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A Survey on Augmented Reality Challenges and Tracking

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Abstract:

This survey paper presents a classification of different challenges and tracking techniques in the field of augmented reality. The challenges in augmented reality are categorized into performance challenges, alignment challenges, interaction challenges, mobility/portability challenges and visualization challenges. Augmented reality tracking techniques are mainly divided into sensor-based tracking, vision-based tracking and hybrid tracking. The sensor-based tracking is further divided into optical tracking, magnetic tracking, acoustic tracking, inertial tracking or any combination of these to form hybrid sensors tracking. Similarly, the vision-based tracking is divided into marker-based tracking and markerless tracking. Each tracking technique has its advantages and limitations. Hybrid tracking provides a robust and accurate tracking but it involves financial and tehnical difficulties.

Keywords:

Augmented Reality, Tracking, Challenges

Goal

The goal of this survey paper is to review current state-of-the-art of tacking techniques and challenges in augmented reality. This survey is more up-to-date, which will be helpful for anyone starting a research in this area. Different challenges in the field of augmented reality are elaborated and a classification of tracking is discussed in detail.

1. Introduction

1.1 DEFINITION

Augmented reality (AR) is a technology through which the view of real world environment is augmented by computer-generated elements or objects. AR is related to a mediated reality, in which a view of reality is modified using a computer system. By contrast, virtual reality replaces the real world with a simulated one

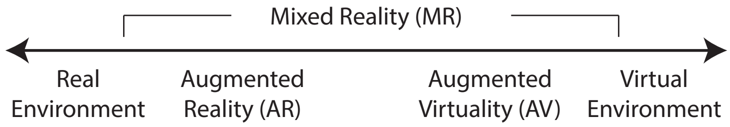

Figure 1. Reality-Virtuality Continuum (Milgram et al., 1994)

(*Milgram et al., 1995*). Augmented reality lies between the virtual world and the real world as defined in the Reality – Virtuality Continuum as shown in Figure 1 (*Milgram et al., 1994*).

Figure 1 demonstrates the difference among virtual environment (where all objects are virtual), augmented virtuality (where virtual environment is augmented by real object(s)), real environment (real world objects) and augmented reality (real world objects are augmented by virtual ones).

Augmented reality allows us to see computer-generated virtual images that exactly overlay real objects in real time. Augmented reality is a direct or an indirect view of real world environment which are augmented by computer-generated input(s). In augmented reality, the user interacts with the real world in a natural way. The difference between augmented reality and virtual reality is that in virtual reality (VR), the user is entirely immersed in an *artificial* world whereas in augmented reality, a computer is used to add information to the *real* world objects. In augmented reality, the computer is used to explore information related to the real world and at the same time the user interacts with computer-generated virtual objects. In contrast, the user of virtual reality completely throws himself into an artificial world (*Azuma, 1997*).

Benford et al (*Benford et al. 1998*) differentiate augmented reality from virtual reality and telepresence as shown in Figure 2.

Ronald Azuma described in his survey paper that augmented reality has the following three characteristics (*Azuma, 1997*):

- augmented reality will combine real and virtual objects in a real environment
- interactive in real time
- registered real and virtual objects in 3D

These three characteristics provide a proper definition of augmented reality.

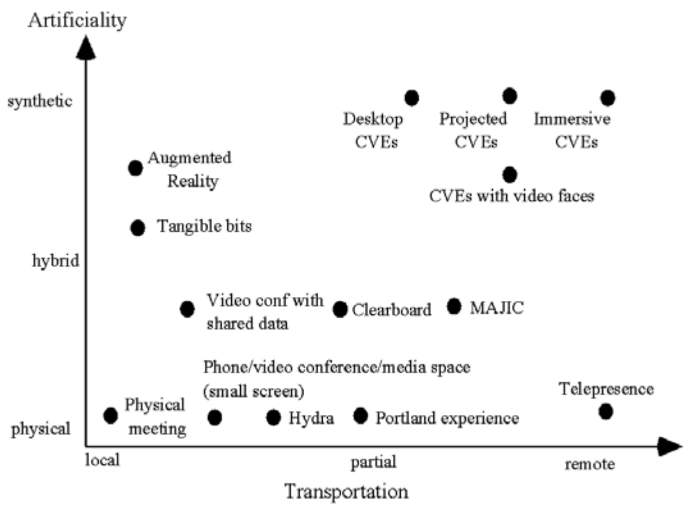

Figure 2. Detailed classification of shared spaces according to the dimensions of transportation and artificiality (Benford et al., 1998)

The combination of virtual and real world in AR is accomplished through the Head-Mounted Device (HMD) and trackers. When a user looks around, certain features in the video images captured by the camera are detected to track the camera's position and orientation relative to the objects in the real world. Graphic images generated with this information are rendered on the HMD (*Azuma, 1997*). A typical wearable computer may be composed of a computer processor with a battery mounted on a belt or a backpack, a head mounted display (HMD), a wireless communications hardware and an input device such as a touchpad or a chording keyboard or voice input capabilities. A wearable computer enables mobility and promises exciting applications with augmented reality. A prominent example is Columbia's "Touring Machine", which assists the user in locating places and allowing the user to query information about items of interest, like campus buildings and library (*Feiner et al., 1997*).

