

MOBILE AUGMENTED REALITY, AN ADVANCED TOOL FOR THE CONSTRUCTION SECTOR

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ABSTRACT: Augmented reality is nowadays a novel technology that is acquiring great relevancy as a research area. This technology complements the perception and interaction with the real world and allows placing the user in a real environment augmented with additional information generated by computer. Throughout last years it is increasing the interest and the results reached in the technologies of augmented reality on desktop environments. However there are numerous environments of application of these technologies that require mobility of the user, need of access to the information at any time and any place, in these cases there becomes necessary the utilization of mobile devices. Construction Sector is a clear example. The development of mobile computing solutions is crucial in construction sites. The permanent change of the site (workers, activities, work place, etc.) implies that users need to get permanently updated information. Mobile computing solutions make this information available without reducing or disturbing the mobility and agility of the users. In this paper we present the mobile augmented reality as an advanced and innovative tool for the construction sector. This technology has a high potential to achieve more sustainability, profitability and higher quality level in this sector. It is structured in two main sections. An initial one that analyses the current status of the augmented reality technologies using mobile devices and describes the benefits provided by these technologies, the most recent challenges achieved, the novel applications and the problems not yet solved. And a second one that analyses the potential applications of the mobile augmented reality in the construction sector and describes a scenario in which the use of mobile computing solutions makes possible to increase efficiency and safety in construction sites.

KEYWORDS: augmented reality, construction, building, mobile computing.

1 INTRODUCTION

1.1 Augmented reality

Augmented Reality is an emerging technology in the area of virtual reality and it is increasingly acquiring greater relevance as a research and development area [5][39]. In the virtual reality the user is immersed in a world completely virtual, without any contact with the surrounding real world. However augmented reality allows the user to see the real world augmented with additional information created by the computer. Ideally the user perceives the real and virtual objects as coexisting in the same space. Augmented reality systems combine the virtual and the real, they are interactive in real time, and integrate three-dimensional objects in the scene. Augmented reality extends the perception capabilities of the user in the real world and his or her interaction with its objects, providing information that the user cannot detect personally and directly. To obtain these results it could use special devices such as glasses allowing to over imposing computer generated information on the real world image. The main problem concerning this technology is the precise alignment of computer generated data and real world data.

The figure below (see Figure 1) shows a conceptual diagram of an augmented reality system [6]. The video camera captures information from the real world. The positioning system determines the location and orientation of the user in each moment. With this information a virtual computer scene is created and mixed with the real world video signal, creating an augmented scene. The combined scene including real and virtual information is presented to the user through a visualization device. On the right image we can see an augmented reality system based on mobile devices, PDA and a portable visualization device.

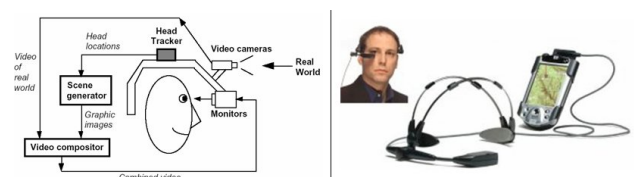


Figure 1. Conceptual diagram of an augmented reality system.

1.2 Safety at work in the construction sector

The Construction Sector is strategically important for Europe, providing the buildings and infrastructure on which all other industries and public bodies depend. The

sector employs more people than any other industrial sector. In all it has been estimated that 26 million workers in the EU-15 depend on the construction sector, comprising 2,5 million enterprises (97% SMEs) and an investment of € 910 billion (10% of GDP). At the same time, this industrial sector exhibits characteristics that make it especially relevant in relation with mobile computing:

- Every new project implies a new working place.
- Construction sites permanently evolve and change during the project execution.
- Difficult and uncontrolled working conditions (open-air, permanent mobility, risky and hazardous spots, etc.).

