Handheld Augmented Reality for Underground Infrastructure Visualization

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Abstract In this paper we present an Augmented Reality (AR) system for aiding field workers of utility companies in outdoor tasks such as maintenance, planning or surveying of underground infrastructure. Our work addresses these issues using spatial interaction and visualization techniques for mobile AR applications as well as a new mobile device design. We also present results from evaluations of the prototype application for underground infrastructure spanning various user groups. Our application has been driven by feedback from industrial collaborators in the utility sector, and includes a translation tool for automatically importing data from utility company databases of underground assets.

Keywords *Handheld augmented reality, mobile spatial interaction, geospatial modeling, online 3D reconstruction*

1 Introduction

Utility companies, such as those managing electricity or telecommunications infrastructure, rely on geographic information systems (GIS) to manage their underground infrastructure. The established way to use GIS in the field is through paper plans, which are plotted as needed and manually annotated on a construction or maintenance site if changes are made.

For improved efficiency, paper plans are increasingly replaced by notebook computers taken to the field to directly consult the GIS. A GIS database normally employs two-dimensional models to represent the geographic data.

There is a certain trend towards 3D-GIS. However, in the utility sector, the need to work with paper plans and the fact that underground assets are normally hidden has limited the interest in 3D-GIS. Nevertheless, the real environment visited by field workers is still three-dimensional. The field workers have a strong demand in locating their assets, for example, structures scheduled for maintenance, or safety for digging at excavation sites.

Accurate judgment of a situation from a map and a GPS location requires applying a mental transformation from map to reality. This assumes that the user is familiar with the significance of map scale, generalization and symbol language. In many cases this cannot be taken for granted. Even users experienced in map-reading may struggle if for example reference surface features are occluded such as by winter snow.

1.1 Applying Augmented Reality in field work

Augmented Reality (AR) provides a suitable alternative to 2D plans. AR superimposes 3D graphics registered with the real world over a field worker's view, thereby providing "X-ray vision" in order to see where underground infrastructure lies. Among the procedures that can benefit from employing AR are contractor instruction, outage management and network planning.

Simple localization is important for the on-site instruction of contracting staff. For this aim, a registered AR view can provide faster and accurate localization of subsurface assets, thereby reducing risks of accidentally damaging underground infrastructure during excavations.

An important task in outage management is the detection of gas leaks and cable damages. Workers must trace a trench with special sensors such as a "gas sniffer". Navigation along the trench with a mobile GIS is rather cumbersome. AR can provide a superior graphical overlay view outlining the trench to follow and highlighting relevant underground assets.

Planning of utility networks is usually done in a planning office using desktop GIS. A plan for a new trench has to be verified on location before being submitted to the responsible authorities. This task is traditionally accomplished by taking paper maps to the field and annotating them. AR provides planners can be provided with a graphical overlay of the planned trench, and can directly modify the plan to incorporate required changes using mobile spatial interaction tools, without the need of any post-processing.

1.2 Contribution

AR can significantly contribute to Mobile Spatial Interaction by allowing a freely roaming mobile user to interact with spatial objects that are virtually superimposed over the real environment. In this way, users can access spatial information wirelessly. While the idea of AR for utility companies sounds simple and appealing, there are a number of problems to be solved in order to put the approach into practice.

(1) **Underground visualization** A suitable visualization and user interface for the objectives of the field worker must be developed. First, geospatial data must be extracted from the GIS and translated into a form suitable for 3D visualization. During the operation of the AR device, the 3D data must be appropriately filtered to avoid display clutter and incomprehensive results [1]. Visualization of hidden structures such as underground infrastructure additionally suffers from a lack of depth cues. Advanced visualization techniques that aim to make the best use of the available information are reported in section 3.

(2) **Hardware platform** A suitable hardware platform to present the 3D graphics must be provided. The platform must encompass a wearable computer, a display, sensor for real-time global pose tracking to register the graphics overlays, and a see-through facility to combine graphics and real-world. Previous work has used see-through head-mounted displays (HMD), placing the computer and peripherals in a backpack. While this approach allows hands-free operation of the AR system, the backpacks are not ergonomically acceptable and too heavy for prolonged use. In recent years, the widely accepted point-and-shoot approach of handheld video-cameras has prompted researchers to try handheld computers with a video-see-through interface as alternative platforms for AR. This approach was adopted for our work, and is described in section 4.

Our developed system, called *Vidente*[1], was tested with an industrial collaborator from the utility GIS industry, field workers as well as the expert public at various public exhibitions. We report on our experiences in section 5. Finally, section 6 draws some conclusions and outlines future work.

2 Related work

The visualization techniques employed in this paper draw inspiration from earlier work in information filtering, magic lenses and X-Ray rendering. A system for managing information overload in AR display through filtering is described in [1]. Their approach automatically incorporates the user's position as the point of focus, while our approach allows to explicitly define an "excavation spot" as the focus of interest. This approach is more related to 3D magic lens techniques [6]. We leverage a more recent magic lens implementation described in detail in [7]. There is also prior work on simulating X-Ray vision, dealing with techniques to properly provide depth perception [8]. Interactive display of X-Ray vision was considered in [9]. The only work that we are aware of that specifically deals with an AR system for underground asset is [10].

