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Mixed Reality on Mobile Devices

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1. Introduction

The evolution of mobile-computing, location sensing and wireless networking has created a new class of computing: *context-aware computing*. Mobile computing devices such as PDAs have access to information processing and communication capabilities but do not necessarily have any awareness of the context in which they operate. *Context-aware* computing describes the special capability of an information infrastructure to recognize and react to the real-world context. Context here could mean many things, e.g. current physical location, weather conditions etc. The most critical aspects of context are location and identity. Location-aware computing systems respond to user's location, either spontaneously (e.g. warning of nearby hazard) or when activated by user request. Immense potential of this area is already envisaged by the mobile manufactures as many of them have started providing GPS (Global Positioning System) receivers in their mobile devices enabling them location aware too.
One such context-aware technology is mobile mixed reality (MMR). As mentioned, the most important aspect of MMR system is to identify the location and orientation of the user to retrieve the context so as to present him/her with context-aware information thereby enhancing the general awareness of the surrounding. This chapter focuses on different approaches for user-localization to trigger MMR based application. The chapter outlines system architecture, enabling technologies and challenges to make the MMR ubiquitous. Particularly, we are interested in the role of computer vision which can make this imaginative area a reality. This section outlines general definitions and requirements of MMR. Applications (Section 2), System Architecture (3), Challenges (Section 4), Tracking and registration (Section 5) are described in subsequent sections.

1.1 Mixed reality

Context-aware services augment contextual information (virtual data) in the user's view (real data). Depending on what is virtual and what is real we get augmented reality (AR) or augmented virtuality, combinely termed as *mixed reality* (MR). In augmented reality, a user's view of the real world context is augmented with additional virtual information (e.g. textual labels, images, graphical models etc.) whereas in augmented virtuality user (i.e. reality) is completely immersed in the virtual world.

- **Augmented Reality:** Virtual information is augmented on real context.

Source: User Interfaces, Book edited by: Rita Mátrai,
ISBN 978-953-307-084-1, pp. 270, May 2010, INTECH, Croatia, downloaded from SCIYO.COM

- **Augmented Virtuality:** Real information is augmented on virtual context.

A successful mixed reality system must enhance situational awareness and should have the following attributes as encapsulated by (Azuma et al., 2001):

- Runs interactively and in real time
- Combines real and virtual worlds
- Aligns real and virtual objects

These requirements make mixed reality very challenging to build. With ubiquitous availability of high-end mobile devices having access to high-resolution digital cameras, displays, graphical capabilities and broadband connectivity can take this area out of small workspaces giving rise to mobile mixed reality.

1.2 Mobile mixed reality

Mobile mixed reality combines a user's view of real world with location specific information. Such information could be in the form of simple text, image, multimedia or 3D graphics. Augmentation of location specific information in graphical format in the user's view enhances the real world experience beyond normal. Possible applications of mobile mixed reality comprise architectural walkthroughs, tourism, exploration etc. Excellent historical updates on *Handheld Augmented Reality* are maintained at the site (*History of Mobile Augmented Reality at Christian Doppler Laboratory*, 2009).

To enhance situational awareness of a user, MMR systems must run interactively and in real time. Estimating camera position and orientation in global space accurately is the most important to provide such mixed illusion. Lack of accuracy can cause complete failure of coexistence of real and virtual world. However, ubiquitous availability of high-end mobile devices with high-resolution digital cameras, displays, graphical capabilities and broadband connectivity has made this achievable. Such free roaming and mixed realism are feasible with external tracking devices such as GPS and orientation sensors. GPS provide geo-referencing of the location whereas inertial sensors provide instantaneous 3D orientation information of the camera (now onwards will be referred as camera pose). These sensors together provide 6 DoF (degrees of freedom) camera pose at interactive rates. However, accuracy, sensitivity and resolution provided by these sensors is of great concern. In some MMR applications, inadequate accuracy/resolution of these devices may be sufficient whereas in others it is less than desired for true visual merging.

