. By combining this with technology to determine location and orientation of the viewer, the basic ingredients of augmented reality are there. Many different layers of information can be added, resulting in a better and integral oversight of the construction plan (different aspects ant the same time). This was already the case six years ago (see Piekarski 2003 and Dias 2003).

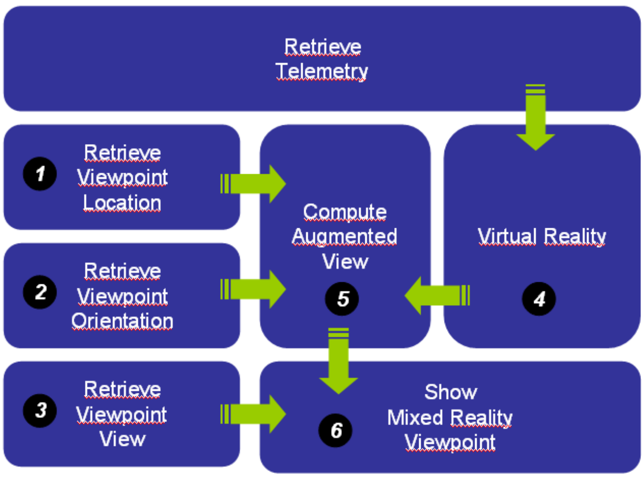
2. SOLUTION APPROACH

On current day construction sites a augmented reality outfit like the one described above is not common yet. This may because of the fact that the technology is less wearable in practice. Also, virtual environements and augmented reality tend to cause simulator sickness, related to motion sickness (see for example Groet et Bos 2008). It could also because of the fact that four years ago computers were not powerful enough with respect to battery power. In this article however we will not provide the reader with an in-depth analysis on why this is the case. We will provide a description on the approaches we took at end of 2008 and in the beginning of 2009 using more recent and higher precision technology. This enabled us to learn about the barriers that keep augmented reality from helping workers at the construction site and also how we could remove those barriers. By trying to prototype two versions of an actual working system, we tried to identify all important issues. The contrast between these two versions helped us to get an even deeper understanding.

2.1 3D-virtual reality on top of a real-life landscape

Just as in earlier approaches we decided to use 3D virtual reality and combine this with a view of the real-life landscape, captured by a camera image. We decided not to use an HMD to start with in order to project this augmented reality, because of several reasons. A tablet sized PC (dubbed *the C2B device*) can be used without having to put on an wearable computing outfit, also it can easily be handed over – especially if in case of a tablet PC - to other people in case of a group experience. Interaction with such is relatively easy through its tactical interface. Furthermore tablet PCs are there in many different sizes of scale (e.g. notebook, laptop, Smartphone, PDA, etc.). And last but not least: the position method in one of the two approaches required us to add some extra components that would not fit to the HMD that well. The one drawback is the fact that the hands are occupied. This means that the C2B device is less useful for construction workers and more useful for inspection workers or architects wanting to share an experience. In the future, when the very accurate method of determining location and orientation has even more portable components, we could add them to a HMD also.

2.2 Generic conceptual model



Our generic conceptual process model we use to create an augmented (or mixed) reality is a continuously looping workflow containing 6 steps. First we retrieve the location of the viewpoint in reality and the orientation of the viewer (a camera) at the viewpoint. Then we retrieve an image from the viewer. Using the location and orientation information of the viewer we compute what the (augmented) view would look like from that position at that orientation in virtual reality. This view is finally visually merged and presented to the viewer. Then, we start at the first step again. In figure 1 there is another step called 'retrieve telemetry'. This shows were real live measurement data (e.g. from sensors) could be entered in the virtual reality to create more accurate data.

Due to the enormous development (progression in precision) in localization systems, it is important to be able to integrate the newest developments available on the market, therefore steps 1,2 are implemented as separated components that are separated ('loosely coupled') from the other components. This gives the flexibility to make an interface for virtually every localization device, for instance iGPS delivers position and orientation, but differential GPS for example only position and special sensors are needed for orientation. This interface connects to the main program with a fixed protocol. Note that the localization and orientation must need to deliver point and vector data. Information about the location in an area, like the information from an RFID based system like the one used in by Sanghyung Ahn et al. (Sanghyung Ahn 2008), is not enough for the visual augmented reality as we see them. Multiple tracking technologies (optical, inertial, GPS) could be used to improve accuracy. The location and orientation components would then use these multiple technologies and provide a more accurate estimate to the other components.