As noted before, early work on mobile AR, such as the Touring Machine [2] used backpacks with laptop computers and head-mounted displays. However these systems are rather heavy and limited for mobile applications deployed over longer working periods. An alternative approach based on a handheld computer was refined into a see-through AR device by Rekimoto [3]. This has started a strong trend towards more mobile, lightweight and socially acceptable devices for AR. For example, Wagner [4] has presented a self-contained AR platform for indoor AR applications running on a smart phone. Reitmayr [5] has shown that even natural feature tracking in real time is possible on small Tablet PCs.

3 Underground visualization

The geospatial data from the GIS cannot be directly visualized using AR, since it consists of a collection of geo-referenced "features" with abstract attributes. The transcoding of such features into 3D scenes composed of polygons and other visual elements is a multi-stage pipeline [12]. Figure 1 gives an example of how such a 3D scene overlaid on the real-world construction site looks like.

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[1] http://www.vidente.at

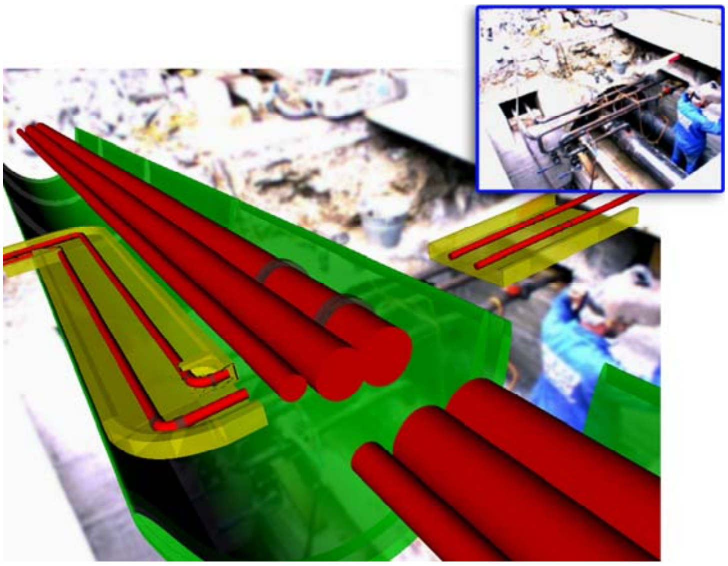

Figure 1: The geospatial 3D model of the underground infrastructure is superimposed on a construction site.

The following sections describe how such geographic data models can be created and what interaction tools can be applied for the visualization.

3.1 Geographic data models

The availability of geospatial models from real-world data is a key enabling factor for the success of applications for handheld devices. As mentioned by Höllerer and Feiner, there are a number of issues that have to be addressed in order to build such geospatial models [1]. Besides structural complexity, the scale of the models is also significant. For example, consider the task of completely modeling a large urban area, down to the level of water mains and electric circuits in walls of buildings.

A key aspect in the creation of geographic models is the acquisition of geospatial data from various sources. Most existing geospatial databases are already in productive use in other contexts such as cadastral survey or utility asset management. AR can largely benefit from the high degree of accurate and up-to-date data essential for those fields of application. Other possible data sources include servers for virtual globe browsers such as Microsoft Virtual Earth or Google Earth[2]. Using a web feature service[3] (WFS) – standard interface specified by the Open Geospatial Consortium (OGC)[4] for delivering GIS features over a network – the information from the production GIS (GE Smallworld^{TM}) is exported to the client as a document in the Geography Markup Language (GML), an XML dialect.

Additionally to existing data sources, we also envision that in the near future, mobile AR users will participate in the creation process of databases underlying a mobile AR application by providing online updates. This approach has been successfully demonstrated by Reitinger [13] with a prototype of the mobile AR Scouting application. This application provides an expert mobile user interface which enables the collection of heterogeneous data (such as images, videos or sounds) within an unknown environment. Since the scout is connected to a

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[2] http://www.virtualearth.com or http://earth.google.com

[3] http://www.opengeospatial.org/standards/wfs

[4] http://www.opengeospatial.org

network using a 3G card and equipped with a GPS receiver, the captured data is annotated with position information and can be transmitted on-the-fly to a processing server. A key technology of the scout is to generate a sequence of 2D images transmitted online to a reconstruction engine typically somewhere in a back office where a 3D model of the captured scene (coarsely geo-located by GPS information) is calculated automatically. The vision-based reconstruction is able to deliver results at an interactive rate. The reconstruction engine immediately calculates the 3D model represented as a point cloud that could be delivered as a GML document.

Afterwards, the GML document is parsed at the client side and translated into a scene graph for a commercial 3D rendering engine (Coin3D). In this step, a mechanism similar to style sheets can be applied to turn the abstract feature attributes data into visualization styles. For example, a curved pipe can be represented as a tubular extrusion shape or as a multi-segment line, depending on preferences [21].