Computer vision based tracking techniques also provide camera pose at slow rates. The pose so obtained is accurate, however, is relative with respect to starting position. These systems need initialization of the starting position to map local pose to global coordinates.

Robust camera pose is then obtained by fusing the data from different sensors such as camera, GPS and inertial devices to achieve global, accurate positioning. Inertial sensors provide fast but inaccurate orientation estimate under large motions whereas camera data is more reliable under medium speeds. Hybrid approaches are normally employed which try to combine strengths of each individual sensor to compensate for others limitation. These systems utilize data of inertial sensors as a rough estimate of the camera pose which vision system refines further. The paper describes overview of hybrid approaches for outdoor mixed reality applications for handheld devices.

One ideal scenario of mobile mixed reality is depicted in Fig. 1, wherein the explorer equipped with mobile and sensing (positioning and orientation) devices is exploring the campus, thereby triggering the location aware services in which graphical model of the building pops up on his display. Such kind of augmentation supplements, enhances,

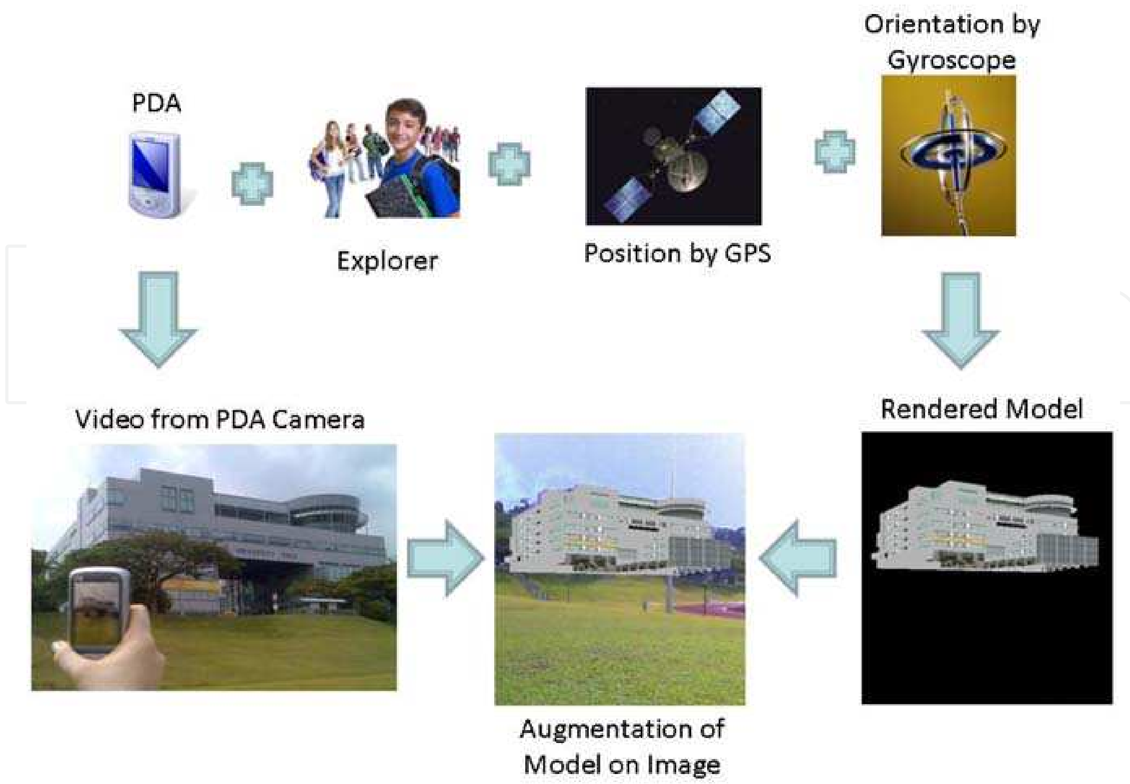


Fig. 1. Mobile mixed reality: Ideal scenario.

improves and can even modify the real information. Examples of location aware computing by text annotations are illustrated in Fig. 2.
Excellent review articles focusing on overall aspects of augmented/mixed reality are published by (Azuma et al., 2001), (Hollerer & Feiner, 2004), Papagiannakis et al. (2008) and (Zhou et al., 2008).

