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Integration of Real and Virtual Light Sources in Augmented Reality Worlds

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ABSTRACT

A number of issues need to be taken into consideration for the output of an augmented reality application to appear realistic. Such issues include the level of detail of the virtual scene, the accuracy of alignment between the two worlds and the correspondence of illumination between the real and virtual components. This paper reviews geometric registration techniques that are commonly used to perform the alignment process and photometric registration techniques that match illumination conditions. A research project that investigates both geometric and photometric registration is discussed. Although a number of geometric registration techniques exist, feature based methods have not yet achieved popularity within production environments because of the associated difficulties. Instead, fiducial marker based systems are being implemented for their robustness and ease of implementation. Many photometric registration techniques require pre-calibration or extensive CPU time. Very few operate in real-time and are compatible with geometric techniques. Further work to be undertaken is discussed towards the end of the paper.

Keywords Augmented Reality Registration Illumination Realism

1 INTRODUCTION

Augmented reality (AR) is the term used to describe the concept of superimposing virtuality over images of the real world, effectively combining real and artificial environments. AR has many areas of application and in recent years the field has begun to receive interest from a number of sectors such as manufacturing, military, medical and the computer games industry [26]. One example is the Battlefield Augmented Reality System (BARS) developed by the US Naval Research Facility. BARS is a wearable device that attempts to gather intelligence from, and provide real-time information on, a soldier's surroundings using augmented reality [5]. AR gaming applications such as ARQuake [25] have been developed and allow users to interact with virtual enemies in their own every day environment. The authors of [19] have also implemented an AR system known as Tinmith which allows the user to construct AR outdoor structures via visually tracked hand movements.

The alignment between the real and virtual worlds must be accurate in order to achieve realistic augmentation. The process of obtaining such alignment is known as geometric registration. A number of approaches have been proposed that use either sensor data, visual cues or a hybrid combination of both. Achieving alignment using visual data alone is often preferred as it eliminates the need for additional equipment, which may be bulky, heavy and expensive. Visual approaches fail under certain conditions therefore some researchers have suggested hybrid systems that make use of both visual and sensor based techniques.

This paper overviews a number of registration techniques that are used within the field of AR. It aims to provide the reader with an understanding of the suitability of a given technique for different types of AR implementation. It also discusses research into augmented reality lighting and outlines the ARLights development project which aims to implement both geometric and photometric registration techniques.

2 LITERATURE REVIEW

To achieve realistic augmented realities researchers have investigated the fields of geometric and photometric registration. Many accomplishments in the geometric field have been made; however few AR systems have demonstrated the ability to achieve realistic augmentation through accurate geometric and photometric registration simultaneously.

2.1 GEOMETRIC REGISTRATION

Visual and sensor based geometric registration approaches are commonly used and often multiple techniques are combined. An overview of some such systems is given here.

2.1.1 Sensor Techniques

A number of techniques use additional information from sensors such as from GPS and radar equipment to assist the visual tracking process. One such technique was presented in [2]. The global positioning system (GPS) network can be used to determine the position of the camera. Such systems only operate when sufficient signal from four or more satellites can be obtained. GPS signals become sporadic in built up areas and can be blocked completely when the receiver is indoors. GPS information is less reliable in such areas.

Sensors have also been used to measure the orientation of AR devices. They include inertial sensors, laser measuring devices and magnetic field sensors. The equipment may provide varying levels of accuracy. Usually, the more accurate the device the higher its cost. These sensors also have their limitations. Electronic compasses are susceptible to interference from localized magnetic fields. Gyroscopic sensors are prone to errors due to the drift caused by bearing friction within the gyroscope. Sensors may provide accurate data given that the correct sensors are used for the current environment; however they are potentially costly and bulky to carry. Due to this, many AR researchers and developers prefer to make sole use of visual sensing equipment.

2.1.2 Visual Techniques

There are two approaches to tracking the real world visually. The first requires the environment to be prepared with fiducial markers which identify key areas. These can then be tracked, and software can calculate the camera pose by estimating the marker's posture. Accurate superimposition can take place once such information has been gathered. Substantial initialization effort is often required when using certain vision-based techniques to achieve accurate registration. Other approaches involve locating interesting features within the image and then tracking them.