A typical AR system consists of tracking, sensing, display and interaction as shown in Figure 3 (*Krevelen and Poelman, 2010*). The key challenges for developing an augmented reality system are registration and tracking, which deals between computer-generated and real world objects. When a user changes his/her position/viewpoints, virtual objects must remain aligned with the position and orientation of real objects. Registration is the proper alignment of virtual objects to the real world objects (*Hoff and Nguyen, 1996*) (*Azuma, 1997*). Tracking is another main issue for outdoor AR (*Azuma, 1999*). Accurate tracking system is required for AR system because even a small tracking error may cause a clear misalignment between virtual and real objects (*Wang and Dunston, 2007*). This survey paper will review augmented reality tracking techniques in detail.

The main components of augmented reality are displays, registration systems, trackers and graphics hardware and software. There are still multiple challenges that need to be overcome. Tracking has been the most popular research area in augmented reality (*Zhou et al., 2008*). This survey is therefore mainly concerned with the challenges of augmented reality and tracking techniques.

1.2 IMPORTANCE AND APPLICATIONS

Augmented Reality is a technology that superimposes a layer of information to the user's view of the real world and has a great importance. Different researchers are trying to find all possible application areas of augmented reality to get maximum benefits.

Azuma discussed various application areas of augmented reality such as medicine, manufacturing and repair, annotation and visualization, robot path planning, entertainment and military aircraft in his survey paper on AR (*Azuma, 1997*). In the early days, augmented reality was only used in medicine, military and industry. Currently, it is used in almost every field of life e.g games, entertainment, direction finding, identifying object, location based communication, consumer design, training, education etc.

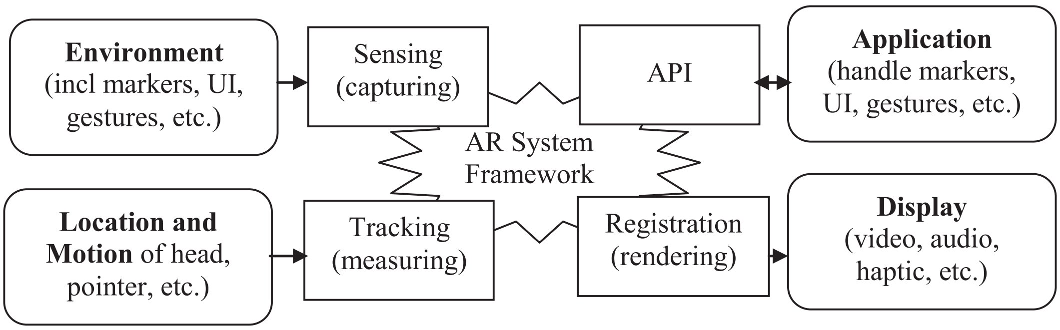

Figure 3. Typical AR System Framework Tasks (Krevelen and Poelman, 2010)

Other applications of augmented reality include visual odometry, aircraft/drone localization and pilot assistance. In the pilot helmet the information about aircraft position, runway, and military targets may be easily displayed. Similarly, augmented reality may also be used in other domains as energy monitoring, robotics, urbanism, architecture and defense (*Dame and Marchand, 2010*). AR can also be used to improve industrial performance (*Scheer and Muller, 2010*).

Krevelen and Poelman also discussed detailed applications of AR (*Krevelen and Poelman, 2010*). They mainly categorize the applications into personal information systems (personal assistance and advertisement, navigation, touring), industrial & military applications (design, assembly, maintenance, combat and simulation), medical applications, entertainment (sports broadcasting, games, movies), office applications and education & training (*Krevelen and Poelman, 2010*). In short the applications of augmented reality are endless.

Survey Layout

A brief history of augmented reality will be discussed in the next section. Section 3 will discuss the different challenges in the field of augmented reality. Detailed discussion of augmented reality tracking is presented in section 4. Section 5 will provide the issues in tracking techniques. The discussion will be in section 6 and the last section is the conclusion of this survey.

2. Brief History of Augmented Reality

The history of augmented reality is as long as that of a digital computer. But the concept of augmented reality was formally introduced in late 1960's, after the invention of the first Head Mounted Display (HMD) by Ivan Sutherland (pioneer of computer graphics), which was then used as viewing device for augmented reality(*Sutherland, 1968*). The head mounted display uses optical see-through display technique. In 1975, Myron Krueger created Videoplace, through which the users interact with virtual objects (*Krueger, 1991*).

The term augmented reality was coined by Tom Caudell and David Mizell in 1990 (*Caudell and Mizell, 1992*). The first special issue of ACM in the field of augmented reality was published in 1993 that broadly highlighted the augmented reality field (Communications of the ACM - Special issue on computer augmented environments: back to the real, Volume 36 Issue 7, July 1993). In this issue KARMA was the first research paper which was completely focused on augmented reality system(*Feiner et al., 1993*). In the same year, Rosenberg developed virtual fixtures (the first functioning augmented reality system), which is an overlay of abstract sensory information in order to improve the telemanipulation tasks(*Rosenberg, 1993*). Rekimoto introduced 2D matrix marker that allows camera tracking with 6DOF (*Rekimoto, 1996*).