According to the Strategic Research Agenda of the European Construction Technology Platform – ECTP [13], one of the main concerns of the sector is creating more attractive work places and identifies workers Health and Safety (H&S) as a key point. The Construction Industry has the poorest H&S record of any major industry. The probability of construction workers being killed is 3 times higher than the average for all industries, and the probability of being injured is 2 times higher. The consequences of this situation are considerable and widely underestimated. The direct cost of accidents in Europe can be estimated at 16 billion € or 2% of the sector’s share in GDP. The development of mobile computing solutions make possible to increase safety in construction sites. The permanent change of the site (workers, activities, work place,...) implies that the responsible of H&S needs to get permanently updated information about the current and planned activities and the qualifications of workers and safety conditions that are needed to do them. Mobile computing solutions make this information available without reducing or disturbing the mobility and agility of the responsible of H&S.

2 ARCHITECTURES OF MOBILE AUGMENTED REALITY

Throughout last years it is increasing the interest and the results reached in the technologies of Augmented Reality on desktop PC environments. Several platforms have been developed with different architectures; including AMIRE[19], ARVIKA[4], StudierStube[37], DWARF[12], DART[9], etc. The use of the augmented reality technologies in the construction sector is becoming a reality with innovative specific platforms and applications, like AR EMS[43], UM-AR-GPS-ROVER[7], etc.

There are numerous environments of application of these technologies that requires mobility of the user, needs of access to the information anytime and anywhere, in these cases it becomes necessary the use of mobile devices. The first prototypes of applications of mobile augmented reality base on visualization devices such as Head Mounted Display (HMD) connected to a laptop. The laptop is in charge of the processing and is usually worn by the user on his/her back [16][31][32][2]. The alternative is the utilization of mobile devices such as PDA or Smartphone. Several experiences exist on the development of applications of augmented reality for these devices with different degrees of autonomy of the mobile device. The most

common implementation and simultaneously the lightest one presents to the mobile device as an element of input/output for visualization and interaction with the user, since the whole processing and composition of the augmented image is realized in a server [3][29]. This architecture generates a very big flow of information between the client and the server and does not fit well with lots of environments of use. An architecture supported in its entirety or almost totally on the mobile device supposes a serious problem of processing time, due to the hardware limitations of this type of devices. Examples exist on PDA [42] or on mobile telephone [25]. Due to the limitation of hardware resources of these devices, in some approximations it is used the concept of augmented reality on-demand, where the virtual objects turn out to be superimposed to an image of the real scene captured in a certain moment [40]. This concept appears faced to the traditional one, where there is performed an augmentation of the real scene every frame.

The following figure (see Figure 2) describes the main tasks in an augmented reality application. First one is the image capture. Information about the environment is captured by the camera, this information will be used as the background image for the augmented scene. When the positioning of the user is performed by image processing techniques the image captured by the camera will serve as a source for this task. The second task is the Tracking of the user position. Apart from the purely augmented reality tasks, other processing tasks can be required in order to build the corresponding augmented reality scene. Rendering of the augmented reality scene is the forth task. Last one is the visualization in the output device. Different client-server architectures can support this process, the following figure shows both extremes, any alternative in the middle will be valid.

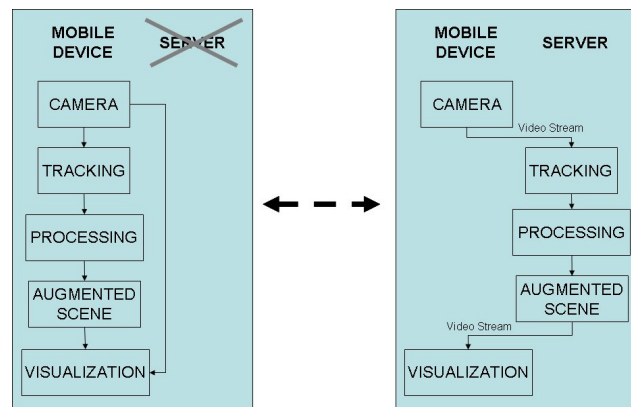


Figure 2. Client-server architecture for an augmented reality system.

3 AUGMENTED REALITY SYSTEMS

An augmented reality system consists of a group of devices with complementary functionalities connected and integrated through a software platform. From the hardware point of view the three main elements of the system are: The processing device, the visualization device and the positioning device. Alternatives for the first two ones will be presented next; in the following section a particu-

lar positioning system, the vision based positioning, will be described.