2.1.3 Artificial Marker Based

Many systems have been developed that rely on placing markers at strategic points within the environment before registration can occur, some of which are shown by [13], [25] and [14]. At present, marker based systems are more commonly used due to difficulties associated with markerless techniques.

A number of software application programming interfaces (API) exist that allow programmers to rapidly develop marker based augmented reality systems. These include the ARTag software development kit (SDK) and the ARToolkit SDK. In order to use such development kits, the programmer merely prints out the chosen API's marker set and creates program code that tells the software exactly how to react to each marker. AR specific functionality such as registration and augmentation is handled by the API itself allowing the programmer to concentrate on application specific code.

2.1.4 Natural Feature Based

An alternative approach is to attempt to detect unique natural image features instead of artificial markers [9]. Such features occur when the signal changes two-dimensionally; for example, where there is a corner, an edge or where the texture changes significantly [8]. The authors of [4] present completely markerless techniques whereby the virtual scene is registered using the results of global bundle adjustment and camera self-calibration of which [7] provides detailed explanation. [22] presented a method of using the planar surfaces that exist within outdoor environments in order to estimate the pose of the camera. [21] used edges and points in a manner that allowed for fast camera motions. A pose estimation method that makes use of SIFT is outlined by [10]. Other techniques such as the Features from Accelerated Segment Test (FAST) algorithm and the Kanade-Lucas-Tomasi (KLT) tracker are also frequently used. The latter is frequently used within the robotics field of Systematic Localization and Mapping (SLAM).

When tracking camera pose visually, accuracy varies in proportion to the range of objects within the image. [16] presents a method that reduces the number of pre-calibrated entities required. The technique only requires camera poses of a few reference images and uses omni-directional camera as opposed to other systems that use a database of environment images. Such systems include those presented by [2], [24] and [3]. The system presented in [16] tracks to 5 degrees of freedom (DOF) and estimates camera pose requiring only 2D - 2D correspondences. A 6DOF camera pose is then derived directly from two 5DOF motion estimates between two reference images and an image from the tracked camera. Two techniques that can perform estimation calculations are the Least Squares technique (LS) and the Unscented Kalman Filter technique (UKF).

[10] presents a fully automated system architecture for markerless augmented reality. The system performs model-based augmentation and results in robust tracking in the presence of occlusions and scene changes using highly distinctive natural features to establish image correspondences. The only preparation required is a set of reference photos taken with an uncalibrated camera. Instead of using markers to assist tracking, stable natural features that are generated from an image using the SIFT algorithm are used as descriptors of local image patches. These features are invariant to image scaling and rotation. They are also partially invariant to changes in rotation and viewpoint.

2.1.5. Model Based

Registration methods exist that estimate the camera pose by visually matching image features with those of a 3d model. High levels of success with this have been achieved by [20]. Model-based tracking relies on the detection of appropriate features within both images and textured 3d models. Such features could be points, edges or corners. [6] has also presented methods of generating this model on the fly. [15] presents a hybrid system that makes use of aerial and frontal views in combination with sensor data to generate models to use for registration purposes on the fly.

2.1.6 Hybrid Systems

To realize convincing augmentation in natural environments the camera pose must be accurately estimated in real-time, even when the environment has not been specifically prepared. [20] used a model and gyro based hybrid tracking system for outdoor augmented reality. [1] presents a technique originally intended for the field of robotics which detects unique features using the Harris [11] and Scale Invariant Feature Transform (SIFT) [18] feature extraction algorithms. Figure 1 shows an example of SIFT extracted features.