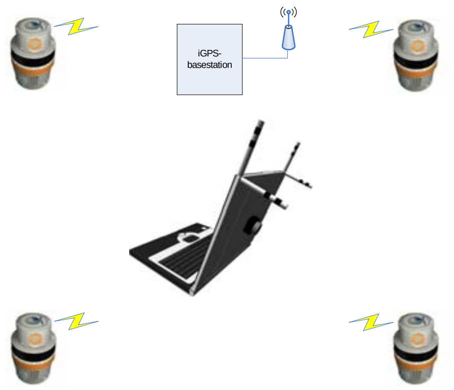
This generic conceptual process model was implemented in two ways, to explore different aspects of augmented reality. Both implementations of the C2B system consisted of a laptop computer, a camera, sensors for determining location and orientation, and software to integrate the hardware and combine the information as described in the process model above.

2.3 The semi-fixed high-precision approach

First we took an approach where a high degree of accuracy was quintessential: preferably < 1mm. This kind of accuracy is required for **in situ verification** augmented reality applications. The viewpoint view in this case was a Prosilica-camera placed at the back of a laptop. The image of this camera (1024x768) was not recorded, but streamed to the laptop display (live). This made the laptop look like a 'see through' laptop (as if there was no screen, but the user was looking right trough a window).

2.3.1 Retrieving viewpoint location and orientation

The high-precision localization and orientation was realized using a system called iGPS. This system consists of a set of laser transmitters and at least one double receiver. Both receivers and transmitters are wirelessly connected to a base station, which calculates the position of the camera which is at the back of the laptop. Due to the fact that the system is based on laser there had to be a Line of Sight (LoS) between receiver and transmitter. And since we wanted our users to be able to walk around with the C2B, the body of the user could block the Line of Sight (LoS). Therefore we added some redundancy to our prototype. It was equipped with 4 transmitters and 4 double receivers (attached to the laptop). In theory one double receiver and 1,5 transmitters are enough to calculate the relative position in the covered area with a precision of less then 1 mm and an angular precision less than 0.1 degree.



The double receiver is about 10 cm height and the two black bands are the actual laser receivers (360ºhorizontal and 120º vertical receiving angle). We wanted total freedom of movement for the user and the vertical angle was limiting the operational space. Therefore two double receivers were perpendicular mounted on the laptop enabling all rotational angles. Due to the earlier mentioned Line of Sight problems, this construction was doubled on both sides (left and right) of the laptop. Because of this elaborate construction the user can walk around, rotate and tilt the laptop. The wireless setup gave great flexibility in the setting up the environment and freedom of movement for the user. Finally the base station calculated the position of the camera (viewpoint location) and the angles at which the laptop was tilted and turned (viewpoint orientation), based on the data retrieved from the sensors.

According to the system vendor Metris this system could cover an area of 300 x 300 meters (indoor & outdoor), which is relatively large compared to most other tracking systems. Also multiple users are allowed. This means that several people could work in the same area with a C2B, all with <1 mm accuracy. At the moment the authors of this article do not know of any other usable system that has a higher accuracy in a large volume (> 10m x 10m). Note that if (exterior) walls are built and sensors the transmitters need to be placed inside these walls and (auto-) recalibrate the system in order to recreate enough Line of Sights.

2.3.2 Computing and mixing the augmented view

In order to superimpose a view of a virtual reality on top of a real camera feed, we first needed to construct that 3D virtual reality. This was done use OpenSceneGraph (open source library). All of the components are more or less standards and the big challenge was integrating these into one program. A big advantage of the OSG-library is the capability of importing files from many different CAD-programs and if there is no direct import possible, there are many (free and open) convertors available on the internet. The image overlay we used was a CAD-drawing. Using the OSG-library implies the usage of real-life coordinate systems and since the iGPS system also uses a real-life coordinate system, hardly any conversions had to be made. Moving 1 meter in real-life is also 1 meter movement in OSG and vice versa. The above shows that the realization of the software was relative easy because of the use of standard components. The update rate of the whole system was at least 30 Hz, giving the user enough interaction to move freely around.