The *processing devices* used from the beginning have been general purpose laptops; however their weight and size do not meet the requirements for an augmented reality system which is comfortable. Currently there are portable computers of reduced weight and size such as the Oqo 01, (02 model already available) [27]. Recently Microsoft presented the new concept of Origami (ultra-portable PC) [28]. The personal digital agenda (PDA) originally designed as an evolution of the pocket agendas, are now presenting functionalities typical for laptops. Commercial products such as the Dell Axim x51v [10] make them, each day more, the ideal devices for this type of applications given the combination of computational power and size. The smallest and most introduced devices are the mobile phones. Differences between current mobile phones and PDAs are becoming insignificant, and there are currently devices, which are referred to as PDA/Smartphone that include high bandwidth internet connection and complete connectivity with EDGE 4-band, Bluetooth and WiFi. For such purpose, there are also other devices to consider, handheld game consoles represent a good alternative due to their computational and visualization power, size and weight; however they are based on proprietary developments which are very difficult to use in other context. Portable devices oriented to multimedia, games and internet are the strong bet for the future of the big manufacturers such as Zune[45] and iPhone[18] of Microsoft and Apple respectively. Processing and graphics capabilities of handheld devices are strongly increased thanks to the new generation of 3D graphic chipsets specially conceived for such devices. Nowadays only the cooling needs, high power consumption and small size of the screens do not allow exploiting all the features of such graphic chipsets. The following figure (see Figure 3) represents a comparative between the described processing devices.

	PROS	CONS
PORTABLE & ULTRAPORTABLE PC 	<ul style="list-style-type: none"> • PROCESSING POWER • GRAPHIC CAPABILITIES • WINDOWS BASED • SCREEN RESOLUTION 	<ul style="list-style-type: none"> • WEIGHT & SIZE • HIGH PRICE • POWER CONSUMPTION
PDA/SMARTPHONE 	<ul style="list-style-type: none"> • BIG MARKET • COMPUTATIONAL POWER VS SIZE • CONNECTIVITY 	<ul style="list-style-type: none"> • NO GRAPHIC ORIENTED • VIDEO OUTPUT RESOLUTION
HANDHELD GAME CONSOLE 	<ul style="list-style-type: none"> • GRAPHIC CAPABILITIES • WEIGHT & SIZE 	<ul style="list-style-type: none"> • PROPRIETARY DEVELOPMENTS • CLOSED PLATFORMS
MULTIMEDIA PLAYER 	<ul style="list-style-type: none"> • WEIGHT & SIZE • CONNECTIVITY • MULTIMEDIA CAPABILITIES 	<ul style="list-style-type: none"> • NO GRAPHIC ORIENTED • PROPRIETARY DEVELOPMENTS

Figure 3. Processing devices comparison.

The *visualization devices* are responsible for providing the mixing of reality and virtual elements. These devices can be classified into two groups: video-through, and seethrough (see Figure 4). The video-through devices are not transparent and require a video camera to capture the images of the physical surroundings. Over these images the system overlays the virtual information forming an image composed of reality and virtual data. Generally these devices are used as HMD devices. The see-through

devices include semi transparent screens through which the user can view the surrounding environment. These screens project the digital content, and the human system of vision integrates both real and virtual worlds of information.



Figure 4. Video-through and see-through visualization devices.

Talking about the *software*, the most introduced mobile devices operating systems are Symbian[38], Windows Mobile and Java in this order. Visualization of the 3D models combined with the reality is the big challenge for the graphic library. Hardware peculiarities of mobile devices and their graphic cards force to proprietary developments for such devices. Low level implementations search for the creation of the standard for the communication between graphic card and the software developments in this direction the OpenGL ES[26] has been defined as a subset of the OpenGL specification for desktop PCs. First implementations of OpenGL ES are PowerVR[33], Vincent[41] and Rasteroid[17]. Windows Mobile 5.0 includes Mobile Direct3D the mobile version of the DirectX graphic library. High level graphic APIs offer very limited functionalities and are generally proprietary implementations which are not based on OpenGL ES. Some examples are: Coin3D[8], MobiX3D[24] and M3G[20].

4 VISION BASED MARKLESS TRACKING

The main problem to be solved in the applications of augmented reality is to find the transformation between the system of reference of the real world and the system of reference of the camera, that is to say, to calculate the position of the camera (user) inside the real world in real time. The knowledge of this relation can be used to define a virtual camera that could insert digital information in the real scene (see Figure 5).