A few years later Mann developed first GPS-based outdoor system. This system provides navigational assistance to the visually impaired people through spatial audio overlays (*Mann, 1997*). Feiner et al. created a prototype of MARS (Mobile Augmented Reality System) that registers 3D graphical tour guide information with buildings and objects the visitor sees (*Feiner et al., 1997*). The first survey paper on augmented reality was written by Azuma, that provides comprehensive report about the topic (*Azuma, 1997*). In 1998, Rasker et al introduced spatial augmented reality. In spatial augmented reality, virtual objects are rendered directly within or on the user's physical space(*Raskar et al., 1998*). ARToolKit was developed by Hirokazu Kato in HIT lab, which provides help in building quick augmented reality systems. ARToolKit is a pose tracking library with 6DOF, using square fiducial markers with template-based approach for object recognition (*Kato and Billinghurst, 1999*).

Thomas et al. developed the first outdoor mobile augmented reality game, ARQuake in 2000 (*Thomas et al., 2000*). Fruend et al presented an AR-PDA, which is a small wireless augmented reality system. Its basic idea include the augmentation of real camera images with virtual objects (*Fruend et al., 2001*). In 2003, Kalkusch et al. presented a mobile augmented reality system that guides user through an unfamiliar building to a particular destination (*Kalkusch et al., 2002*). Wagner and Schmalstieg presented an indoor augmented reality guidance system working autonomously on a PDA (*Wagner and Schmalstieg, 2003*).

In 2004, Möhring et al. developed a system for tracking 3D markers using a mobile phone. This is the first video see-through augmented reality on a cell-phone. It works on the detection and differentiation of different 3D markers and correct registration of 3D graphics in a live video stream (*Möhring et al., 2004*). Reitmayr and Drummond developed hybrid tracking system for outdoor augmented reality in urban environments using model-based tracking that enabled accurate, real-time overlays on a handheld device (*Reitmayr and Drummond, 2006*). Klein and Murray launched a robust real-time tracking and mapping in parallel in small workspaces with a monocular camera (*Klein and Murray, 2007*). Wikitude AR Travel Guide was introduced in 2008 with android phone. In the same year, Wagner et al. developed the first real-time 6DOF implementation of natural feature tracking on mobile phones (*Wagner et al., 2008*).

In 2009, Morrison et al. introduced MapLens, that used magic lens on a paper map to give a mobile augmented reality map (*Morrison et al., 2009*). In recent years augmented reality has gained more attention of the researchers. This will help common user to get benefits of augmented reality applications. Nowadays, a large number of augmented reality systems and applications are being developed. After the launching of iPhone and iPad, the field of mobile augmented reality has started new revolution.

3. Challenges in Augmented Reality

A considerable amount of work has been made in the area of augmented reality but there are still several challenges need to be overcome or improved. These challenges can be categorized as performance challenges, alignment challenges, interaction challenges, mobility/portability challenges and visualization challenges as shown in Figure 4. These challenges are discussed as below:

3.1 PERFORMANCE CHALLENGES

Performance challenges are concerned with real time processing, responding and evolving with the change of real world environment. Real time processing can slow down the performance of augmented reality applications. Performance issue is a major concern of mobile AR (*Yang and Maurer, 2010*). Even for simple markers, visual recognition is computationally very expensive (*Wagner and Schmalstieg, 2009a*). The 3D models for a mobile AR implementation should have reduced complexity to achieve an acceptable memory footprint (*Wagner and Schmalstieg, 2009b*).

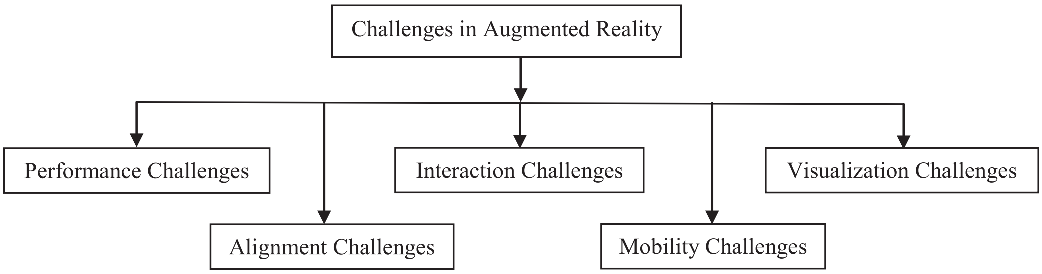

Figure 4. Categorization of Challenges in Augmented Reality

3.2 ALIGNMENT CHALLENGES

Alignment is concerned with a proper placement of a virtual object to the real world objects. Incorrect alignment may cause problems such as incorrect rendering of information to the real world. This misalignment is more severe in medical applications. Alignment challenges include registration problems, which is the most basic problem in AR (*Azuma, 1997*). Registration is the proper alignment of virtual objects to the real world objects (*Hoff and Nguyen, 1996*) (*Azuma, 1997*). Tracking is another important issue in outdoor AR (*Azuma, 1999*). Accurate tracking system is required for AR system because even a small tracking error may cause a clear misalignment between virtual and real objects (*Wang and Dunston, 2007*). Calibration is also required for augmented reality system (*Fuhrmann et al., 2001*).