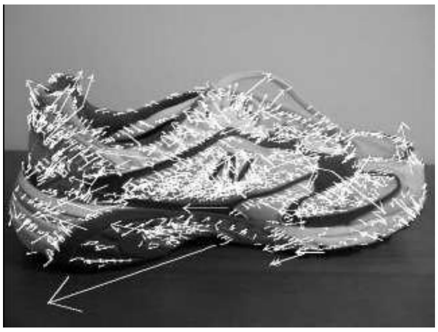

Figure 1: SIFT Extracted Features

The hybrid registration method presented by [12] utilizes edges and vertices of a 3d model of the target object. When this object comes into view, the camera position and orientation are estimated by detecting the vertices and true edges every frame. Multiple edge candidates are considered and the 'best' is used in order to reduce the influence of misleading edges. Either a magnetic sensor or artificial visual markers are used in combination. This allows the system to obtain the approximate camera position and orientation when the target object goes out of view or if the camera moves too fast to detect natural objects. By using such hybrid techniques the accuracy and robustness is increased, especially during rapid camera movement. Model based techniques only work when an object within the environment is known in advance. Using markers alongside natural features allows for fast and stable pose estimation. However substantial preparation time is needed to deploy markers and calibrate them. Calibration involves measuring the size of and the spacing between each marker. Mis-correspondence and mis-tracking causes decrease in the accuracy of the estimation. However using a feature based approach the original scenery is left intact and augmentation can take place anywhere. Model based systems such as [17] provide higher registration accuracy. However it is difficult to construct a 3d model of everything within the environment that could be tracked, therefore some researchers and developers prefer to model just some of these objects and consider the implementation of a hybrid system.

Hybrid techniques allow a system to take the advantages from each technique used while mitigating any weak areas. The authors of [12] use cameras with pre-estimated intrinsic parameters as devices to capture image sequences. A 3d object whose shape is already known is placed within the environment. This could be a house or a box for example. They provide the option of using either a magnetic sensor or artificial markers which increases the robustness of this system. This technique uses the KLT tracker which tracks features as shown in figure 2.

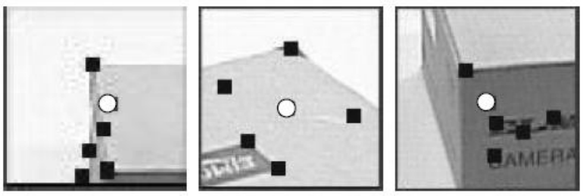

Figure 2: The KLT Feature Tracker

[2] presents a technique that uses outdoor horizon silhouettes to assist the registration process. The camera is initially located via GPS allowing for elevation data to be gathered from digital elevation maps for the camera's current location. Providing the terrain is sufficiently well structured the horizon extrema can be evaluated visually and the camera orientation can be calculated. This technique would fail in flat areas where the horizon contains too few dips and peaks to obtain any useful information. As such it may be more useful as part of a more involved hybrid system than as a stand-alone pose estimation technique. [15] draws on SLAM techniques and utilizes GPS and inertial data, aerial photography and frontal imagery. The aerial and frontal images are used to visually generate models of buildings with sufficient detail for tracking purposes. Thus eliminating the need to manually create 3d models prior to augmentation. As civilian GPS data is of variable accuracy additional sensors may be required.

The hybrid registration method discussed by [20] uses an edge-based tracker for accurate localization and gyroscopic measurements to deal with fast motions. Magnetic field and gravitational measurements are used to avoid drift and a back store of frame information is saved to mitigate the effect of occlusion.

2.2 PHOTOMETRIC REGISTRATION

A number of approaches to photometric registration have been explored. Researchers attempt to estimate real-world illumination conditions by gathering various metrics from the real scene. This data is then used to illuminate the artificial component. An overview of such techniques is given below.

[27] suggests a technique that utilizes spheres with a Lambert surface as calibration objects to gather illumination parameters. Figure 3 shows the uniform reflectance of a Lambert surface that makes calibration possible. [27] claims to achieve an identical match between real and virtual components, the result being a seamless augmented reality scene. This technique operates in real-time with relatively low operational complexity however fails if multiple real light sources are introduced. The technique is not suited for combination with any geometric registration approach as a stationary camera is required once pre-calibration has taken place. [27] does not observe or attempt to reproduce cast shadows.