This virtual world was then finally superimposed on the 'grabbed' video image from the camera using the GigE Vision SDK (a de facto standard in Machine Vision) for video grabbing and presentation. Microsoft Foundation Classes were used as a basis to combine all components into an application.

2.4 The mobile low-precision approach

For the second approach we assumed there is far less need for precision and more need for mobility and the ability to get an *impression* of 'how a 3D structure would look like in reality'. This system would be more suited for the **in situ experience** and **warning** type of applications. The viewpoint in this case was a Hercules Classic Silver webcam. This is regular camera that can operate with a resolutions ranging from 320x240 to a maximum of 800x600 (with interpolation). With an USB cable it was connected to a laptop. It had a refresh rate of at least 1 image per second, depending on the speed of the laptop we were using (Dell Latitude D800 or a Dell Tablet XT).

2.4.1 Retrieving viewpoint location

For this approach we wanted to impose as less restrictions on the *out-door* environment as possible. So the use of special two-dimensional barcodes like those used in the Augmented Reality Toolkit (ARToolkit) was forbidden in this experiment. Using features of well known environments as used in the MOBVIS project did require an existing environment, so that was neither suitable. Since we also assumed that we would do out-door use only with a clean Line of Sight to enough satellites, so we could use a Global Navigation Satellite System.

We decided we did want to have sub meter accuracy. This ruled out 'standard' GPS, which can be inaccurate for as much as 10 meters. Also, we needed the ability to interface with a laptop and keep the entire setup as mobile as possible. This made us select a Trimble® SPS351 DGPS/Beacon Receiver. It makes use of a technology called differential GPS (dGPS) and uses extra beacons (on earth) to correct for any possible errors. In our case a mobile phone could be used for a mobile Internet connection that provided the error correcting signals. Which is in fact a box with electronical hardware for computational purposes, with a form factor with dimensions 24 cm length, × 12 cm width × 5 cm depth. The receiver is accompanied by an antenna (the GA530), which is mounted on a pole (about 2 meters high) and is connected to the receiver by cables. The entire setup updated its position at least once per second. It weighed about 2 to 3 kilograms. Using a Bluetooth connection and an Application Programmers Interface we were able to transmit the position information to our application on the laptop.

Note that this system does not deliver the same accuracy in all directions. In the horizontal range it is less than 1 meter. In the vertical range it is less than 5 meters (according to the supplier Trimble). This is a significant shift for actual buildings. Therefore some kind of calibration has to be carried out with a basic reference object in reality that overlaps with an object in virtual reality.

In this setup the position of the receiver (i.e. the antenna) is (just like in the high-precision experiment) not the exact same position of the viewer (the camera). Depending on where the camera is mounted on the total setup, corrections for the actual location need to be carried out. If the camera is mounted on top of or below the antenna, only a small correction for height is necessary. The moment however the camera is mounted sideways to the pole, the rotation of the pole (in the horizontal plane keeping the pole vertically all the time) comes into the equation. If the pole is not in an upright position calculating the actual position of the viewer also requires the angle that the pole is making with respect to the ground. This would mean including information on the orientation of the pole.

Note that the GPS signal can be sometimes be blocked at a building site. The use of Dead Reckoning Modules (DRM) based on inertia-based technology would help provide location information during (temporary) loss of the GPS signal.

2.4.2 Retrieving viewpoint orientation

In order to feed our computer application with real-time orientation information, we decided to use the 'OS5000-US solid state tilt compensated three axis digital compass'. This is a square (1") piece of electronics with a 0.3" depth and provides information on the angle of rotation across three axes. There is the compass axis (based on the earth magnetic field), which provides a fixed reference frame in the horizontal plane. Then there are two axis of tilt (under a 90 degree angle). This provided us with an orientation vector anywhere on the globe. Note that irregularities in the earth magnetic field influence this device, as well as other magnetic sources. The device has about a 1 degree accuracy (in a 360 degree system) – given a maximum 30° tilt, which seemed tolerable for buildings that were in relatively close range.