3.3 INTERACTION CHALLENGES

Interaction challenges refer to the interaction of users with virtual and real objects at the same time. Interaction uses various interfaces that may be acoustic, haptic, tangible, gaze, or text-based through which the user interacts with virtual objects. The interaction with virtual objects may cause various interaction problems such as in a football or cricket match as shown in Figure 5; the virtual line only appears to the television users. Ulhaas and Schmalstieg introduced a finger tracker which is based on a special glove with retro-reflective markers (Ulhaas and Schmalstieg, 2001). Interaction Techniques and User Interfaces are still problems which need to be solved (Zhou et al., 2008).

Figure 5. First-Down Line (Howstuffworks, 2012)

3.4 MOBILITY CHALLENGES

These challenges are concerned with the portability of augmented reality systems. It should be small and light so it can be used anywhere. The best augmented reality system will be portable outside a controlled environment (*Azuma, 1997*). Schmalstieg et al developed a wearable system which needs to carry a whole set of heavy equipment for a long time (*Schmalstieg et al., 2000*).

3.5 VISUALIZATION CHALLENGES

Visualization challenges include display issues (HMD based or monitor-based), contrast, resolution, brightness, and field of view. The illumination of the virtual object and real world object is required to be the same (*Fournier, 1994*) (*Drettakis et al., 1997*). Another visualization issue is occlusion, i.e. a process which determines which surface or its parts are not visible from a certain view-point (*Wang and Dunston, 2007*) (*Fuhrmann et al., 1999*). For a realistic view, correct handling of occlusion between virtual objects and real world objects in the scene is important (*Fischer et al., 2003*). Lepetit and Berger presented a semi-automatic solution for occlusion in AR systems (*Lepetit and Berger, 2000*).

Apart from these challenges, the issues of privacy, social and ethnical acceptance are also worth considering when thinking about the growth of augmented reality in different applications.

4. Tracking in Augmented Reality

Accurate registration and tracking between computer-generated objects and real world objects are crucial challenges for developing an augmented reality application. When a user moves his/her position or viewpoints, the virtual objects must remain aligned with the position and orientation of real objects. The alignment of virtual objects and real world objects depends on accurate tracking of the viewing pose, relative to the real environment and the annotated objects (*Neumann and Majoros, 1998*). In AR, it is necessary to sense the environment and track the viewer movement with 6DOF.

Zhou et al (2008) categorized the augmented reality tracking techniques in sensor-based, vision-based, and hybrid tracking techniques (*Zhou et al., 2008*). Sensor-based tracking techniques are based on sensors that are placed in an environment. Vision-based tracking techniques used image information to track the position and orientation of a camera (*Yang et al., 2008*). Azuma et al (1998) described that none of the existing techniques gives a complete solution for outdoor tracking, so hybrid tracking techniques have been developed which combine several technologies (*Azuma et al., 1998*). The classification of AR tracking is shown in Figure 6.

This section provides a review of these tracking techniques in detail.

4.1 SENSOR-BASED TRACKING

Active sensors are used in sensor-based tracking, which are then used to track the position of camera movement. Sensors may be optical, magnetic, inertial, acoustic or ultrasonic (*Yang et al., 2008*). Each sensor has its own advantages and disadvantages. The selection of a sensor depends on different factors including accuracy, calibration, cost, environmental, temperature and pressure, range and resolution. Rolland et al (2001) presented a detailed review of sensor based tracking (*Rolland et al., 2001*).

4.1.1 OPTICAL TRACKING

In optical tracking system, a video camera is used that may be visible light or infrared type. With the help of a single video camera, 2D tracking of an object is possible. For 3D tracking with 6DOF, at least two video cameras are required. These cameras are placed at different angles to view the target object. The position and the orientation of each camera is calculated using the epipolar geometry between two planes of the images (*Sehatullah, 2011*). Optical tracking is inexpensive and provides more accurate and robust tracking in controlled environment, whereas these sensors are sensitive to optical noise, occlusion and require heavy computation that makes the system relatively slow (*Yang et al., 2008*). Similarly, optical tracking systems are very sensitive to lighting conditions and tracking is difficult while multiple similar objects in the scene.

4.1.2 MAGNETIC TRACKING

In a magnetic tracking system, numerous variations of magnetic fields are used. When electric current is passed through coils (in the source), as a result magnetic field is created (See Figure 7). The position and orientation of receivers are measured relative to the source. Magnetic tracking system is cheaper to implement but less accurate than optical systems. The magnetic field is also disturbed in the presence of electronic devices nearby (*Sehatullah, 2011*). Magnetic tracking sensors suffer in terms of jitter, accuracy degrades with distance and sensitive to electromagnetic noise (*Yang et al., 2008*).