Filtering of information can occur both by the selection of data from the GIS, during the transcoding, or finally during the rendering by omitting or modifying nodes in the scene graph. This approach depicted in Figure 2 makes the data model flexible and allows to implement a purely data driven application, also simplifying iterative development.

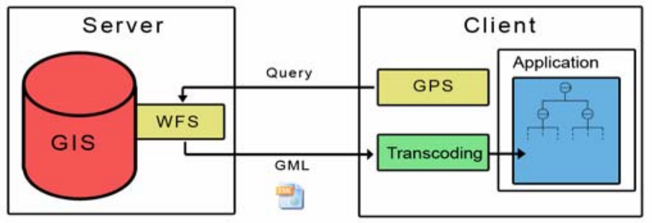

Figure 2: Export of data from the GIS server to the AR client through a Web Feature Service. The service delivers XML-encoded Geography Markup Language documents, which are translated into 3D scene graph on the client side.

AR models must be structured in a flexible manner in order to address a wide range of AR applications and lend themselves an interactive use.

3.2 Spatial Interaction tools

Once the data is available in the AR browser, a number of interaction tools are required to make the 3D presentation useful described in the following.

Excavation tool Simple X-Ray vision, which indiscriminately overlays hidden information on top of visible real-world entities, carries several depth perception problems [14]. Virtual objects appear to float on top of the real ones because of overdraw. Therefore we employ an excavation tool resembling a hole in the ground, thereby providing plausible interpretation of depth through partial object occlusion as well as motion parallax. The excavation tool is implemented using a magic lens technique described in [15], but additionally makes use of contextual information [10] derived from the attribute data in the GIS. As the user selects the excavation tool, the system will initially position the lens two meters in front. The user is then able to reposition the lens. Once the excavation is satisfactorily positioned, it stays put and the user can move about to better appreciate the underground data. This type of visualization has been shown to improve depth perception in monocular displays [21]. Figure 3 (left) shows simple overlay rendering, while Figure 3 (right) shows the excavation tool.

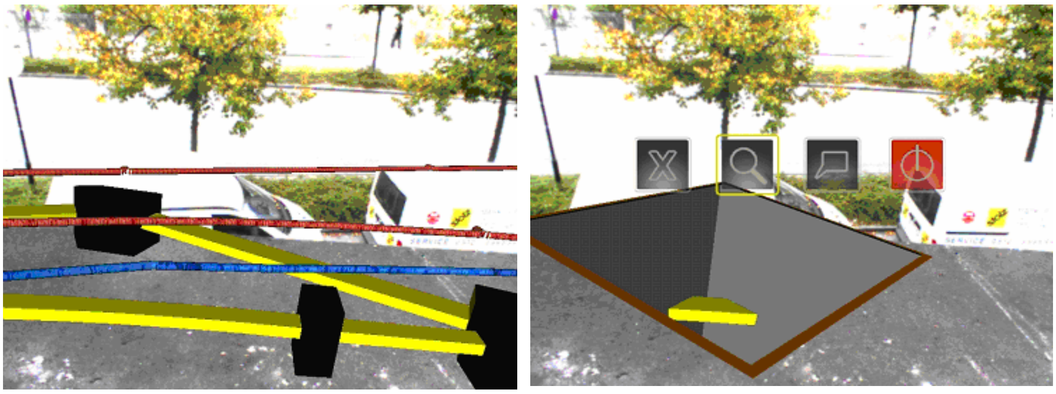

Figure 3: (left) Simple rendering of the underground infrastructure on top of the video stream lacks depth cues, the pipes appear to float on top of the street. (right) Improved depth cues with the excavation tool.

Labeling tool We have also implemented a labeling tool, helping the user to visualize the meta information of the infrastructure. Meta information includes part number and ownership, etc. and is derived from the original geo-data and stored as non-geometrical attributes on the 3D model. Once the user activates this mode, he can place a crosshair target on top of an asset, and confirms with a button. A label displaying the information of the asset appears on the right of the screen (Figure 4).

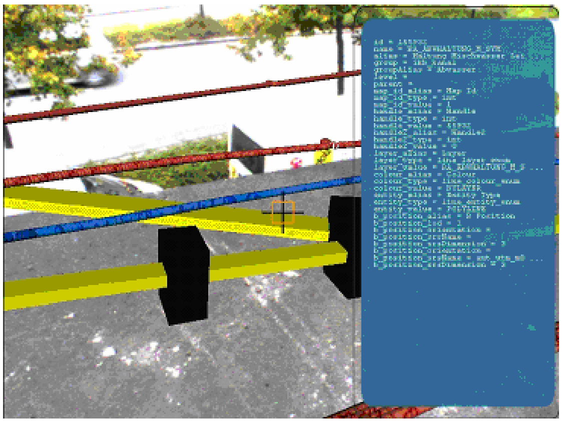

Figure 4: Meta information is displayed after selecting an asset with the cross hair.