2. Applications of MMR systems

Many applications of mixed reality are envisaged. Here we present some applications, particularly interested in outdoor ones which could get greatly impacted by this technology. Medicine, entertainment, education, assembly and construction are some other indoor application areas of MR which will be greatly benefited.

Fig. 2. Examples of augmented reality wherein live video is annotated with information such as neraby eateries, taxi stand, house on sale etc.

2.1 Tourism

MMR systems for tourism is like traveler is walking with his/her own tourist guide, exploring historic monuments as per his/her interest. In such cases, MMR systems can identify the destination, display information like 3D models of related art or architecture, life and work of architect or architectural changes over the centuries etc. in the form of images, textual information, voice or graphical representation. Such applications are only limited by the extent of content and the capabilities of hardware. Not only architectures, same philosophy can be extended to anything that traveler wishes to explore and something which catches his/her fancy like nearby restaurants, menus served there, approach paths to different locations, their addresses, phone number etc. (Papagiannakis et al., 2005) had build one such example in ancient Pompeii to visualize ancient Roman characters reenacting historical stories.

2.2 Architecture and cultural heritage

MMR systems enable to view past and future information in the context of present visual information available via camera data to the viewer. Past information preserved in e-cultural heritage can be presented to the viewer which otherwise can only see the ruins of them. Architects can benefit by merging their designs (building, bridged etc.) about to be constructed on a particular site for better visualization of the future. (Vlahakis et al., 2002) developed AR guides in the site of ancient Olympia, Greece in order to visualize the non-existing ancient temple edifices.

2.3 Navigation and path finding

MMR systems have potential application as a navigational aid for explorers. While traversing physical buildings or outdoor locations, approach roads behind the occluding buildings or directional annotations etc. can be overlaid on real visual camera data for assistance. (You et al., 2008) have developed treasure hunt game based on navigation and path finding using mixed reality.

2.4 Collaborative working

MMR systems allow multiple geographically distributed workers to collaborate, design and assemble the information according to their locations and knowledge saving time and design cost. (Santos et al., 2007) presents example of collaborative working for designing and reviewing of 3D architectures or automotive parts by dispersed users with mobile mixed reality.

2.5 Maintenance and inspection

MMR system is well suited for situations where direct visibility is not possible and capability to see through solid structures for maintenance and inspection is required. Assistance is provided to maintenance worker via MMR system which overlays the hidden structures such as cable connection within the walls of a building, or pipe layout beneath the road to provide direct visualization of the problem area for inspection before carrying out maintenance task. On-site mobile augmentation for industry professionals was demonstrated by (Makri et al., 2005). (Schall et al., 2007) shows prototype for subsurface infrastructure visualization (e.g. water mains, electricity lines etc.) for urban environment.

Fig. 3. Mobile mixed reality: Interaction of mobile device with backend AR server with wireless coneectivity.

2.6 Military training and combat

MMR systems for military warriors could be very useful as they often face unexplored territories. By projecting maps and view of battle scenes, additional information can be provided to them easily which otherwise could be difficult to communicate. Mission planning information and reconnaissance data obtained/prepared from other sources could be conveyed to update the situation. (Tappert et al., 2001) presented application of wearable computers and augmented reality for military.

3. MMR system architecture

This section presents enabling technologies, basic components and infrastructure requirements for making MMR systems a true reality. As illustrated in Fig. 1 and 3, these technologies are mobile devices, displays, sensors for tracking and registration, modeling/content-creation of environment, wireless communication and interaction techniques. Brief overview of each of them and their current state of the art is summarized below.

3.1 Mobile devices

Numerous mobile devices ranging from PDAs (personal digital assistants) weighing few grams to backpacks weighing few kilograms have been employed by AR researchers for variety of applications.