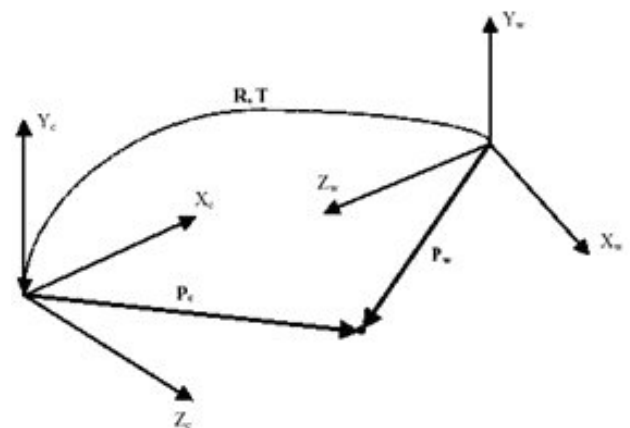


Figure 5. Transformation between system of reference of the world and the camera.

The main aim in this area is to obtain a method to estimate the position, orientation and the three-dimensional movement of a camera from the captured images, using for it the only calibrated camera and without the need to add any type of markers in the scene. The positioning system is based on the images captured by means of a camera and the recognition of those images. In this process, there are two main tasks:

- The initial pose estimation where the system must recognise the scene and compute the camera pose for that frame.
- Once the initial pose has been computed, the system must update the camera pose according to the movements of the real camera. This is the tracking phase.



Figure 6. Image recognition based on the 3D representation of the environment.

The figure above represents the image given by a camera, on which virtual information corresponding to the 3D representation of the environment has been added. For the 3D modelling, the model represents some information of the scenario to be tracked so, it is not necessary a visually exact model, it just has to contain the enough information to help the tracker. The most common method is the use of a CAD model composed of faces and edges (see Figure 6) [14][11]. Other systems use a set of 2D and 3D features points tracked along the video sequence (see Figure 7). A good tracker can get information from the motion of the features and compute the camera pose each frame [21][22][36].

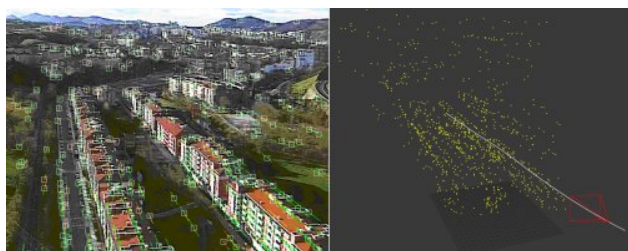


Figure 7. Optical flow and 3D reconstruction of the scene.

5 TRANSMISSION AND REPRODUCTION OF VIDEO/MULTIMEDIA IN MOBILE ENVIRONMENTS

In the last years the concepts of mobile communications and reproduction of multimedia content are being incorporated in the everyday life of our society. The citizen with mobility employs with regularity and familiarity technical terms such as wireless networks IEEE 802.11 (a, b, or g) and UMTS, streaming technology, and mobile devices such as PDA, PocketPC and smartPhone. The development and implementation of mobile augmented reality applications demands that the communication between devices and the transmission of contents of video and multimedia meet the requirements of these types of applications.

5.1 Wireless communications

The communication system must guarantee the mobility of the user and flexibility of use in the spatial/geographic environment of application. For this reason, wireless networks provide the required services; in particular, radio wireless networks provide the optimum environments for the requirements of mobile devices. The following table (see Table 1) shows a comparative analysis for the different technologies used in radio wireless networks [44].

Table 1. Comparative Analysis of Radio Wireless Networks.

	WiMAX 802.16	Wi-Fi 802.11	Mobile-Fi 802.20	UMTS y cdma2000
Rate	124 Mbit/s	11-54 Mbit/s	16 Mbit/s	2 Mbit/s
Range	40-70 km	300 m	20 km	10 km
License	Yes/No	No	Yes	Yes
Advantages	Speed and Range	Speed and Cost	Speed and Mobility	Range and Mobility
Disadvantages	Interferences?	Low Range	High Price	Slow and Expensive

The most widely know technology in wireless networks is Wi-Fi, published under the 802.11 standards. There are implementations of augmented reality developed using this standard which use PDA's as assistant in guiding the user while in the interior of a building [29] and for the visualization of large 3D models [30].