Filtering tool Desktop GIS systems offer advanced possibilities for filtering and selecting information to avoid cluttering. The filtering is based on detailed attribute selection, and was found to be powerful, but too complicated for interaction with the AR system in the field. Instead, the mobile AR user relies on quickly selecting a small region of interest with the excavation tool first, turning on and off sets of 3D features based on pre-grouping into asset categories (gas, water, buildings and so on). This two-step filtering approach is sufficient to reduce the displayed information to a manageable amount, while requiring only minimal interaction. The image on Figure 5 (left) shows excess information presented to the user. Figure 5 (right) shows an example of our filtering by contextual information. The effects of both content filtering and excavation tool combined are clearly visible.

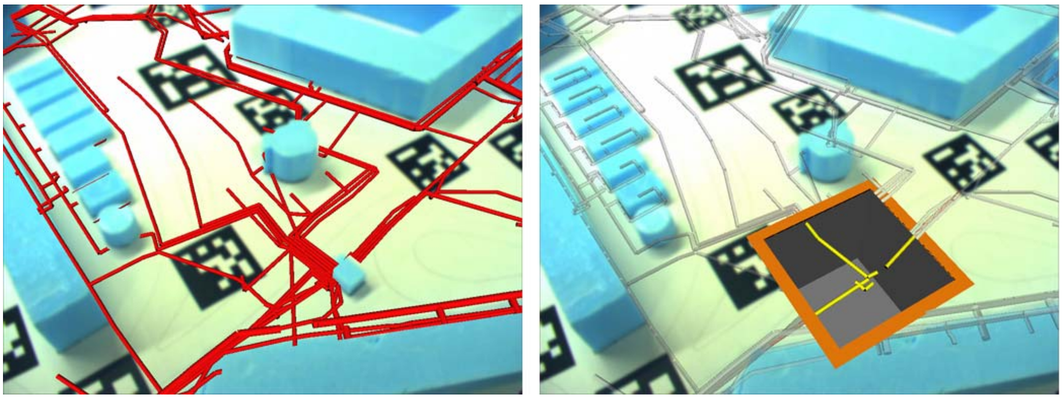

Figure 5: (left) Rendering the full model of underground assets at the Jakominiplatz site may show too much detail. (right) Filtering reduces the shown information to a relevant subset.

Snapshot tool During our discussions with personnel of utility companies we learned that in order to support collaboration, snapshots are an important tool. A user may freeze an image at any point in time and share it with colleagues. It is always accessible with an exclusively assigned button on the AR device. The snapshot tool is also useful for logging. The system automatically saves a bitmap of the snapshot image that can be later used for archiving or further analysis back at the planning office.

4 Hardware platform

Outdoor AR applications, such as the one considered in this paper, are particularly challenging in terms of hardware requirements. There is no room for placing permanent instrumentation in the environment, thus the AR platform needs to be completely self-contained. A system of any practical value must at least address the following challenges:

- The system must provide sufficient computing capabilities on a platform that allows for several hours of battery-powered operation.
- The system must have an ergonomic form factor that allows holding the AR device for extended periods without excessive fatigue, and performing typical operations with high convenience.
- The system must include a pose tracker which delivers six degrees of freedom with real-time updates, is globally registered and robust.

Compared to body worn equipment, a handheld device is less intimidating and can be more easily shared by multiple workers. A handheld AR display – as opposed to a head-mounted display – can also be viewed collaboratively.

Considering the above mentioned constraints for *Vidente*, an ultra-mobile PC (Sony Vaio UX, Intel Core Solo 1.1GHz, Windows XP, 0.5kg) was chosen as the core hardware platform, running the *Studierstube*[5] software framework developed in our research group.

The UMPC is extremely powerful given its weight, but with the additional peripherals required by AR, the weight adds ergonomic restrictions on the duration and type of actions being performed. Hence, we designed a new device construction, described in the next section.

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[5] http://www.studierstube.org

4.1 Vesp´R

In order to come up with a suitable device construction, we performed an extensive design study finding ways to support MSI using a handheld in new and effective ways. As a result of this analysis, we came up with the following needs on the construction: it needs to hold the additional peripherals, make available a range of well reachable controllers, and allow for flexibility in usage including freedom of movement. The latter specifically requires that multiple grips are possible: one possibility in which the construction can be grabbed with both hands to split the weight on both hands and arms, and a single-grip version that allows for the second hand to either control the UMPC (pen input) or perform an independent task (like marking a road).

After the study, we created multiple prototypes to come to the final construction called Vesp’R [22]. The Vesp’R construction, made of sturdy ABS material covered with rubber, consists of a main hull around the UMPC, to which either one or two handles can be connected. (see Figure 6). The hull contains an empty space, holding the peripherals (GPS, orientation sensor, and camera). The handles, also simply called “joysticks” hold multiple kinds of controllers, from simple micro-joysticks to midi-components. Currently, the application mostly makes use of micro-joysticks and buttons.