Distance	Deviation
1	0,02
10	0,17
100	1,75
1000	17,46
10000	174,55
100000	1745,51

TABLE 1.: Deviation of focal point in a certain direction, given a one degree inaccuracy

At a distance of 1 meter an inaccuracy of 1 degree in a certain direction means a deviation of the focal point of the viewer of 2 centimeters in that direction. At 100 meters a deviation of 1,75 meters can occur. This means that a building in virtual reality - which is at 100 meters from the viewer - might seem to float in the air when projected on top of a live camera feed, assuming that the position of the viewer is measured exactly. When comparing this to the inaccuracy of the location determination (1 meter in horizontal plane, 5 meters in vertical plane), it immediately follows that the inaccuracy of the orientation is of the same scale somewhere at a distance of several hundred meters.

This device was connected to the laptop using a virtual COM (serial across USB) connection. It updated the orientation information at least once every second. By firmly attaching this square device on top of the camera and have the tilt-axes correctly align with the lens of the camera, we were able to determine the orientation of the camera. Note that in order retrieve tilt information about the pole, the camera with the OS5000 device had to be firmly attached in an upright position to the pole also.

Note that deviations in the surrounding magnetic field (e.g. influence of large steel bars) could result in further errors since the digital compass is based on magnetic sensors. We did not examine this, but suspect this effect is noticeable in the presence of structures that impact the earth magnetic field. We also suspect that a (digital) gyroscopic compass / tilt sensor would probably deliver better results. When such a device would become available to use in the same form-factor as the OS5000, we would be interested in comparing them. .

2.4.3 Computing and mixing the augmented view

Construction construct of the virtual reality was done using the building blocks of Microsoft Windows Presentation Foundation (WPF) on the Microsoft .NET platform version 3.5. It provides developers with a unified programming model for building so called 'rich Windows smart client user experiences that incorporate UI, media, and documents'. A discussion of this programming framework is beyond the scope of this article. We only deal with 3D

Graphics, a part of the Graphics and Multimedia section of WPF. The framework offers a component (also known as an element) called the '*Viewport3D*'. It functions as a window - a viewport - into a three-dimensional scene. A 3-D scene can be projected onto the 2D surface of this element. The way it is projected is determined by the camera settings of the Viewport3D.

Within a Viewport3D element a programmer can define a camera object. We used the 'Perspective Camera' with vanishing points as in reality. In order to have a proper alignment between the view in the real camera feed and the virtual world camera, it was important to have the same Field of View (FoV). This can be defined as the ratio between the amount of horizon that can be seen at a certain distance. In terms of a person standing in front of a window: if the persons stands close to the window he can see a lot of the outside scenery. If he stands at a greater distance, he can see far less of the scenery outside. Depending on what camera (and of course the lens) one uses, the FoV changes. Using a calibration board we measured out the distances and determined the FoV of our camera. By setting set the FieldOfView attribute of the camera object in our application, the FoVs of the real (Hercules) and virtual (WPF 3D Perspective) camera were aligned.

We then tried to align the origin of the virtual world with a coordinate in the real world. Since we opted for a mobile approach we had to take into account the effects of being in 'open wide space'. From a theoretical point of view this immediately caused problems, because of the essential differences of the coordinate systems. The GPS system uses polar coordinates, assuming a sphere system. The WPF 3D coordinate system assumes a cubical grid. One can devise mappings, but they always will result in some kind of distortion of reality. Cartographers have know this for years – at least in the 2D case - and have come up with many attempts to remove distortion for certain purposes. Discussion of this is beyond the scope of this article. Although we do not often perceive curvature of the earth, it is not something you can neglect that easy. For example if you have a perfectly straight bar of 100 meters and the ground is completely 'flat', i.e. it follows the perfect shape of a sphere, the bar will not fit to the ground. Instead, if you balance it in the middle, both ends will stick out 5 cm above the ground. Because of the inaccuracy of the location determination and the orientation, we decided this inaccuracy was tolerable for this approach. However, with objects far away at the distant horizon, the inaccuracy will be noticeably much more severe.