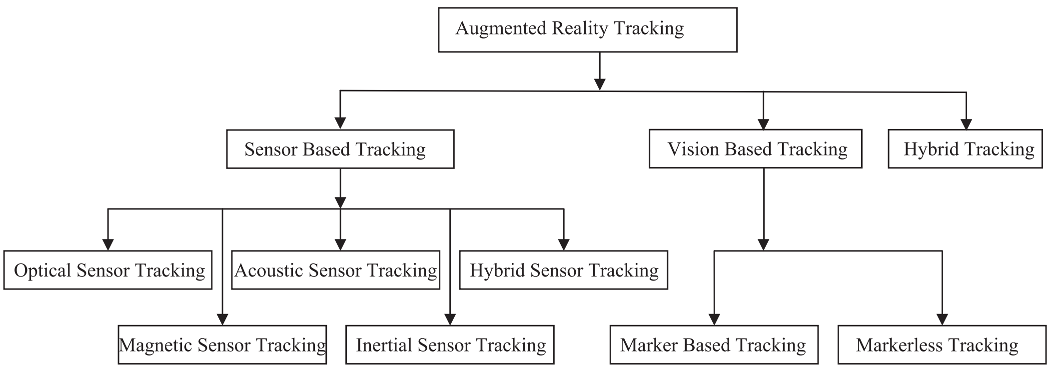

Figure 6: Classification of AR Tracking

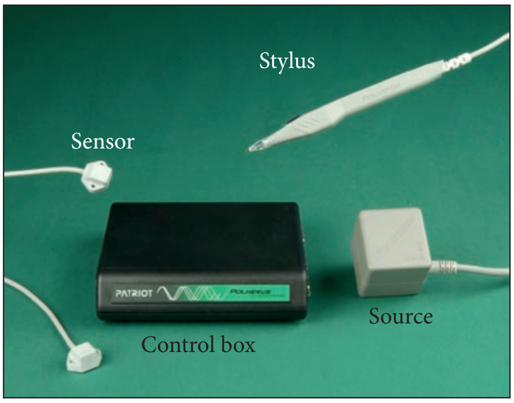

Figure 7. Polhemus Patriot Magnetic Motion (Polhemus, 2012)

4.1.3 ACOUSTIC TRACKING

In acoustic tracking system, ultrasound transmitters and acoustic sensors are used. The user wears ultrasound emitters and sensors are fixed in the environment. The position and the orientation of a user is calculated on the basis of time taken for sound to reach the sensors. As sound travels relatively slowly, acoustic tracking system is rather slow compared to other sensors tracking. Similarly, the speed of sound in air can change due to the change of temperature or humidity in the environment, which can affect the efficiency of the tracking system (*Sehatullah, 2011*).

4.1.4 INERTIAL TRACKING

In the inertial tracking system, tracking is performed so as to conserve either a given axis of rotation (mechanical gyroscope) or a position (accelerometer). Mechanical gyroscope system is based on the principle of conservation of the angular momentum. The orientation of the target can be computed from the rotational encoder angles. As the axis of rotating wheel provides the reference, this tracking system does not require any external reference to work. Problems can occur in this system due to small friction between the axis of wheel and bearing. Accelerometer is used to measure the linear acceleration of an object. Accelerometer finds a position with one degree of freedom. This sensor is lightweight and is reference free (Rolland et al., 2001).

4.1.5 HYBRID TRACKING

The combinations of various sensors are possible to make hybrid sensor tracking systems. Each sensor tracking system has its limitations, so hybrid systems provide a relatively good solution but these hybrid systems increase the complexity and the cost of tracking (*Rolland et al., 2001*).

Table 1. Summary of Sensors based Tracking

Sensors Tracking	Accuracy	Sensitivity	Cost	DOF	Advantages	Disadvantages
Optical Sensors	Accurate	Light	Cheaper	3/6 DOF	High update rate, better resolution	Effect with optical noise, occlusion
Magnetic Sensors	Less Accurate	Electronic Devices, electro-magnetic noise	Cheaper	6 DOF	No occlusion problem, high update rate	Small working volume, distance affect accuracy
Acoustic Sensors	Less Accurate	Temperature, Humidity, Pressure	Cheaper	3/6 DOF	Slow, Small, light, no distortion	Occlusion and ultrasonic noise
Inertial Sensors	Accurate	Friction	Cheaper	1/3 DOF	No reference needed, No prepared environment needed	Due to small friction conservation error
Hybrid Techniques	Accurate	Depend on sensors used	Costly	6 DOF	Compact, accurate, stable.	Depend on sensors used

Auer and Pinz (1999) built a hybrid tracking system by combining optical and magnetic tracking. In this tracking system, magnetic tracking is used to provide a robust estimate of position and orientation, which is then refined in real-time by optical tracking. This hybrid tracking system is faster and reliable than an optical tracker and more precise than a magnetic tracker (*Auer and Pinz, 1999*).

The characteristics of different sensors are summarized in Table 1.

4.2 VISION BASED TRACKING

Vision-based tracking is the most active area of research in AR (*Zhou et al., 2008*). In vision-based tracking, computer vision methods are used to calculate the camera pose relative to the real world objects (*Bajura and Ulrich, 1995*). Early vision-based tracking used fiducial markers in prepared environments (*Narzt et al., 2006*) (*Shin and Dunston, 2008*). Currently, vision-based tracking research is based on markerless approach (*Comport et al., 2003*) (*Chia et al., 2002, Ferrari et al., 2001*) (*Gross et al., 2003*).

