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Supporting Mobile Maintenance in Construction Industry

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Abstract. This workshop paper presents a system to support mobile maintenance in construction industry. Using mobile augmented reality (AR) technology combined with a web-based collaboration system, the proposed system helps to improve the communication and collaboration processes. The cooperation between workers and remote experts will be supported. The paper describes also the results of a user study to evaluate the system.

2 Introduction

The construction industry is faced with a dilemma that until a building is in progress some problems are not foreseen and this has impact on the handover time to the customer. This invariably implies default and penalty clauses that affect the profitability and the return on investment for the builder.

As building realization necessarily uses local labour, plans and construction information is not always interpreted correctly in line with the design intent and the architect’s vision. This leads to on site operative being faced with unforeseen problems that are potential job stoppers. In view of the above, it is envisaged that an improvement in the communication and collaboration processes is likely to have considerable impact on the success of the construction project which is measured in terms of project total cost, duration and quality. Furthermore, the

introduction of the collaboration technology may result in reengineering of the problem solving process, this leading to further increase in productivity.
For this reason we developed a mobile service application, which can be used by construction site workers or maintenance engineers to collaborate with remote experts to solve complex engineering tasks. Using mobile computing and augmented reality technology collaboration between mobile workers and experts at remote locations will be supported.
After giving a short overview of related work, the next section explains the scenario, the platform and the tasks of the user tests. The evaluation methodology and the results of this user test will be presented in section 4. The paper closes with a conclusion in section 5.

3 Related Work

There has been already some work for mobile augmented reality applications in industrial settings. Each one follows different approaches and is applied to several industrial sectors. The work presented in [7] introduces an approach for the aerospace sector. The focus of this paper is on usability engineering, ergonomic questions on the system and the user interface and their evaluation. The test scenario for the described prototype includes assembling tasks in production of airplanes. The system presented in this paper consists of a standard PC and a head-mounted display.
A more mobile approach is described in [6]. Two different prototypes are compared. The first prototype is a tablet PC and the second prototype is a laptop-based AR system with a video-see-through display. The paper discusses different evaluation methods. This prototype is applied to service and maintenance tasks for machines.
Koch et al. [4] present a mobile AR system for maintenance tasks in the automotive industry. Their system contains a mobile PC connected to a backend server. This server will be used to take over the computational tasks for the tracking.
In contrast to the related work presented in this section, the approach described in this paper offers new possibilities of accessing the entire building information model on-site using a remote server. It provides a tailor made solution for site supervisors and workers in the construction area to collaborate with partners and stakeholder.

4 User Collaboration and Interaction

The main purpose of the mobile AR system is to enable site workers or site supervisors to access the digital building information model which is stored on a remote repository. Using this information unforeseen problems, like a missing element or a wrongly installed component, can be detected by comparing the real and the virtual model.
Furthermore, additional information can be displayed by clicking on appropriate parts of a model. This way for site supervision important dates like last inspection date or responsible persons can be shown on the screen of the mobile device.
An integrated media streaming function guarantees a distributed collaboration between the site workers and remote colleagues.

A knowledge repository is essential for collaboration because it comprises all necessary data for a construction project from the different stakeholders. This facilitates the process of various construction steps due to the list of involved partners could be very long. Table 1 shows an example of the involved stakeholders for the scenario described in section V.

	Stakeholder	*Role*
1	Project Manager (PM)	Representing the Main Contractor and the client-based on site
2	Architect	Producing the architectural design and drawings
3	Structural Engineer (SE)	Producing the structural design and drawings
4	ME Engineer	Producing the Mechanical Engineering design and drawings
5	Plumbing Sub-Contractor (SME1 foreman)	Plumbing work-based in the office
6	SME1 operator	In-charge of installing plumbing work on site
7	HVAC sub-contractor (SME2 foreman)	Heating, ventilation and air conditioning work-based in the office
8	SME2 operator	In-charge of installing HVAC work on site
9	Quantity Surveyor	Cost estimates
10	Contractor Senior Manager (CSM)	PM reports to- based in the company
11	Commercial Director	Costing implication
12	Authorities	Examples: fire, environment, police, planning, etc.