Fig. 4. Mobile devices.

PDAs were the earliest light-weight mobile devices available for AR research. PDAs are often equipped with color displays, wireless connectivity, and GPS sensors. However, their limited computational capability, like lack of 3D rendering engines and floating-point support makes their use difficult for AR.
High end notebooks in the form of backpacks coupled with HMDs (head mounted displays) do not have computational constraint as that of PDAs but weight and size makes them highly inconvinient posing ergonomic issues.
Tablet PC, a notebook size mobile computer with touch screen offers a more convenient way of interaction with no ergonomic issues associated with backpacks and equally computationally rich as compared to PDAs.
Ultra mobile PCs (UMPCs) also provide all the computational capabilities of backpacks and mobility of PDAs without much of ergonomic constraints. Their small form factors compared to tablet-PC makes them the obvious choice for outdoor applications. However, interaction is by more conventional keyboards.

3.2 Displays

There are numerous approaches to present visual information to mobile user with variety of display technologies, such as hand-held, wrist-worn or head-worn displays, projection on arbitrary surface etc. Displays used in MMR systems can be categorized into two: optical see-through displays with which the user views the real world directly and video see-through displays with which the user observes the real world in a video image as acquired from a mounted camera. Issues associated with them are field of view, cost, perception, latency, human factors etc.

3.3 Data storage

In MMR systems, client needs to connect to multiple distributed data servers in order to obtain information relevant to the current environment and situation. Such systems require georeferenced data to present world-registered overlays. Typical data needed by client could be geometric models of the environment, annotation material as well as conceptual information that allows the client to make decisions about the best ways to present the data. Unified framework is needed to express, maintain, deliver, store and present such meta-knowledge. (Schmalstieg et al., 2007) presented one possible model and a family of techniques to address these needs.

For interactive applications, as is the case with MMR systems, as much as possible the data to be needed should be cached on the local client computer to take care of unreliable connectivity. This raises the question of how to upload and page in information about new environments that the mobile user is ready to explore. Such information can be loaded preemptively from distributed databases in batches of relative geographical closure.

3.4 Networking

Issues associated with wireless networking such as latency, limited bandwidth, bandwidth fluctuations and availability directly impact the performance and quality of MMR systems based applications. Practical mobile AR systems demand low latency and sufficient data rate as and when user wants. Different types of networks have been tested for applications demanding different coverage areas. The wireless wide area networks (WWANs) are ideal for MMR systems that need to support large-scale mobility e.g. location-based services. Wireless local area networks (WLANs) typically support much higher data rates and lower latency than WWANs but limited by mobility. Depending on the applications, appropriate network can be used by MMR systems.

3.5 Modeling of the environment

Geometric models of the physical environment in which MMR systems to be deployed are often needed. For example,

- to augment user's view by overlaying hidden/underground structures or
- for detecting occlusion with respect to user's point of view or
- for model-based vision tracking approaches etc.

Creating 3D model of large environments is a research challenge. Depending on the task at hand, models could be photorealistic or simple 3D point clouds. Complexity of the problem increases depending on the details that need to be modeled. For example, complete modeling of large urban area, down to the level of water pipes and electric circuits in building walls is quiet complex and time consuming. Fully automatic, semiautomatic and manual modeling techniques are often employed depending on the required accuracy. Bigger challenge lies in maintaining these geometric models as real environments are dynamic and models also need to be dynamically updated to reflect changes in the real environments like construction or destruction of any structure etc.

3.6 User Interfaces (UI)

Effective and efficient user interaction in MMR systems is another open research area. The desktop UI metaphor is not suitable for mobile and wearable computing as it places unreasonable attention demands of mobile users as it is interacting with mobile world. Providing user interfaces for MMR system applications is challenging as care had to be taken not to divide the user attention between physical world and interaction methodology.
Mobile UIs should try to minimize encumbrance caused by UI devices. Ultimate aim is to have a free-to-walk, eyes-free and hands-free UI with miniature computing devices which are easy to carry. This ideal UI cannot be accomplished with current mobile computing and UI technology. Some devices, e.g. auditory UIs, nicely meet the size and ergonomic constraints of mobility. However, standalone audio UI cannot offer the best possible solution for every situation and more general audio-visual-touch based UI need to be developed.