4.2.1 MARKER-BASED TRACKING

In marker-based tracking, fuducials (artificial markers) are placed in the scene for augmented reality applications. Visual markers are widely used in the AR systems. These markers have some specific properties that make them easy to identify their position in the real world. Naimark and Foxlin (2002) presented a circular 2D bar-coded fiducial system for vision based tracking. The fiducial design allows having thousands of different codes, thus enabling uninterrupted tracking throughout a large building at very reasonable cost (*Naimark and Foxlin, 2002*). Samples of ARToolKit markers are shown in Figure 8.

Circular-shaped marker clusters with various parameters (number of markers, height, and radius) were developed as shown in Figure 9 (Naimark and Foxlin, 2002). This marker frame configuration delivers excellent pose information, which translates to stable, jitter-free augmentation (*Vogt et al., 2002*). Different AR applications have different marker detections and tracking requirements. A detailed discussion among different markers have been evaluated in (*Zhang et al., 2002*).

Marker-based AR tracking was presented that tracked and identified real-time known 2D markers made up of corners to estimate the accurate camera pose. Robustness at a large range of distance and reliability under severe orientations are the advantages of tracking corners (*Ababsa and Mallem, 2004*). A tracking solution for mobile phones was developed that tracks colour-coded 3D marker (*Möhring et al., 2004*). Steinbis et al presented a set of 3D cone fuducials for scalable indoor/outdoor tracking, that are easy to segment and have a large working volume (*Steinbis et al., 2008*). Maidi et al developed a system that combined extended Kalman filter and an analytical method with direct resolution of pose parameters computation. This system improved stability, convergence and accuracy of the pose parameters (*Maidi et al., 2010*).

4.2.2 MARKERLESS TRACKING

The most popular and earlier markerless 3D visual tracking system is RAPiD (Real-time Attitude and Position Determination), described by Harris (1993). This system is a good example

Figure 8: Sample Markers of ARToolKit (ARToolKit, 2012)

of markerless tracking and many subsequent vision-based tracking systems share the work of Harris (1993). This technique minimizes the amount of data that needs to be extracted from the video feed (*Harris, 1993*). In 1998 Park et al presented a method that allows natural features to be used for tracking instead of artificial features. From the known visual features, first the camera pose is calculated so the system dynamically acquires additional natural features and uses them to a continuous update of the pose calculation. This method provides robust tracking even when the original fiducials are no longer in view (Park et al., 1998).

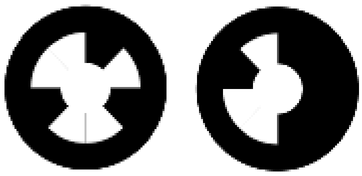

Figure 9: Circle Markers (Naimark and Foxlin, 2002)

Vacchetti et al. (2004) combined edge and texture information to get a real-time 3D tracking. Interest points are found in the image for each frame and these interest points are then matched with interest points of the reference frame which are used for smooth camera trajectory (*Vacchetti et al., 2004*). A real-time model-based line tracking approach with adaptive learning of image edge features was introduced that can handle partial occlusion and illumination changes. In this approach a CAD model of the object is used for proper tracking to improve the robustness and efficiency (*Wuest et al., 2005*).

A model-based tracking system for outdoor augmented reality in urban environments was introduced, that enabled accurate real-time overlays for a handheld device. This system combines several well-known approaches i.e an edge-based tracker for accurate localization, gyroscope measurements to deal with fast motions, measurements of gravity and magnetic field to avoid drift and a back store of reference frames with online frame selection to reinitialize automatically after dynamic occlusions or failures (Reitmayr and Drummond, 2006). Markerless tracking for outdoor AR was introduced that provided robust and reliable tracking using mobile handheld camera. This system is efficient for partially known 3D scenes which combined edge-based tracker with a sparse 3D reconstruction of the real-world (*Ababsa et al., 2008*).

Dame and Marchand (2010) presented a direct tracking approach that uses Mutual Information as a metric for proper alignment. This approach provides a robust, real-time and an accurate estimation of the displacement (*Dame and Marchand, 2010*). Sanchez et al 2010 have presented a solution of real-time camera tracking and 3D reconstruction (Sanchez et al., 2010). A method has presented for improving accuracies of 3DOF position and orientation for outdoor AR. This method uses corner points of buildings, detected as vertical edges in the image, and use it for refining GPS location and compass orientation (*Park and Park, 2010*). A real-time solution for modeling and tracking multiple 3D objects in unknown environments was presented, which can track 40 objects in 3D within 6 to 25 milliseconds (*Kim et al., 2010*).

Ababsa and Mallem proposed particle filter framework with points and lines model-based tracking to achieve real-time camera pose estimation. The advantages of this implementation are simplicity and flexibility. They showed that their algorithm can accurately track the camera pose successfully under sever occlusions and non-smooth camera motions (*Ababsa and Mallem, 2011*). A textureless object detection and 3D tracking with online training using a depth camera was presented in 2011. This method eliminates the requirement of prior object model, since any data for detection and tracking is obtained on the fly, which enhances the depth map (*Park et al., 2011*). For Augmented Reality applications tracking-by-synthesis is a promising method for markerless vision-based camera tracking. This system can run at high speed by combining fast corner detection and pyramidal blurring (*Simon, 2011*).