Table 1 Involved Stakeholders for the described scenario in section V

Due to the limited storage of the mobile device, it is not possible to have the complete data of a construction project stored on one device. Therefore using an identification approach, the currently required data will be downloaded from the repository on demand. Without the downloaded data and model from the knowledge repository, there is no interaction and overlay. According to the detected ID, the appropriate data is loaded. With the downloaded 3D model, the virtual model will be displayed superimposed and the site worker is able to interaction with the scene.

5 System Overview

The overall system for mobile maintenance consists of three main components. The first component is the remote knowledge repository, where the required data is stored. The second component is responsible for identification and tracking tasks and the third components is the mobile AR system.

5.1 Knowledge repository

The Knowledge repository is based on the BSCW Shared Workspace system [2]. The BSCW ("Basic Support for Cooperative Work") is an extended web server, which provides basic facilities for (primarily asynchronous) collaborative information sharing, activity awareness and integration of external applications. The BSCW server provides a web-based access to documents, contacts, appointments and resources (s. 0). The digital building information model (BIM) is represented by the stored data on the server. Background information of resources, specifications, pictures, reports, good practice reports and other building related content are stored in a context-aware manner, which makes it easy to access the appropriate data and interaction possibilities for users in specific working situation.

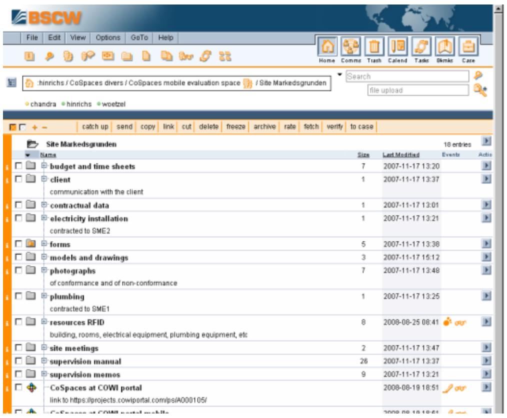

Figure 1 Screenshot of a digital building inforamtion model based on a BSCW system

Providing an interface to the mobile AR system using web services, the remote worker on site is able to having access to the complete data set. In case of unforeseen problems, he can get in touch with the responsible expert using the contact data of co-workers and experts stored in the system.

5.2 Positioning and Identification

The second component of the system is the positioning and identification component. This component is responsible for several tasks. On the one hand, identification techniques like RFID or fiducial markers [3] allow to determine specific parts of a building thus only the required data is selected and downloaded from the remote repository. On the other hand, the estimation of the current camera position and orientation (camera pose) of the AR system is important for augmentation issues. The camera pose is required to display a virtual overlay (s. 0).

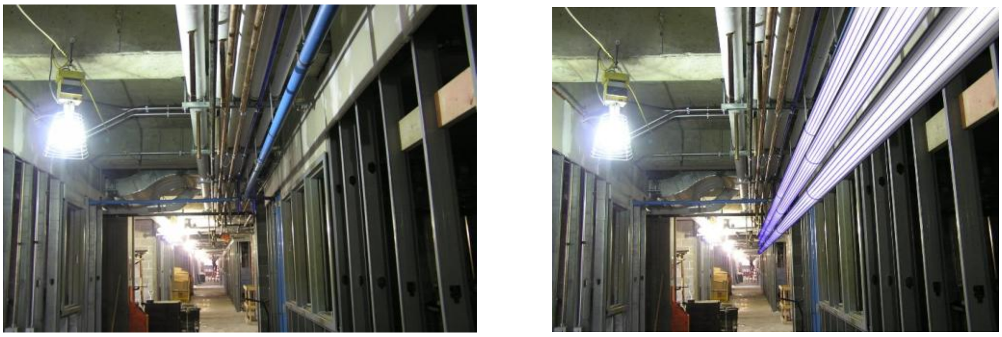

Figure 2 Augmentation of a real scene (left image) with a virtual overlay (right image). The appropriate placement of the virtual object was determined by the identification and positioning component.

There are several approaches for computer vision based pose estimation. Some of these approaches make use of further 3D knowledge of the environment. One kind of these approaches are marker-based tracking techniques.