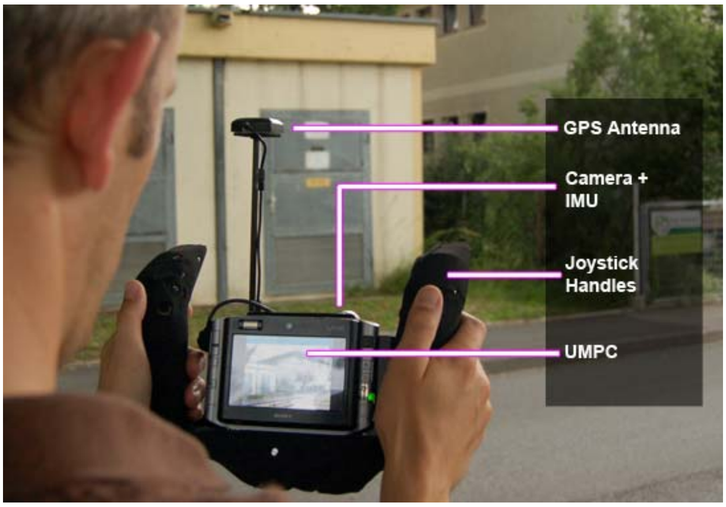

Figure 6: Vesp´R is a design for an ergonomic handheld Augmented Reality device designed around an ultra-mobile PC.

The first setup consists of two handles connected to the sides of the hull. In this way, weight is equally distributed over both hands, and can be handled well due to the powerful grip on the joysticks (power grip, [11]). Hence, users can make use of the device construction for longer periods of time without being restricted by fatigue that is possibly caused by holding the construction in front of the body.

In the second configuration, the joysticks are removed from the side: one joystick is placed below the hull. Due to the power grip on this joystick, which supports a steady way to hold the construction, it is possible to make use of the second hand for other tasks. However, the single-handed grip can cause fatigue in the arms and hands: this setup cannot be used continuously for longer durations. However, since the second hand can always support the construction, periods of relief can be added to the task performance cycle.

In addition to the balancing of weight, it has been of great importance to ergonomically map functions to controllers. The power grip is an important factor while using Vesp’R: the fingers grasp the handle and press it against the palm of the hand. Hereby the thumb and index finger can be moved freely when balancing the device firmly. This ability is the key to our control structure because all major tasks are controlled with the thumb and index finger. For this purpose an eight-directional micro joystick is mounted in one of the handles easily accessible by the thumb. On the back of the grip a second joystick with a trigger button is placed, which can be used with the index finger. Using the micro joystick is ergonomically effective: since it is constrained to eight directions, the thumb can use it without requiring precision.

Menu control with the micro joystick is kept straightforward. For mode changes, a linear menu overlay is operated with the left/right direction of the joystick. Similarly, the micro joystick is used to perform constrained spatial interaction, such as moving objects in the ground plane.

4.2 Tracking

AR requires a relative accurate position and orientation tracking and temporal resolution to align or register the virtual urban 3D model with the physical buildings and objects. Outdoor tracking of Vesp´R is provided by a combination of GPS (uBlox Antaris) and an inertial measurement unit (InterSense InertiaCube3). GPS measurements with the Antaris, which uses the European wide area augmentation system EGNOS, are typically accurate within a few meters in the European Union. The InertiaCube3 measures 3DOF orientation with RMS accuracy below one degree.

5 Evaluations

In order to get an overview of the quality of the different system components, we performed a structured evaluation, analyzing a range of aspects. These factors included the general quality of the user interface, the visualization methods being used, the matching of industrial requirements obtained in the system requirement phase, and the actual operation by end-users including cooperation aspects. The factors were mapped to different kinds of users in order to get the most useful feedback. We started with evaluating system aspects with system experts in order to go through refinement cycles of the system before the system was presented to the actual end-users. Naturally, end-users had seen and used prototypes of the system before: their feedback has flown directly in the initial development phases, but we did not perform any formal evaluations with them till later.

5.1 Mobile computing developers

The first range of trials and interviews was performed at the Ubicomp 2007 conference. Ubicomp is the one of the main conferences visited by mobile computing experts. The demo setup focused on analyzing an underground infrastructure of the area around the conference centre. The main aim was to investigate the quality of the software and hardware interfaces to control the application. In the evaluation, users made use of the single-handed setup of Vesp´R. Following the usage sessions, participants were requested to fill in a questionnaire using a 7-point Likert scale rating.

17 participants (16m/1f) took part in the experiment. All had good computer skills, but no professional experience with GIS for underground infrastructure. The average duration of the session was about 10 minutes per person. At the beginning of the session, each participant was instructed how to interact with the application using Vesp'R. Participants could see the underground infrastructure superimposed in 3D on the street below a platform outside of the conference centre (Figure 7). During the try-out, complete freedom was given to the participant to orient the device and look at different parts of the underground infrastructure.