5.2 Services

The introduction of video and multimedia contents in mobile applications could potentially provide a number of services which will provide great interactivity and multimedia base information for the user. Among these services we find the services of video streaming on demand, IP video-conferencing, instant messaging and web services.

The streaming services provide the user access to a collection of archived videos and multimedia content. Among the commercial platforms available, the server Real Helix Universal Mobile is the better suited for such applications since it is optimized to distribute most of the existing formats of multimedia over the different wireless network standards and over a large number of mobile devices [15]. The service of videoconference provides the

users with video and audio communication with an agent of the application which allows implementing requests, consultations and tasks related with the standard experience of the application [34]. The services of instant messaging IM allow the users to exchange information through the use of written communication and the transfer of multimedia files.

6 MOBILE AUGMENTED REALITY APPLICATIONS

In studying the state of the art of mobile augmented reality we need to include as well the analysis of applications developed by the most relevant research groups in the areas of technological applications of augmented reality in mobile devices. The study of prototypes and applications implemented by these research groups will help provide a better global perspective of the field of mobile augmented reality.

The project MARS (Mobile Augmented Reality System) (see Figure 8) [23] developed between 1996 and 1999 represents the first important event in the evolution of systems of mobile augmented reality; this systems includes a portable PC equipped with a graphics accelerator card for 3D mounted on the back of the user, a GPS system, a pair of visualization glasses, a tracking systems, and a wireless connection for the communication of the different components with the PC, where all the data processing is implemented.

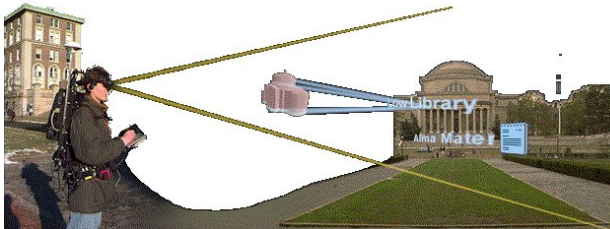


Figure 8. MARS Mobile Augmented Reality System.

The first utilization of a PDA as a device for augmented reality where all the processing was implemented in the same device was presented in the project SignPost (see Figure 9) [35]. It consists of a video-through augmented reality system, where the image of the real world is captured by a camera and the image is augmented with the digital information. It uses a processing system based on the recognition of images using markers, which demands the previous configuration of the environment and lighting requirements to maintain constant light levels.

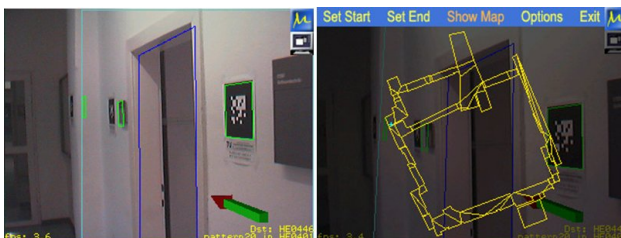


Figure 9. SignPost project.

In the construction sector the project ARARAT (see Figure 10) by VTT Technological Centre in Finland is one of the most complex existing at this moment. The objective of the project is the development of augmented reality solutions for Architecture, Building and Interior design [1]. The project focus on 4 applications: Augmented reality for interior design, mobile augmented reality, augmented reality for product catalogs and augmented mock-ups.



Figure 10. ARARAT project.

7 SCENARIO IN THE CONSTRUCTION SECTOR

Safety at work is one of the main concerns of the construction sector according to the number of accidents and their consequences. Construction environment is very different from other industrial environments, mainly because it is a very changing, fast moving and also uncontrolled environment. Some of the benefits provided by mobile computing technologies, and mobile augmented reality in particular, in the construction industry are the following ones:

- *Mobility and functionality.* Due to the mobility of the workers, mobile computing makes the technology useful in many places where a PC could not be used.
- *Increase productivity,* by automatically providing access to information necessary to perform its task and real-time decision making on the construction site.
- Show information according to the context, depending on the project phase specific information will appear.
- Allow context detection in an uncontrolled environment, improving monitoring the status of all the elements involved in the safety at work place.
- *Low user-machine interaction,* which enables users to keep the attention on the environment. It must not imply for the user much effort of learning.