3.7 User tracking/localization

Apart from above mentioned technological challenges, the single most important technological challenge of MMR systems is user localization in outdoor environments. In small, controlled indoor places user/camera tracking has been successfully implemented with sufficient accuracy, low latency and high update rates by (Klein & Murray, 2007). Doing the same in general mobile setting is much more challenging as one cannot rely on any kind of tracking infrastructure in the environment. In Section 5 we explore technological advancements in the area of tracking and registration in general environments.

3.8 Software architecture

AR software system architecture should be plug-in type to allow prototyping of different AR components separately and heterogeneously as opposed to single monolithic piece of software. That way different components can be updated independently as per the technological advancements in that particular area without affecting other components.

4. Challenges to MMR systems

In spite of potential foreseeable applications of MMR system, the research has been exclusively confined to prototype applications. Technology is not yet ripe for commercialization as it is exposed to wide range of operating conditions. Apart from that, technological constraints as explained below do not make it viable at present.

- **Resource poor**: While mobile devices have outgrown over last years, with increased reliability in communication, computational power, storage, battery life etc., however they are still small brothers of desktop computers. Moreover, they should be light weight, small, powerful and have longer battery life. High end processors have high power consumption which present challenge for their deployment in mobile devices. Ruggedness is also required as sensitive electronic equipment could get damaged easily.
- **Graphical capabilities**: Special effects seamlessly merge computer generated data with real images. Such efforts are very time consuming and do carefully handcrafted integration of the virtual data into real footage. In MMR systems, rendering needs to be performed in real time, also decision of what and where to merge the virtual data needs to be determined automatically and on the fly. Making the visuals as informative and realistic as possible, rendering with the correct lighting to provide a seamless experience is an open-ended challenge. Absence of dedicated 3D processing units in mobile devices is the limiting factor for rich content creation. Such capabilities are now available on devices such as UMPCs.
- **Communication**: Ever increasing bandwidth has spurred new audiovisual networked media applications and MMR systems can build on them. Efforts need to be put in to standardize accessing mechanism which retrieves data from databases and exchanging them reliably with mobile client. Content adaptation, sharing and personalized interfaces between users and databases need to be addressed.
- **Content creation**: Depending on the tracking technology, AR systems need to have access to model of the environment that they are suppose to work in and creating accurate modeling could be a challenging task. Database of the environment paired with accessing it with location needs to be created and maintained. For reliable and accurate service, maintaining the content up to date is also time consuming.

- **Tracking and Registration**: Tracking deals with localizing the user in outdoor environment so as to trigger other location specific queries. In registration, the desired information is accessed, seamlessly merged with camera data and ultimately presented to the client. Localizing with sub-meter accuracy for seamless integration, single sensor such as camera, GPS or gyroscope alone is not sufficient. The current trend shows the combination of them can provide more reliable results than individual sensor. Tracking in unprepared environments is still elusive. This chapter looks at the current technologies pertaining to tracking, registration, sensor fusion and hybrid techniques in next section.
- **Social Acceptance**: Wearable MMR systems must be as unencumbered as possible. Contrary, current MMR systems are bulky and intrusive. Social acceptance of these systems is very important for their successful deployment.

5. Tracking and registration for MMR

MMR systems require very accurate position and orientation information of the user camera in order to align virtual information with the physical objects. In absence of correct localization, merging of virtual and physical objects will be out of sync and seamless integration will be completely lost. As observed by (Zhou et al., 2008), over last couple of years largest group of papers have been published on tracking as it is one of the fundamental enabling technologies for AR. Still, the problem is unsolved with many fertile areas for research. This section reviews different methodologies that have been proposed for estimating/tracking camera pose.