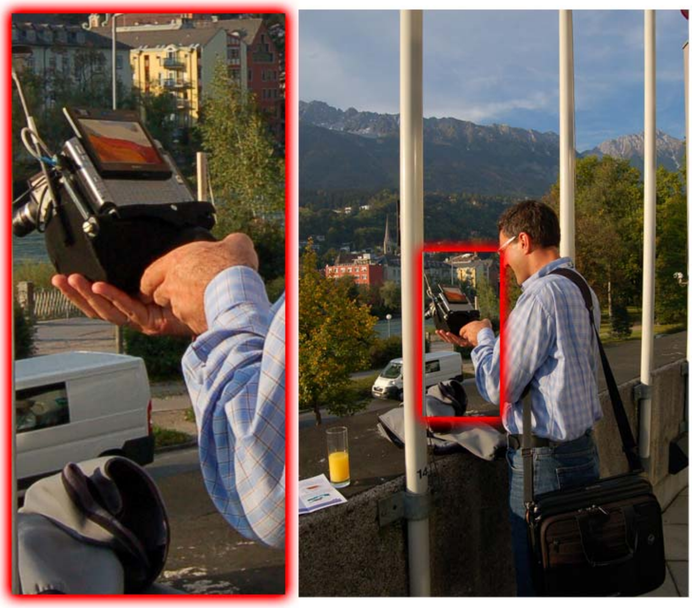

Figure 7: A participant testing the Vidente application exhibited during the Ubicomp 2007 conference.

The participant was also asked to use the controls of the Vesp´R device for interaction like switching on/off single layers of underground infrastructure. Furthermore, the user could switch between different visualization styles like x-ray or excavation and also combine both to avoid display clutter and use the Vesp´R for further interaction with the geospatial data. After finishing the session, the participant rated specific aspects concerning both the device and the user interface. We grouped our questions around two main topics: hardware setup (including ergonomics) and user interface quality.

Hardware setup

The participants were relatively satisfied with the placement of the controllers, and did not perceive fatigue. The weight balance of the device was not rated satisfactory for most participants. However, most users did not report fatigue. Unfortunately, the setting did not permit comparison against other grip configurations, holding a standalone UMPC, or even holding a full-size laptop such as currently used in conventional field work.

On our observations we noticed that a significant portion of the users held the device single handed. Those who used two hands placed the non-dominant hand in the round back of the device without having received explicit instruction how to hold it (Figure 7). One of the users held the device always from the back and only accessed the control buttons sparsely with his dominant hand. None of the users showed any significant hand tremor or high muscular tension; only one of the users had to lay the device down for a couple of seconds to relief strain.

During the try-out, direct sun cast led to rather poor display contrast causing most users to hold the device at eye level instead of chest level as expected. It is likely that the uncomfortable pose affected the subjective rating of ergonomics.
Subjects rarely switched the focus of their gaze from the on-screen image to the real world, suggesting that the depth cues of the application were sufficient to provide spatial awareness.

User interface
The effectiveness of the application control was also received positively, while the usefulness and effectiveness of the controls received high acceptance. Among the tools presented, Magic Lens (excavation) and x-ray were preferred by the users. One reason for the high rating of the Magic Lens is the better depth perception this style offers.

5.2 Mixed user group

Obviously, we had mixed results from the first evaluation, in which most people did not find the single-handed grip satisfactory. However, since we had no comparison to other kinds of grips and device setups, we did not know the actual value of the results.
Hence, in order to get a better insight on the ergonomic factors of the Vesp'R setup, we performed a study to focus on the pros and cons of the different possible grips in comparison to other device setups. In the test, subjects had to perform a placement task in which objects needed to be moved virtually from one location to another, thereby applying different kinds of grips and (body) postures to use the devices. We used the following device setups: UMPC only, UMPC with simple plastic enclosure, single-handed Vesp'R mode and two-handed Vesp'R mode.
15 subjects (12m/3f) participated in the evaluation, having different "body configurations": we tried to pick people with different hand sizes and levels of "muscular conditions" (normal people, sporty people) to see how easy it was to hold and control the different setups. All users had a background in computer science, but this had no direct effect on the ergonomic considerations being evaluated.

Hardware setup
Figures 8a and 8b depict results of user comfort ratings of two-handed usage and single handed operation. The different setups have largely varying weight factors: the UMPC only just weighs about 550 grams, whereas the Vesp'R with two joysticks and all the needed peripherals gets close to 1250 grams. As such, it came to no surprise that most users found the UMPC comfortable to hold (avg. 5.33 / stdev 1.54) – nonetheless, the two-handed Vesp'R was rated most comfortable, which was a big success considering the weight difference with the other devices (avg. 6.07 / stdev 1.38). Users could easily balance the weight (avg. 6.20 / stdev 1.20) and found the controllers well-placed (avg. 6.00 / stdev 0.88). In line with the first experiment, the single-handed version of Vesp'R was rated less comfortable, but still within mid range (avg. 4.60 / stdev 1.80): users could still hold the construction. It is not the user's first choice, but, in case the second hand needs to be used for another task it easily outperforms the UMPC setup: all users

did not prefer to make use of the UMPC in single handed mode, since it easily tilts to one side, causing considerable fatigue.