Artificially designed fiducials, so called markers, are added to the scene. These markers, typically rectangular patterns with a black/white texture, need to be detected by basic image processing algorithms. The disadvantage of this method is, that the environment has to be prepared by attaching markers to e.g. walls or doors.

In contrast to fiducial-based approaches, image-based information can also be extracted by the mean of natural features detected in the image. These detected natural features can be combined with a priori 3D knowledge. The 3D knowledge can be obtained by CAD models of the scene object, a set of planar parts, or even a rough 3D model such as a cube. To this category belong also model-based techniques [8].

The third category considers natural features without any other 3D knowledge [1]. The estimation of the camera pose is based on camera images only, without any other knowledge of the environment.

Regarding the usage within the mobile maintenance system, the question of the most suitable positioning technique depends on the current working situation.

5.3 Mobile Augmented Reality System

The mobile AR system consists of a mobile device suitable for mobile AR applications on construction sites and the appropriate software functionalities.

As mobile device, an Ultra-Mobile PC (UMPC) is used. It is used with a so called “Magic Lens”-metaphor, which means that an AR application running on this device enables to enhance the reality by superimposing the live video image with virtual objects. In our case we use a Sony Vaio VGN-UX280 (0). The device is equipped with an in-built camera at the back which provides the live video for augmentation. The screen size is 4,5`` and the weight without any attached sensors is 0,6 kg.

Figure 3 The mobile device: A Sony Vaio VGN-UX280

The device provides several buttons which could be used for interaction. In our case only the left mouse button is used. It is represented by a button on the upper left of the device, thus it can be used conveniently with the left thumb. This UMPC is running Windows XP 32bit. It is equipped with 1GB RAM and an Intel Core Solo U1400 1.20GHz.

For the special purpose of detecting unforeseen problems, the superimposed virtual model of a building or parts of a building will be compared with the real situation.

The enabling software is the VR/AR framework MORGAN [5]. The 3D rendering capability is one of the major parts of MORGAN. Its own render engine has been particularly designed to meet the requirements of distributed multi-user VR and AR applications, providing native support for different file formats and scene graph structures. This is achieved by the MORGAN specific approach of using internal and external scene graphs. The underlying concept separates application or file format specific information from pure rendering information.

Following the concept of external scenegraphs, such a scenegraph supports the IFC file format. IFC – Industrial Foundation Classes – is the international standard for digital building information model (BIM). Supporting the IFC file format, the AR interface enables to visualize the digital building information model on-site.

All components such as the render scenegraph are integrated into MORGAN by a specific plug-in mechanism. Using this plug-in mechanism other components like a media handler can be included. This media handler for instance could be used for audio and video streaming for distributed and mobile collaboration. Figure 4 shows an example of a streamed video from remote site supervision.

Figure 4 A site supervisor streams a live video to a remote expert

6 Use Case and Evaluation

6.1 Scenario

The scenario corresponds to a realistic vision of the European industries concerning the innovative way technology could be used to improve future collaboration, based on workshops and interviews with construction companies. Within these workshops concrete work areas and working environments which are most suited for technological support by the Mobile AR application has been identified.

The resulting scenario considers the situation of a small or medium enterprise (SME) who is attempting to install piping services to a previously installed heating and ventilation air conditioning system. This system is being installed by a second SME. The problem created is that there is insufficient space and access to install the supply pipe as well previous holes access has been utilized.

The scenario is a derivative of a more generic case associated with the occurrence of “Unforeseen Events”, where there is a need for information and a decision from a variety of stakeholders to resolve the problem as early and efficiently as possible.

For this situation the main objective is to reach a resolution in the most efficient way and in the minimum of time, without excessive cost implications. This is to be achieved through better means of communication in an efficient collaborative setting.

6.2 User study

The approach used in the evaluation is the Living Lab approach. The user study was carried out two times. One study was conducted with experts at a construction company with people from the construction area and another one was staged at our research institutes with IT experts. For the participants (six in total) it was at most the second time they had contact with the mobile AR interface.