A real-time method to track weakly textured planar objects and to simultaneously estimate their 3D pose was introduced recently.

The basic idea is to adapt the classic tracking-by-detection approach, which seeks for the object to be tracked independently in each frame, for tracking non-textured objects (*Donoser et al., 2011*). The tracking performance deteriorated by viewing the plane to be tracked has a significantly oblique angle to the viewing direction or by moving object to a distant location from the camera. This problem has been solved by modeling the sampling and the reconstruction process of images. The main idea is to correct the template by applying a linear filter, which is generated by means of a tracked pose of the plane, and then using it for the optimization, which tracks the plane in real time (*Ito et al., 2011*). Lieberknecht et al (2011) presented a real-time method based on a consumer RGB-D camera that tracks the camera motion within an unknown environment. While tracking, it reconstructs a dense-textured mesh for it (*Lieberknecht et al., 2011*). Another approach was presented that demonstrates the detection and the tracking of different types of textures including colorful pictures, fiducial markers and hand writings (*Uchiyama and Marchand, 2011*).

4.3 HYBRID TRACKING

Each sensor-based tracking and vision based tracking has its own limitations. Due to these limitations, since a robust tracking solution is not possible for some augmented reality applications, hybrid methods have been developed. Hybrid tracking technique is the combination of both sensor-based tracking and vision-based tracking that attempts to compensate the shortcomings of each technique by using multiple measurements to produce robust results. State et al developed a hybrid tracking technique that combined vision based tracking (landmark tracking) and sensor based tracking (magnetic tracking) (*State et al., 1996*).

Azuma et al (1998) described that not a single technology gives a complete solution for outdoor tracking, therefore a hybrid tracking technique was proposed for outdoor augmented reality system, which is based on GPS intertial and computer vision technologies (*Azuma et al., 1998*). Hybrid tracking techniques are the most promising way to deal with the challenges in indoor and outdoor mobile augmented reality environments (*Hughes et al., 2005*).

In 2000 Kanbara el al combined vision-based with inertial sensor to get a hybrid system. The vision-based approach is used for estimating the position and orientation of the camera by tracking markers in the real world environment, whereas inertial sensor is used to track stereo images and a camera orientation to produce a robust tracking system (*Kanbara et al., 2000*).

By using small and inexpensive sensors, Foxlin et al achieved a better position accuracy and angular accuracy with low latency. This is achieved by applying miniature MEMS (Micro Electro-Mechanical Systems) sensors to cockpit helmet-tracking for synthetic vision by inertial tracking between helmet-mounted and aircraft-mounted inertial sensors, and novel optical drift correction techniques (*Foxlin et al., 2004*). A model-based hybrid tracking system for outdoor augmented reality in urban environments was introduced in 2006. This hybrid tracking system enables accurate and real-time overlays for handheld devices. This system combines several approaches: edge-based tracker to track accurate localization, gyroscope measurements to deal with fast motions, measurements of gravity and magnetic field to avoid drift, and a back store of reference frames with online frame selection to re-initialize automatically after dynamic occlusions or failures (*Reitmayr and Drummond, 2006*). A hybrid tracking approach that combines SFM (structure from motion), SLAM (Simultaneous Localization and Mapping) and model-based tracking was presented by Bleser et al. (*Bleser et al., 2006*).

A hybrid tracker was developed that combined optical sensor and vision based approach. This tracker used component-based framework that are designed for wide range tracker (*Ababsa et al., 2007*). Schall et al introduced a 3DOF orientation tracking approach that combines the accuracy and stability of vision-based tracking with the correct orientation from inertial and magnetic sensors. They demonstrated that this approach considerably improves absolute orientation estimation on a mobile phone device (*Schall et al., 2010*). Waechter et al introduced a mobile multi-sensor platform to overcome the shortcomings of single sensor systems. This platform is prepared with an optical camera and a mounted odometric measurement system that provide relative positions and orientations with respect to the ground plane. In this hybrid tracking approach, the camera is used for marker-based as well as for marker-less inside-out tracking which provide better tracking results (*Waechter et al., 2010*).

Similarly, Bleser et al presented a hybrid system that combines the egocentric vision with inertial sensors to track upper-body motion. In this hybrid system visual detectors of the wrists are used with the images of a chest-mounted camera to substitute the magnetometer measurements (*Bleser et al., 2011*).

5. Issues in Augmented Reality Tracking

Despite the advances made in the context of augmented reality tracking, there are still some issues in this area that need to be overcome. This section will highlight these issues.

Currently, no single tracking technique provides the best solution for the orientation and pose tracking in the outdoor unprepared environment. In unprepared out-door environment tracking is the main issue for developing an augmented reality system. The major research area in augmented reality is tracking and now-a-days lot of research work focused this area. The problem is involved in the modeling of complex 3D spatial models and the organization of storage and querying of such data in spatial databases as these databases need to change quite rapidly with real environments as they are dynamic (Krevelen and Poelman, 2010). Similarly, drastic motions often lead tracking failures and recovery is time-consuming with a temporary loss of real-time tracking abilities (Zhou et al., 2008).