[28] presents a real-time rendering solution that simulates colour consistent virtual shadows in real-scenes. Shadow regions are estimated and then confirmed using texture information and are segmented using canny edge detection. A binary mask is then used to track which pixels contain shadow information. This information is then analyzed and the data gathered is passed to either a shadow volume or shadow map algorithm which allows for the casting of shadows from artificial objects. Shadows are cast onto both virtual and real objects. [28] out performs other shadow matching techniques as the technique correctly combines real and virtual shadows without producing an unrealistic overlap. [29] identifies a number of illumination methods for augmented reality and classifies them into two categories. These are common illumination and relighting. Common illumination matching techniques attempt to simulate consistent lighting when artificial objects are inserted into a real context. Relighting techniques modify the real component in response to the insertion of a virtual object. [28] performs both by making use of the inverse illumination technique discussed by [30]. This technique collects illumination parameters such as the Bidirectional Reflectance Distribution Function (BRDF) from the real scene for use within the virtual. The technique requires that approximate knowledge of real scene geometry be known prior to augmentation. [31] propose an AR system that favors the use of shadow maps and [32] suggests the use of shadow volume techniques. Both techniques allow the AR system to simulate shadows at low operational cost, after the real-world illumination data has been acquired. [33] and [34] present methods of locating shadows within an image, but do not perform any analysis of the data obtained. [35] presents a method of detecting multiple illuminants within a scene and accurately estimating their pose. This method does not require the use of a pre-calibration object. Additionally the data collected from the technique allows for the virtual recreation of three dimensional object shapes. The illuminant detection results the technique yields are directly applicable to development of realistic augmented reality systems, however the calculations required are slow and therefore would not be capable of processing a live video stream in real-time. [35] provides good results compared to a number of other techniques as it analyses both shadows and the shading of arbitrary scene objects. The technique finds it easy to obtain multiple illuminant information from shading when specula reflections are present but finds the task difficult when observing diffuse reflections alone. An extra level of robustness exists with this technique as it is less prone to error caused by cast shadows moving outside the camera's field of view or being occluded than techniques that observe either object shading or cast-shadows exclusively. [36] presents a robust method of estimating the azimuth of a single illuminant.

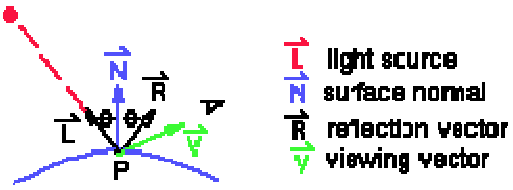

Figure 3: Illumination Model

3 ARLIGHTS

3.1 Project Aims

The ARLights project, currently under development at the University of Huddersfield, aims to create convincing illuminated AR scenes. This is achieved by generating artificial lighting that matches the conditions of the real environment. This can be done a number of ways, either manually or automatically. If a camera is of a known fixed position then light information can be manually hard-coded into the application. However, this technique assumes the lighting within the environment is heavily constrained. It is anticipated that the camera will move within an AR application, therefore a more flexible approach is preferable and autonomously detecting a light source allows for such flexibility. This way any artificial object placed within the scene will be illuminated in a similar manner to objects within the real world environment, regardless of the camera position. Presently the system relies on marker and object tracking based approaches but eventually aims to remove this limitation by tracking lights themselves in order to provide the capability of realistically and dynamically lighting AR scenarios. As a whole the system aims to be robust and should be adaptable to environmental change. The intent is to design, develop and test an augmented reality lighting system that is accurate enough to render a scene with sufficient realism for a computer games application.

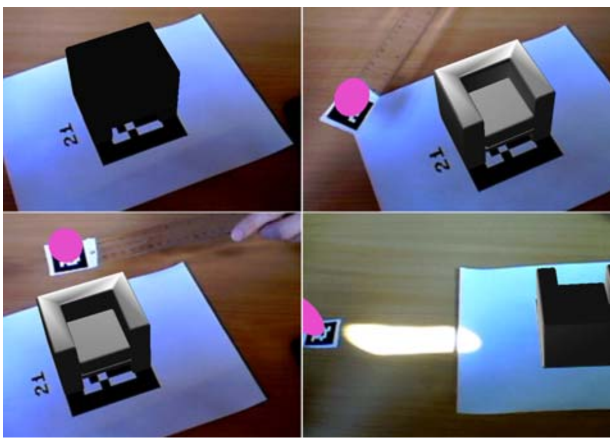

Figure 4: Screenshots

3.2 System Performance

The ARLights system currently has the ability to load up to eight artificial lights. These lights are positioned and orientated based on information provided by fiducial markers within the scene. Special markers placed within the world identify different objects and lights. Spot, point and distant lights can be placed by introducing their respective marker to the camera view. Point lights emanate light in an omni-directional manner from the position of the marker. Spot lights can be placed the same way but can be also be orientated by rotating the marker. Distant lights are not positioned, however the marker is detected and the application generates a light that illuminates the virtual component globally. This light has the same orientation as this marker. When a marker is removed from the camera's field of vision the virtual object or light associated with it is deleted.