An important criterion of these approaches is how much tracking devices are present on the user's body and in the environment. In truly outdoor explorations, the goal is to wear as little equipment as possible without engineering the environment. GPS is ideal for such applications, although environment is prepared in this case on a global scale rather than on local scale by satellite constellation around the earth. Vision based approaches require some knowledge about the environment in the form of 3D model or training image database for successful tracking and registration.

General requirements for tracking can be summarized as:

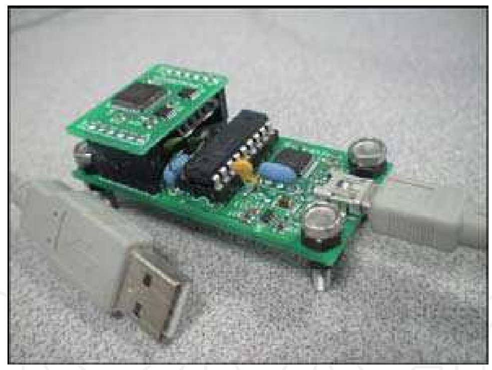
- no engineering of the environment
- less user preparation
- highly accurate and robust
- driftless and
- instantaneous

This section presents different camera pose estimation approaches. Generally, tracking devices used must be light in weight and insensitive to any kind of external disturbances. They should have fairly wide operating range under varying environments. Currently there does not exist a perfect tracking solution for all scenarios. Different approaches were developed keeping in mind some specific application needs and may make them unsuitable for other scenarios. Earlier tracking was purely sensor based, however with ubiquitous availability of video capture capability, camera data is also used for tracking and registration purposes.

5.1 Tracking with position and orientation sensors

Position tracking with GPS receiver is a natural choice for outdoor environments since it is globally accessible. Only constraint is, at least signals from four satellites should be visible at

HOLUX M-1000 GPS position receiver



OS5000-S 3D Rotational sensor

Fig. 5. Position and orientation sensors to estimate user pose.

user location. They generally provide accuracy between 5-10 meters in urban environments depending on the satellite connection. Position accuracy can be increased with *assisted*-GPS depending on the other technologies available in that country/area. GPS receivers are getting inexpensive and finding their places in high-end consumer devices such as PDAs and mobile phones.

Data obtained from gyroscopes and accelerometers provide absolute, but rough estimate of orientation and normally used for initialization. However, they suffer from drift and jittering effects over time. As accelerometer data is integrated twice with respect to time to recover correct angle. Small errors in them lead to rapidly increasing errors in the resulting orientation estimates causing large drifts. In spite of using Kalman Filter to stabilize the output, jittering effects are still present due to external interference. Typical GPS and gyroscope devices are illustrated in Fig. 5.

First outdoor MMR system was created by (Feiner et al., 1997) with GPS and orientation sensors. Approach presented by (Azuma et al., 1999a) tried to stabilize the sensitivity of these sensors in outdoor AR environments. Similar approach was used by (Schmeil & Broll, 2006) to build outdoor companion. Approach presented by (Pustka & Klinker, 2008) employs mobile and stationary sensors apart from gyroscope to increase the robustness of overall localization.

These inertial sensor based tracking systems are analogous to open loop systems with errors and no mechanism to estimate and correct them.

5.2 Marker tracking

A common approach for AR applications is to make use of fiducials, easily recognizable markers. Markers are of different types (see Fig. 6 for their illustration):

- infrared (IR) markers such as passive (made from retroreflective material) or active (infrared LEDs) which are tracked by IR cameras
- black and white (B/W) and grayscale visual markers tracked via optical cameras