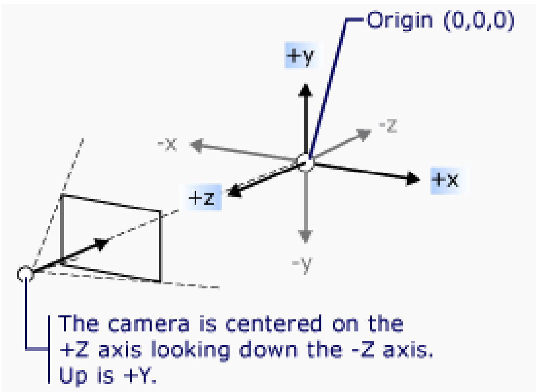


FIG. 1: Camera and coordinate system in WPF 3D graphics (from the Microsoft MSDN website)

In practice we **aligned** the **location** of the virtual and real world by choosing an anchor point in reality. That point was defined as 'point Zero' (0,0,0) in the WPF3D coordinate system. We then built a scene in the WPF3D space by using the 3D drawing primitives (lines, rectangles, etc.). Coordinates in reality were 'corrected' by using a delta between the real world coordinates and the anchor point. Note that the height of the camera was also corrected by a default distance since it was fixed on a pole. **Aligning orientation** was done in a similar way: we assumed that the real (magnetic) south to north direction always was parallel to the z-axis running from the positive to the negative end. Based on that, a simple scenery of objects was drawn, were it was assumed that the cubical geometry of the virtual world also applied in reality. Which of course was not true, but acceptable with in the hundred meter range. For mapping of measurement units in the physical reality to measurement units in virtual reality we took a short cut and did some manual calibration by drawing several square squares in virtual reality and align this with square objects in reality.

Finally, using the Extensible Application Markup Language (XAML) within WPF we were able to tell (‘declare’) the WPF framework to automatically map Viewport3D element onto another element that showed the camera feed from the Hercules camera. Only the objects from the scenery were visible, there was no background of the virtual reality with in the Viewport3D, only transparent pixels, which allowed the background reality camera feed to be seen. The combination of the two resulted in augmented reality.

3. USAGE EXPERIENCE

During the construction of the two prototypes we carried out several tests and could experience the usage of the developing C2B prototypes first hand.

3.1 The semi-fixed high-precision approach

We had the following positive user experiences with respect to the iGPS based system

- The user can work with a highly accurate augmented reality in a relative large volume. One of the applications could be checking the placement of the poles used for brick-laying or in an even advanced way placement of these poles. Another useful application could be laying tiles in complex (colored) patterns; with the prototype the original drawings show the correct tile in real life.
- In our opinion setting up and calibrating the iGPS system was simple and fast compared to many other large volume tracking devices. It is possible to carry the setup to a construction site, set it up, perform some calibration and start using the system.
- The usage of the entire system was intuitive and self explanatory. People tend to ‘get the hang of it’ rather soon, once they perceive the C2B as a window on an augmented reality.

There were also less positive experiences in usage:

- One of the first problems we experienced was Lag-Time: the system did not respond fast enough to motion. This was introduced by the iGPS system, which had an update rate of 60 Hz, but did not deliver new location information every 1/60th of a second. It collected a few samples and sent them in a burst mode. Using new firmware we this problem was solved.
- The need for a Line of Sight restricted the movement of users in the beginning. After repositioning the receivers, this was nearly eliminated.
- The system is a bit more bulky, compared to the original artists impressions. The iGPS system is the main reason, the receivers are not very small and they also need boxes with batteries and wireless transmitters.
- The position of the users head has to be aligned with the axis of the camera, otherwise the real-life world behind the laptop and the image presented by the camera does not really match and the ‘window on the world’ effect disappears. A HMD does not suffer from this problem.
- Due to the fact that a Line of Sight is needed, it is less suitable when walls are erected between the beacons and the receivers (i.e. so much walls that all redundancy is lost).

3.2 The mobile low-precision approach

We had the following positive user experiences with respect to the Differential GPS and tilt-sensor based system

- While staying in a fixed position with the setup a user can get some kind of impression of an virtual object in its real surroundings.
- Users do not have to set up beacons in advance, since the GNSS satellites have already been put into place by other people.
- A user cannot block the line-of-sight between the Differential GPS receiver and himself.

There were also less positive experiences in usage:

- A collection of huge buildings or other large objects will probably block the GPS signal.