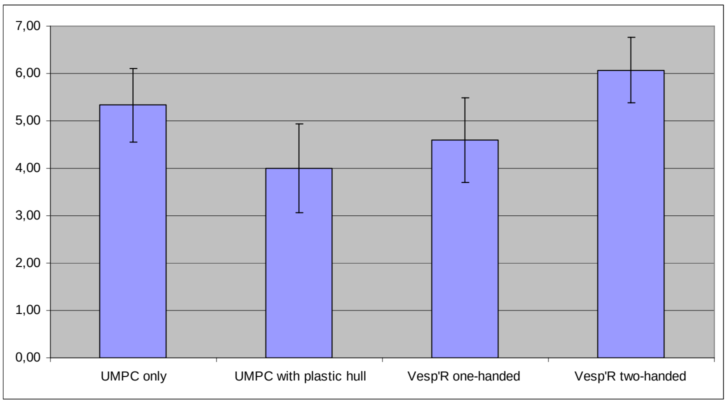

Figure 8a: User comfort of two-handed usage.

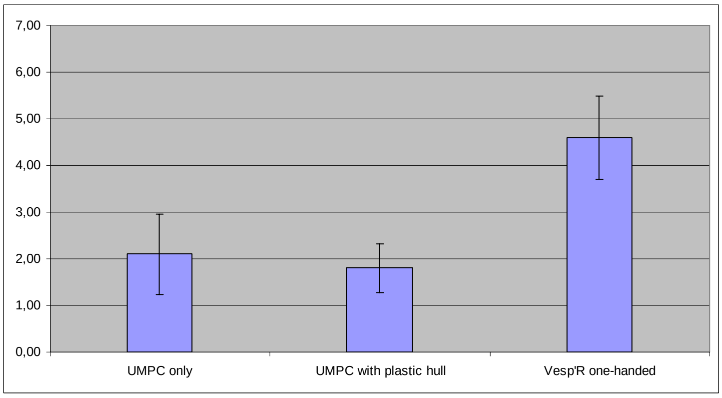

Figure 8b: User comfort of single handed operation.

User interface

In relation to user comfort and the placement of the controllers, users found the two-handed Vesp'R the best choice for interacting with an application (avg 6.20 / avg 0.56), whereas the (avg 5.00 / stdev 1.77). Both the UMPC and the UMPC with plastic hull only scored mediocre in the range around avg. 3.60. Users also found they could still operate an application single-handed with the Vesp'R (avg. 4.60 / stdev 1.64), whereas they could not at all perform interaction with the UMPC and UMPC with plastic hull configurations (both rated around avg. 2.00). These results were completely in line with the user comfort results.

Overall, the study showed that the two-handed Vesp'R is ergonomically superior to all other setups and can be well used for longer durations. The single-handed Vesp'R is not the ideal choice, but currently offers the only acceptable solution for mixed tasks: UMPC only / UMPC with plastic hull configurations are definitely not suitable.

5.3 Field worker interview

The previously presented studies mainly covered ergonomic issues of the hardware setup, whereas the following studies focus on the practical relevance of our prototype. By conducting an interview with field workers from local industrial utility companies (2 employees from the local power supplier E-Werk Gösting

Stromversorgungs GmbH and 3 employees from ENERGIE GRAZ GmbH & Co KG) we obtained valuable feedback from experts with strong practical experience for years. Four employees had significant background in the electricity sector whereas one employee had relevant experience in the gas supply sector.

First, we introduced the Vesp´R setup (single handle as well a two handle setup) and the Vidente application to the field workers. Then they used the setups to visualize the underground infrastructure at the outdoor site and interacted with the application (see Figure 8). Second, we conducted a semi-structured interview to assess both the practical applicability of the hardware setup and the application in the field.

Figure 8: Expert field worker with (left) conventional measurement device and (above) two handle Vesp´R setup for finding underground infrastructure.

Scope of application The interviews showed that field workers from both companies E-Werk Gösting and ENERGIE GRAZ gave positive feedback to our prototype. They confirmed that potential fields of application are tasks like construction instruction, outage management and planning.

Visualization Most importantly the visualization overlaying the underground infrastructure over the real world needs to be highly accurate. High priority was given to depth perception of the buried assets which reconfirmed our expectations. Field workers expressed their wish to see all underground assets buried at one spot, allowing to achieve a complete overview. It became evident that color coding for different bands – voltage bands for electricity or pressure bands for gas pipes – is highly desired, since it helps a lot in classifying the assets. Vidente can support that by choosing the color code according to the attribute values of the underground infrastructure.
Furthermore, field workers mentioned photorealism of all rendered graphics not to be of primary importance. Concerning the user interface, also touch screen based interaction would be conceivable, since many people are used to control applications that way.

Collaboration between utilities and their contractors is classically done by spraying markers on the ground. When using Vidente, spraying would no longer be needed. The snapshot tool as described in Section 3.2 has high relevance when a certain situation of underground infrastructure needs to be discussed, for documentation purposes or for presentations.