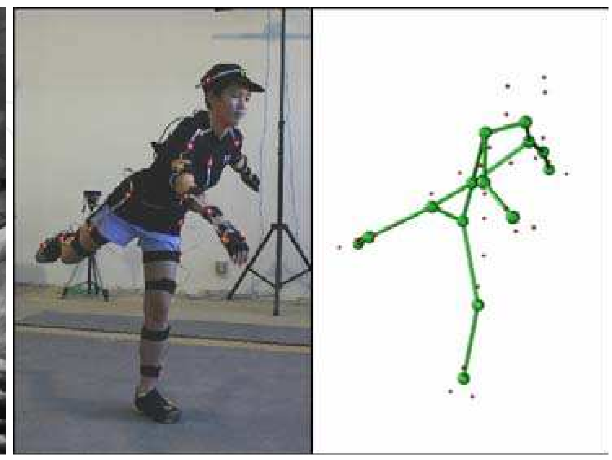
5.2.1 Infrared markers

Both active and passive infrared markers reflect light in narrow band which is captured by IR cameras tuned to that narrow band thereby completely blocking out the visual spectrum providing clean, noise free binary images for tracking. Due to their robustness, they have been used in commercially available tracking systems and real tracking applications.

B/W Marker

Passive retro-reflective markers

General grayscale marker



Active infrared LED markers

Fig. 6. Different Markers.

Nonavailability of IR cameras in consumer mobile devices and engineering of the environment with markers makes them unsuitable for outdoor AR applications.

5.2.2 Visual markers

Black and white visual markers with square frame, proposed by (Kato & Billinghurst, 1999), are the most popular visual markers used for indoor AR applications. They can be tracked using freely available ARToolkit systems with normal inexpensive cameras. Their peculiar structure makes them easily identifiable in cluttered scenes. Vision based techniques have been developed by (Lowe, 2004), Ozuysal et al. (2007) to track highly textured general grayscale marker surfaces. In absence of square frame, these approaches rely on natural features present in the image to track the general surfaces. Recently, (Wagner et al., 2008) ported these approaches on mobile phones. Both B/W and grayscale marker based tracking provides very robust and drift free estimation of the camera pose.
Even though visual marker tracking approaches are cheap and robust, applicability of them to outdoor AR is infeasible as one has to prepare the environments.

5.3 Visual markerless tracking

Availability of low-cost video capture capabilities in recent years has spurred the use of video camera as a means for tracking position and orientation of a user. Model based vision approaches are a viable option for 6 DoF pose estimation as observed by (Klinker, 2000). These vision techniques use natural features such as fiducial points/corners, lines, edges present in video data to track camera pose. Frame by frame tracking of video data provides closed loop tracking which is helpful for removing mismatches and drifts associated with inertial sensors. However, these model-based vision techniques need accurate model of the environment with known landmarks for object recognition and automatic registration. Commercially available match-moving software tracks feature points in the image sequence, leading to relative, rather than absolute tracking solution. Such systems need manual initialization of the data, prone to drifting due to tracking errors and are computationally heavy. (Lepetit & Fua, 2005) presents excellent review of model based vision tracking approaches.

Future vision approaches could be based on image databases in which images are tagged by position and orientation with respect to some common global coordinates. Such systems use content-based image retrieval (CBIR) techniques to extract the reference image with respect to current view query image. Feature based tracking in then employed between current query image and retrieved reference image to estimate camera pose. (Ta et al., 2009) have proposed one such prototype on mobile phones. Such approaches provide automatic identification and tracking providing complete 6 DoF camera pose without manual initialization.

Another approach could be similar to that of SLAM (simultaneous localization and mapping), primarily developed for robot navigation. As robot navigates in unexplored territories, SLAM constructs models of the surrounding on the fly without any prior knowledge of the world. PTAM (parallel tracking and mapping) approach, similar to SLAM, has been proposed by (Klein & Murray, 2007) for small AR workspaces. However, scaling it to general and big AR spaces is very challenging.

In summary, pure vision based algorithms still lack robustness and requires high amount of computational power making them not yet viable option for real-time tracking. Currently, hybrid techniques combining vision based tracking and other sensing technologies show the biggest promise.

5.4 Hybrid techniques

No single technology/sensor provides absolute 6 DoF tracking in unprepared outdoor environments. Comparison of GPS, gyroscope and camera based tracking with respect to requirements listed in Section 5 is presented in Table 1. Table reveal shortcomings of each sensor used for tracking with no clear winner.