In sensor-based tracking optical, magnetic, inertial, acoustic or ultrasonic sensors are used. Optical tracking sensors are sensitive to optical noise, occlusion, they are computationally very costly and slow (Yang et al., 2008). Tracking is difficult in optical tracking when tracking multiple similar objects in the scene. Magnetic sensors are disturbed by the presence of electronic devices nearby (Sehatullah, 2011). Magnetic tracking sensors also suffer in terms of jitter, accuracy degrades when their distance increases from the source and are sensitive to electromagnetic noise (Yang et al., 2008). The update rate for acoustic system is low as sound travels relatively slowly. The speed of sound in air can change due to the change of temperature or humidity in the environment, which can affect the efficiency of the tracking system (Sehatullah, 2011). In inertial tracking system, a problem may occur due to small friction between the axis of wheel and bearing. Hybrid systems increase the complexity and the costs of tracking (Rolland et al., 2001).

Marker-based tracking can be used in the indoor prepared environment. Due to a limited range, marker-based tracking cannot be used in large scale outdoor environments. Model-based tracking extends the tracking range by using natural features for tracking but these techniques lack robustness and have high computational costs. Model-based tracking requires heavy computation for generating models of complex environment. Hybrid tracking provides a robust and accurate tracking but it is costly and involves computational difficulties.

The main challenge in the augmented reality system is to produce fast and accurate tracking with minimal efforts and costs in the settings and changes in the environment. Tracking in large factories that satisfy industrial demands is also an issue in augmented reality applications.

6. Discussion

Augmented Reality aims to combine virtual information with the real world that enhances the user perception of the real world. Augmented reality has still several challenges that need to be overcome or improved. These challenges are categorized as performance challenges, alignment challenges, interaction challenges, mobility/portability challenges and visualization challenges. Ideally, virtual information is required to act like the real world objects. A correct estimation of the user's viewpoint (camera) with respect to the virtual information is important to track properly. This requires an appropriate tracking system.

The augmented reality tracking techniques are divided into sensor-based tracking, vision-based tracking and hybrid tracking. In sensor-based tracking different sensors are used for tracking in augmented reality environment. Sensor-based tracking is further categorized in optical tracking, magnetic tracking, acoustic tracking, inertial tracking or any combination of these sensors. Optical tracking provides accurate and robust tracking in controlled environment but is sensitive to optical noise, occlusion. Magnetic tracking is cheaper but provides less accurate tracing than optical systems. Magnetic field is disturbed due to the presence of electronic devices. Acoustic tracking is slow as compared to other sensors tracking and affected by the change of temperature and humidity in the environment. No external reference is needed in inertial tracking but small friction does affect the tracking process. Hybrid sensor tracking provides a relatively good solution but these hybrid systems increase the complexity and the costs of tracking.

The vision-based tracking is divided into marker-based tracking and markerless tracking. Marker-based tracking reduces the requirements for computation with robust solution. But marker-based tracking is only used in limited range and cannot be used in a large scale outdoor environments. Model-based tracking extends the tracking range by using natural features for tracking. Vision-based tracking provides accurate registration of the virtual information with low latency between the virtual information and the real world. But these techniques have a lack of robustness and high computational costs. The combination of sensors and vision-based tracking form hybrid tracking. Hybrid tracking provides a robust and accurate tracking but this involves certain financial and technical difficulties.

7. Conclusion

This survey paper presented a comprehensive review of different tracking systems and categorized the challenges in the field of augmented reality. The challenges in augmented reality are categorized in performance challenges, alignment challenges, interaction challenges, mobility/portability challenges and visualization challenges. The augmented reality tracking is mainly classified into sensor-based tracking, vision-based tracking and hybrid tracking. Based on different sensors, the sensor-based tracking is further classified into optical tracking, magnetic tracking, acoustic tracking, inertial tracking and hybrid-sensor tracking. These different sensors-based trackings were then compared based on cost, accuracy, robustness and sensitivity. Similarly, their advantages and disadvantages were highlighted.

Similarly, vision-based tracking is classified in marker-based tracking and markerless tracking. Vision-based tracking provides an accurate registration of the virtual information with no delay. But these techniques have a lack of robustness and high computational cost. Limitations and benefits of each tracking technique have been elaborated. The combination of sensor-based and vision-based tracking form hybrid tracking whose examples were considered and compared with other techniques. Hybrid tracking provides robust and accurate tracking but it is costly and computationally difficult.

8. Future Work

A significant amount of work has been made in the augmented reality tracking during the last few years. Several robust tracking have been developed which perform tracking in real time in indoor environment. As already discussed in this survey paper, there are still some issues in AR tracking, for example, some amount of occlusion issue, different illumination environment, different contrast with respect to background and different color intensities.

Future work will emcompass the design of algorithms that provide robust and accurate tracking in different illumination, contrast and lighting condition using marker-based tracking.

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