Hardware setup Because of optimal characteristics in terms of balance and weight, field staff from E-Werk Gösting preferred the Vesp´R hardware setup with 2 handles clearly to the one with the single handle. Generally they were satisfied with the interaction capabilities of the setup. But two field workers expressed the wish for further interaction possibilities, like a scroll wheel. Slightly different, field experts from ENERGIE GRAZ considered Vesp´R with 2 handles and Vesp´R with 1 handle equally useful. They remarked that the latter setup allows for spraying markers on the ground at the same time. A major issue for outdoor use concerns the ruggedness of the system, that is water-repellent casing, sunlight-readable display, well protected sensors and grip material suitable for rough outdoor conditions.

Operation mode Lately field workers at ENERGIE GRAZ started using a tablet PC for the process of marking gas pipes in order to test for leaks in a yearly interval. Therefore GIS data is stored on the mobile tablet PC and is synchronized with the office GIS system weekly.
E-Werk Gösting usually needs to locate 50-100 meters of trench length a day. The device would be operated in a discontinuously mode, which means the field worker uses the Vesp´R setup for approx. 5-10 seconds, walks further, and again uses the device. The overall time of usage at one construction site would be around 15-20 minutes.

Industrial requirements need to be taken into account: most importantly a positional accuracy of 30 cm needs to be achieved in locating the buried assets. Reliability of the data and the values is a relevant issue as well.

Field workers form E-Werk Gösting mentioned the system would alleviate their work by allowing them to carry fewer measurement devices with them. Commonly a smaller workload and less wrong excavations are expected by using Vidente. The biggest advantage of the system is an improved spatial overview of the construction site through the egocentric visualization of the underground infrastructure. All field workers clearly preferred a 3D visualization to one in 2D. Especially, the depth perception of the pipes was considered beneficial.
Something we did not foresee was an additional usage scenario of the device. Vesp´R could also function as a device for measuring the position of a newly passed pipe by simply following the path of the pipe and stopping at several positions to record the according GPS position. In this way – given high tracking accuracy – the position of new pipes could be measured accurately.

5.4 Management level feedback

In the final stage, we gathered feedback from industry at the Austrian Smallworld User Group Meeting 2007 (ÖSWUG) where attendees (management level, field workers) from approx. 20 utility companies were present. We showed a hands-on outdoor demo (using the single-handed Vesp´R setup) visualizing the underground infrastructure at a nearby street crossing. Seven people answered a short questionnaire after the outdoor test. Since most people were at a management level, we obtained useful feedback from a management view from utility providers to this application.

Only some rated the weight and form factor of Vesp´R no as not optimal, which is in line with the previous results on the one versus two-handed setups. When asked for the advantages they mentioned the visualization itself, the interaction with the application and the real time tracking. Attendees rated the usefulness of the visualization as high. Significant time savings could be achieved using a system like presented. Many providers could foresee using this application in the process of construction instruction. Furthermore, people expressed the wish for seeing 3D city models additionally to underground infrastructure.

5.5 Evaluation summary

The evaluations provided us with a wealth of information. Overall, the interactive visualization seems to be appropriate for the end-users: both field workers and management claim that the presented methods provide an effective and highly useful method for outdoor inspection tasks, probably saving both time and money. Hence, the interactive visualization is in line with their industrial and operation requirements. Though sometimes receiving mixed results of computer scientists, end users were positive on the developed hardware infrastructure, not too much worried about fatigue effects as we were afraid of. Better said: the device construction in both one and two handed versions could match the ergonomic requirements for most tasks of the field workers. The one handed construction may not be ergonomically ideal, but a big step forward in comparison to older setups and allows for user freedom in performing non-computing tasks. Notwithstanding, the system still has potential for improvement, both on the hardware and software side, to even better support the needs for the field workers.

6 Conclusions and future work

We have presented an augmented reality system for the visualization of underground infrastructure for utility companies. Our work addresses a variety of problems in mobile applications, including 3D modeling, tracking, application interaction and device form-factor.

We reported on a broad evaluation, from which we drew observations that will drive the next generation of our prototype. Our efforts will focus on reducing the weight and improving the balance and grip of the device.

During other outdoor tests we experienced shortcomings of the GPS tracking system delivering poor results in street canyons. GPS dead reckoning strategies or sensor fusion of GPS with another outdoor tracking system could help improve it. In the next generation of our handheld prototype we will integrate a Real Time Kinematics GPS receiver suitable for our handheld Vesp´R device for achieving accuracy below 30 cm. The usage of natural feature tracking provides superior post estimation and can be implemented on UMPCs [17]. We intend to incorporate this approach in the near future into our solution. Additionally, on site correction of data will be interesting to investigate. Depth perception will also remain a major issue in our research. A promising direction for AR is work by Kalkofen et al. [18] in which real world features are used as depth cues. More advanced filtering techniques that include users' tasks and properties [19] are an interesting approach that we intend to include in our next prototype.

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