Sensor	Engineering of the Environment	User Preparation	Tracking Time	Tracking Errors	Tracking Drifts
GPS	Yes	No	Few miliseconds	Large	Driftless
Gyroscope	No	No	Few miliseconds	Medium	Large
Camera	Depends	Depends	Few miliseconds to few seconds	Small	Medium

Table 1. Comparison of Different Tracking Devices

To overcome the practical limitations of these different modalities in the context of mobile clients, hybrid approaches are normally employed for estimating the camera pose. These hybrid approaches generally employ vision based closed loop tracking fused with open loop inertial sensors to estimate position and orientation for general AR scenario. They use their complementary nature to compensate for each others limitations. Vision based techniques have low tracking errors, but drastic motions often leads to tracking failures. However, inertial sensors are fast and robust under rapid motions. Optimum solution is to use inertial sensors for initialization as they provide absolute registration while intermediate tracking is carried out by vision tracking technique.

Over last couple of years variety of hybrid approaches have been presented in the literature. These approaches mainly differ by:

- which sensors are used for fusion,
- how fusion is accomplished,
- how many degrees of camera pose are estimated and
- which vision technique is employed for tracking natural features.

Table 2 outlines comparison of hybrid approaches presented in literature for outdoor augmented reality applications based on above criterions. Many flavours have been proposed with none of them actually satisfying criterions listed by (Azuma et al., 2001) for practical MMR systems. Main difficulties in coming up with general purpose solution are:

- Vision techniques are sensitive to occlusion and outliers
- Gyroscopes are prone to drifts and often need calibration
- Poor resolution of GPS receivers in urban environments etc.

Publication	GPS Sensor	Orientation Sensor	DoF	Vision Algorithm
(You et al., 1999)	-	✓	3	Point Tracking
(Azuma et al., 1999b)	✓	✓	3/5/6	Point Tracking
(Satoh et al., 2001)	-	✓	3	Point Tracking
(Behringer et al., 2002)	✓	✓	6	Point/Edge Tracking
(Jiang et al., 2004)	✓	✓	6	Line Tracking
(Hu & Uchimura, 2006)	✓	✓	6	Model Tracking
(Reitmayr & Drummond, 2006)	-	✓	6	Edge Tracking
(Honkamaa et al., 2007)	✓	-	6	Point Tracking
(Zhou et al., 2009)	✓	✓	6	Silhouette Tracking

Table 2. Hybrid Tracking Techniques for Outdoor AR

6. Summary

This chapter has presented brief overview of mixed reality systems adapted to mobile devices for outdoor clients. The chapter presented potential applications of MMR systems, challenges faced by them and enabling technologies that can make MMR systems practicable. Overview of these enabling technologies was also presented. In particular, the most fundamental and the core enabling technology for MMR is tracking and registration. Research carried out over last couple of years and current state of the art was emphasized in this chapter.

Truly deployable MMR systems are possible by convergence of following independent technologies:

- User localization and tracking
- Location aware computing
- Geospatial databases and data mining
- Human interaction with geospatial information
- High-quality geospatial information
- Hardware support (displays, sensors etc.)

Technological advances in these areas have the potential to make this imaginative future *a reality*. Challenge lies in convergence, coexistence and seamless integration of these technologies to deploy a truly practical MMR system.

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User Interfaces

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Designing user interfaces nowadays is indispensably important. A well-designed user interface promotes users to complete their everyday tasks in a great extent, particularly users with special needs. Numerous guidelines have already been developed for designing user interfaces but because of the technical development, new challenges appear continuously, various ways of information seeking, publication and transmit evolve. Computers and mobile devices have roles in all walks of life such as in a simple search of the web, or using professional applications or in distance communication between hearing impaired people. It is important that users can apply the interface easily and the technical parts do not distract their attention from their work. Proper design of user interface can prevent users from several inconveniences, for which this book is a great help.