As user tests, a simulation of a real scenario was performed. The workflow of the mobile application scenario comprises several tasks, which have to be executed by the participants. To follow the described scenario in section A, the users were asked to conduct the following tasks:

- Login to knowledge repository and access the appropriate building information model workspace
- Start interacting with the scene. The user has to figure out that without the downloaded model from the repository, there is no interaction and overlay
- Select the necessary data by identification of room using an optical marker attached to the door. According to the ID, the appropriate model will be downloaded from the remote repository
- Compare the virtual 3D model superimposed on the real environment and figure out the difference
- Since the interaction is enabled, the user has to get some information by selecting a scene item.

6.3 Results

The evaluation method for the mobile maintenance system is subdivided into two parts.

The first part is a questionnaire which consists of two types of questions. The first set of questions is closed questions with semantic scales to test the usability of the user interface, the likeability and the system utility. The second set of questions was open questions to collect the participants' views on the process itself.

The second part is a verbal protocol. As participants vocalize thoughts, goals, feelings and talk about their actions whilst performing a task, this method was selected to validate the usability of the system and to also understand the users' reasoning when interacting with the system. The first part of the questions was about the overall system. It contains the impression of the entire framework. The results of user tests regarding the overall system are shown in table II.

	Question	*Mean*
1	I would like to use this system frequently	3
2	I found the system is unnecessarily complex	4,2

	Question	Mean
3	The system is easy to use	2,8
4	I need technical support to use this system	4,4
5	There is too much inconsistency in this system	3,6
6	The system is very uncomfortable to use	3,4
7	I needed to learn a lot of things before I could get going with this system	3,6
8	I found the system very awkward and uncomfortable to use	2,6
9	I felt very confident using the system	3,2
10	I enjoyed using the system	2,4

Table 2 Overall System

After a short introduction to the user test, the participants got a manual on how to use the system and what to do within this test. All participants succeeded the test and fulfilled the required tasks.
In some cases the setup of the system and the creation of the meeting have to be repeated due to technical problems. This could be one reason why some participants stated their opinion of the complexity and inconsistency of the system as very high.

The second part of the questions was about the mobile AR interface based on the MORGAN framework. The results of user tests regarding the mobile AR interface are shown in table III

	Question	Mean
1	Importing / converting of 3D files is simple	3,8
2	The layout and design of the GUI is appealing	4
3	The GUI needs to be revised further	3,2
4	It was difficult to navigate in the 3D scene	2,6
5	The quality of the model display was sufficient	3,4
6	The rendering quality needs to be improved	3
7	The response time on user interaction was short	3
8	The different layers (of each discipline, i.e. structural, electrical, plumbing) of the model were not clearly visible	3,4
9	The image quality was poor	2,4
10	The system facilitated decision making	2,8
11	The system can help to detect unforeseen problems	4
12	Using the system would not help companies to reduce cost	2,8
13	The device was easy to carry around	4
14	The device made interacting with the content easy	4
15	I found the interface confusing	2,2
16	I found the device confusing	2,4
17	Using the device was a natural way to interact with the real environment	3,8

Table 3 Mobile AR Interface

Regarding the overall impression of the mobile AR interface, the users didn't had problems using the device and interact with the scene.

Sometimes some irritation occurred when selecting an item. This could be explained by temporal inaccuracies of the tracking. For the test scenario, a marker based approach was used. For this approach it is very important that the marker is always visible and the light condition is sufficient.

The users agreed, that the layers according to each disciplines are not differentiated clearly. It is not visible which part of a building is actually selected, for instance plumbing or electricity.

The interaction with the device was no problem. The users described the way using the device to interact with the real environment as natural and intuitive.

7 Conclusion

To summarize the results of this final user test for a mobile maintenance system, the prototype was well accepted by the experts.

After analyzing the results we got a positive impression. But we have to mention that the evaluation was done by very supportive project partners with a positive attitude towards the project.

Besides the mostly positive feedback, the participants remarked also some critical points. First of all they commented the complexity of installation and preparation of the entire system. They recommend a more user-friendly approach.

Regarding the AR interface, they missed a clear distinction in visualization between the different disciplines. A more sophisticated and powerful user interface would even more support the site workers.

But generally speaking, all participants agreed, that the system facilitates maintenance work and supervision and it has a big potential to save time and money when employed in industry.

One participant has seen the mobile maintenance system as even more: "This will be the killer application!"

8 Acknowledgements

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