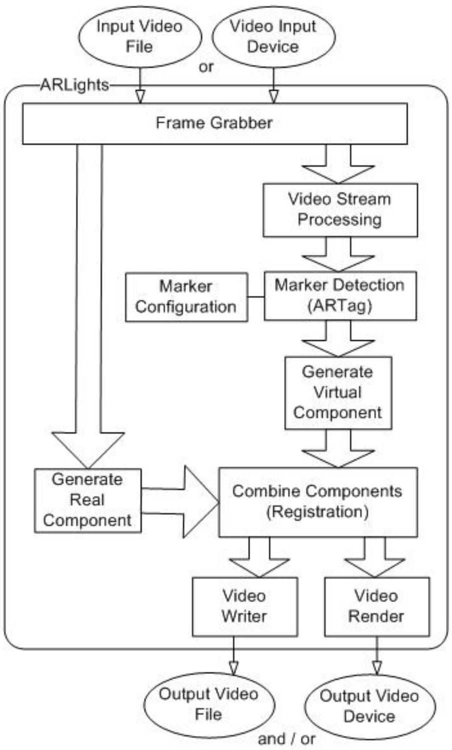

Figure 5: System Diagram

Figure 4 shows the ARLights system at run-time

- The upper left image shows a model of a chair being augmented over a fiducial marker. No markers have been placed to indicate light sources so the chair has not yet been illuminated.
- The upper right image shows the same model, but this time it is illuminated by a single light source represented by the sphere in the scene.
- The bottom left image shows the same model illuminated from a different arbitrary angle.
- Finally, the bottom right image shows the marker being used to identify an actual light source which illuminates the model in a similar manner to how it would be highlighted in the real environment.

Figure 5 shows the processes that are undertaken to achieve a properly registered and illuminated augmented reality scene. Initially a video processing module, known as a frame grabber, obtains the current frame of video from either a video input device such as a webcam or from a video file. These frames are then converted into a stream of RGB data suitable for passing to the other modules. This stream forms the real component of the augmented scene. A copy of this stream is pre-processed and feature detection algorithms are deployed to identify any markers that may be present. A configuration file is then used to bind markers to either lights or objects. It is possible to specify arguments within this file to change the behavior of each marker and set options that alter the behavior of the object or light. The virtual scene is then constructed and the pose of each marker is calculated in order to achieve accurate registration. The virtual and real components are then combined, in each frame, in order, resulting in an augmented reality video. The stream of video data can then be rendered directly to the display or saved into a video file. Any number of objects or lights can be bound to markers via the configuration file, up-to eight light markers may be present within the scene at any given moment and 2048 unique markers may be used. The marker system currently in use is that utilized by the ARTag API. The project will progress in a number of directions. At present the application can only operate in constrained scenarios where markers have been placed to identify a light. The aim is reduce the amount of preparation required to identify light sources and light direction visually. This can be achieved by implementing photometric registration techniques that analyze the frame data for features such as areas of high intensity, edges or points representing the lamp. The lamp can also be detected using computer vision based object recognition techniques. Surface reflections can be analyzed and illuminant direction can be estimated through observing the specula and diffuse reflection of a light source on an object. Further research into photometric techniques will be undertaken, including those that analyze both shadows and surface shading. Findings will be incorporated into future iterations of the ARLights project.

4 CONCLUSIONS

It has become clear that in order to achieve a realistic scene, two important tasks must be accomplished; the first is to achieve accurate alignment between the artificial and real world environments and the second task is that of matching illumination. By matching the lighting conditions between the two environments the AR scene can be rendered more convincingly. Artificial markers provide a fast and accurate method of registration; however the associated preparation effort and environmental constraints make them unpopular. On the other hand, sensors, while potentially fairly accurate, fail in common circumstances due to interference and other anomalies. It can also be expensive to obtain accurate sensing equipment and also increase the load the AR user has to carry. Natural feature based vision techniques are preferred by many AR developers as they allow camera tracking to take place without any environmental preparation. They do have weaknesses and are often found to be less robust. At present, model based registration systems are the most accurate. All visual systems are vulnerable to lighting and occlusion problems. Some techniques exist that allow for an estimation of illuminant direction and provide a reasonable illumination match between the real and virtual scene. However these techniques assume a constrained scenario and many have limitations which deem them unfeasible for realistic AR systems. Research is taking place into new techniques that allow AR applications to track and reproduce the lights within a real scene whilst maintaining accurate geometric registration and overall realistic augmentation.

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