Here we describe a scenario in which the use of mobile computing solutions, including mobile augmented reality, makes possible to increase efficiency and safety in construction sites. The safety responsible (SR) person is the person in charge of verifying that all the prevention and safety requirements are fulfilled in the work place. This is a high responsibility job, but SR counts only with his/her expertise and the walking visit on-site. Actually, SR collects all the information manually written on a paper by inspection and directly asking to the workers. The SR's work requires freedom of movement as well as reaction capacity through the uncontrolled work place, for this reason heavy devices or elements, which can distract its attention from the environment, are not appropriate for this job.

The proposed scenario shows the SR person equipped with wearable technology moving around the working place (see Figure 11). The SR enters the working place

wearing a PDA, at this moment the system downloads from the server at the work place the information relative to the current phase of development (safety requirements can vary according to the status). SR is equipped with a PDA, an RFID reader, a headset to record results and heard previous inspection status, positioning system to follow SR position, a camera for precision positioning and elements detection by image processing, an interaction wristband for the user interaction with the PDA (gestures recognition), and a head mounted display (HMD) for visual information. SR starts the inspection checking the identity and training skills of the workers. Thanks to each worker is equipped with a RFID tag, SR can identify each worker by means of the RFID reader connected to the PDA. The system provides identification information about the worker (including a picture for visual identification) as well as the training skills and the work to perform according to the skills. Any additional information about the workers could be requested by the SR to the server. On the other hand, every worker must also be equipped with the corresponding safety equipment. Some elements of this equipment depend also on the tasks to be performed by the worker. The system will show SR the required equipment to be worn by each worker and SR will check it visually, interacting with the system using the wristband or through oral commands.

The second phase of the inspection corresponds with the identification of safety elements in the working place. In this phase, while SR is walking around the working place; the system will automatically detect safety elements in the environment and ask SR for checking that they are located in the correct place. SR will be able to confirm the position or ask for help to the system. In this case, the system will show him through the HMD a map with the correct position of the element. Missing elements will be asked to visually inspect by SR. At the end, results and reports of the inspection will be recorded in electronic format (documents and audio notes) and transferred to the server.



Figure 11. Safety at work in the construction sector.

8 CONCLUSIONS

Although augmented reality is still a novel technology it has an enormous potential for its application in the construction sector. Augmented reality is a technology in the area of virtual reality that allows the user to see the real world augmented with additional information created by

the computer. This novel technology complements the user perception and interaction with the real world.

This technology has a high potential to achieve more sustainability, profitability and security in the construction sector. The development of mobile computing solutions is crucial in construction sites. Some of the main benefits provided by mobile augmented reality technology in the construction sector are: Mobility of the user, access to permanently updated information on-site, context detection in an uncontrolled environment improving safety at work place, low user-machine interaction which do not disturb the user main attention, etc.

In this paper, mobile augmented reality is presented as an advanced and innovative tool for the construction sector. Augmented reality systems consist of three main elements: processing, visualization and positioning subsystems. The main requirements for the processing device are processing power, graphic capabilities, connectivity, weight and size. Current PDAs are the devices that better fit these requirements. There is a great variety of visualization devices in the market, light weight and small size are the main requirements for the device in the construction scenario. Tracking of the user position is one of the most critical aspects of an augmented reality system, ideal positioning technology does not exist and the challenge is to select the one that better fits each application. Vision based tracking are high precision and does not require putting any additional infrastructure in the environment. We choose markless vision based tracking in our scenario. Mobility of the user must be guaranteed by the communication system, main technologies for wireless networks are identified. Mobile augmented reality is progressively being introduced in several areas of application, apart from the construction sector, training of workers in industrial processes, marketing tasks, interior design, multimedia museum guides, education and others. In this paper we describe a scenario in which the use of mobile computing solutions makes possible to increase efficiency and safety in construction sites.

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