- The tilt-sensor can be disturbed by strong magnetic fields.
- The entire setup is mobile, but not light. The pole with receiver, antenna and a laptop can be carried by one person (as long as everything is taped together securely), but it requires some strength. It also turned out that the pole is very useful a support for the laptop.
- When moving around the augmented view becomes pretty unstable because of all the components moving and vibrating. Only when the entire setup is put to the ground again and allowed to 'rest' for a while, a steady image appears again. This seems partially because the tilt-sensor is very sensitive. Small movements create different readings which alter the view. On a relatively slow laptop this is clearly visible.
- A 3D virtual object that is behind a real object on the camera will still be projected in front of the camera image. This pretty much ruins the illusion. The way to solve this is by creating a representation of the real object in virtual reality and have this object rendered with the texture of the underlying camera image. We did not carry this out due to time limitations within the project.

4. TOWARDS SELECTION CRITERIA

We state that it would be useful to have selection criteria that predict what approach would be best, depending on one of the three major categories of application. Based on our experience we think it is too early to come up with precise selection criteria. We do state several remarks that should bring us towards the selection criteria during further research. With respect to in situ verification we strongly suspect that the choice for an approach heavily depends on the level of accuracy a specific building inspector needs. The 10cm error in GPS-position combined with the 1 degree error in tilt in the mobile low-precision approach can cause deviations of more than 20 centimeters at a distance of 10 meters. Depending on whether or not this is precise enough, how mobile the inspector wants to be and how much financial resources are dedicated to inspections, one of the two approaches is the better one. Note that we did not carry out studies with a HMD. This might cause simulator sickness (see Dodson et al. 2002) and probably is a criterion of its own.

In situ experience seems to be less demanding than in situ verification, but we think more research should be done on user experience before selection criteria can be defined. In general we currently cannot provide (precise) numbers with respect to percentages in deviation between aspects of augmented reality and physical reality. When we showed the C2B approaches people tended to react differently. While several people reported it as helpful (e.g. 'it supports the imagination'), other people focused on the difference in augmented and physical reality (e.g. 'it is not real enough'). Because we did not carry out a scientific study on the experience on a representative population, we can not further elaborate on this.

Finally for in situ warning, we suspect that mobility can be more important than precision when it comes to warning people in the building area. Also, the chance of inducing motion sickness is important in this approach, since people would walk around continuously. Both approaches in this article lean on visual feedback. We think that audio or tactile feedback might be of better use. Think of a sound or a vibration in the presence of fall-through openings for example.

5. CONCLUDING REMARKS

Our goal was to learn about the barriers that kept augmented reality from helping workers at the construction site and how we could remove those barriers. By trying to prototype two versions of the C2B system, we have been able to identify the important issues. Apart from the obvious need for real accuracy in situ verification and also in situ impression applications, the main challenges of creating C2B seem to be in:

1. Integrating and calibrating all the different components. Especially in the case of the mobile approach the user has to walk around with all kinds of components connected by cables. We suspect this acts as a barrier too. The arrival of consumer smartphones with a GPS and a compass build-in seems very interesting in that respect. Although the accuracy is not at the dGPS level, the usage experience in some areas of application seems to be good enough. See for example the Layar application (www.layar.eu).
2. Aligning the Virtual World with the Real World. We suggest creating (software) components that take into account that the world is not flat. For example: towers at larger distances should be less visible due to a

curvature in the earth. From a certain distance the viewer should not be able to see the base of a very high tower. In further research we would like to investigate the amount of computing power (and energy) needed for the correction of complicated scenes.

3. Ease of deployment when high precision is demanded. The semi-fixed system still needs setup-time. Once the walls go up users need to (auto-)recalibrate the site. A solution might be to use a signaling medium that is less obstructed by physical objects, like radio. To our current knowledge however higher-precision (<10 cm range) radio location information systems (e.g. those from Ubisense) still require calibration and initial setup time. Also, we have no experience how (thick) walls influence the accuracy of these systems. We would welcome experimental data in those areas.

In order to solve the issue of more accuracy in orientation (in the mobile approach), we need a component that is far less depending on the earth-magnetic field. This component should fit on a wearable camera and should be low on the usage of power. We are looking forward to collaboration with organizations which are trying to develop (hardware) modules like these.

Once we have met these challenges in the future, the C2B system can be made even more powerful by including 4D renderings (i.e. a 3D model and a schedule). Also we could integrate real-time sensor information to increase the so called situational awareness of construction workers with recent information.

6. REFERENCES

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