ARCADE: Augmented Reality Computing Arena for Digital Entertainment

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Abstract— Augmented Reality (AR) technology for digital composition of animation with real scenes is to bring new digital entertainment experience to the viewers. Augmented Reality is a form of human-machine interaction. The key feature of the Augmented Reality technology is to present auxiliary information in the field of view for an individual automatically without human intervention. The effect is similar to composing computer-animated images with real scenes. To achieve the new Augmented Reality experience, two main problems are: How to keep track of the viewing parameters of the individual viewer? How to render a virtual image in the field of view correctly and seamlessly? To tackle the above, we are designing and implementing an enabling framework, called Augmented Reality Computing Arena for Digital Entertainment (ARCADE), to support the creation of Augmented Reality entertainment applications. Moreover, we are also developing two new video object tracking algorithms, 3D surface markers tracking and human head and face tracking. In this paper, ARCADE's system architecture and its components are described in detail and illustrated with an application example.

Keywords—Augmented reality, video object tracking, surface marker, head and face tracking.

TABLE OF CONTENTS

1. INTRODUCTION

Augmented Reality (AR) is a multi-discipline research area. The two main technological challenges of Augmented Reality are i) to keep track of video objects with their movement, orientation, size, and position accurately; and ii) to render a virtual image seamlessly with accurate lighting, shadow, color and other environmental aspects. We engage the innovative application of Augmented Reality technology for digital entertainment with our research result in video information processing [1], [2], visual information analysis [3], [4], and computer graphics rendering [5], [6].

We propose to build an enabling environment called "Augmented Reality Computing Arena for Digital Entertainment (ARCADE)" for supporting the creation of Augmented Reality entertainment applications and to develop two new video object tracking algorithms, 3D surface markers tracking and human head and face tracking. The former tracking technology will provide new tools for TV production and digital animation procedure. The latter tracking technology will bring new entertainment experience to theme park or amusement park visitors, kiosk-based entertainment viewers, and mobile entertainment application users.

Apart from entertainment, the technologies developed can be applied to aerospace industries. Augmented Reality can put more information directly in front of the engineers designing aircraft and the manufacturing workers who build them [7]. With the AR technologies, pertinent diagrams and instructions can be put before the eyes of manufacturing staff, who will use the information to work on or assemble pieces of an aircraft. Robot path planning is another possible application. Teleoperation of a robot is often a difficult problem, especially when the robot is far away such as on other planets, with long delays in the communication link. Under this circumstance, instead of controlling the robot directly, it may be preferable to control a virtual version of the robot. The user plans and specifies the robot's action by manipulating the local virtual version in real time. The results are directly displayed on the real world. Once the plan is tested and determined, the user tells the robot to execute a specified plan. The object tracking technologies we developed enable us to develop such a system.

In ARCADE, the Video Object Tracking Engine (VOTE) is the core technology. By tracking an object's position and orientation in the video, VOTE facilitates the automatic rendering of computer-animated virtual images. VOTE is a generic software framework to support different video object tracking algorithms. By applying different tracking algorithms, different video objects can be tracked with different accuracy and

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performance level for different application needs.

VOTE is consists of numbers of component. The generic video format converter is included for accepting various digital video input formats. Then, VOTE extracts and analyzes the low level visual information of the video and performs the high level object tracking with predefined information. Accordingly, the 3D environment matrix is calculated for performing to acquire accurate tracking information of the object and rendering engines in the subsequent digital composition tasks.

In this paper, we outline the ARCADE's system architecture, describe its components and how they are related, and illustrate the system with an application example.

2. BACKGROUND AND RELATED WORK

Augmented Reality is a variation of Virtual Reality as it is more commonly called. Virtual Reality technologies completely immerse a user inside a synthetic environment. While immersed, the user cannot see the real world around him. In contrast, Augmented Reality allows the user to see the real world, with virtual objects superimposed upon or composited with the real world. Therefore, AR supplements reality, rather than completely replacing it. Ideally, it would appear to the user that the virtual and real objects coexisted in the same space.

Milgram [8] defined a continuum of real-to-virtual environments, in which AR is one part of the general area of mixed reality, shown in Figure 1. In both augmented virtuality, in which real objects are added to virtual ones, and virtual environments (or virtual reality), the surrounding environment is virtual, while in AR the surrounding environment is real.

Augmented Reality enhances a user's perception of and interaction with the real world. The virtual objects display information that the user cannot directly detect with his own senses. The information conveyed by the virtual objects helps a user perform real-world tasks. [9]

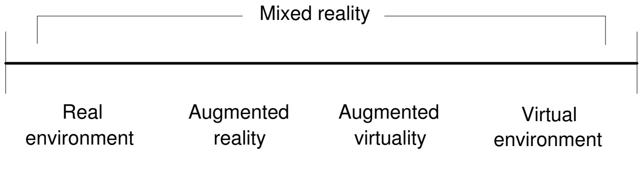

Figure 1. Milgram's real-to-virtual continuum

There are numbers of enabling technologies for building compelling AR environments. Examples of these technologies include displays, tracking, registration and calibration.

Related Projects

In recent years, Augmented Reality technologies have been applied to different areas. Following are some projects related to Augmented Reality.

Boeing Computer Seattle is developing two real-time applications – one in virtual reality, the other one in augmented reality – aimed at putting more information directly in front of the engineers designing aircraft and the manufacturing workers who build them [7].

For many years, military aircraft and helicopters have used Head-Up Displays (HUDs) and Helmet-Mounted Sights (HMS) to superimpose vector graphics upon the pilot's view of the real world. Besides providing basic navigation and flight information, these graphics are sometimes registered with targets in the environment, providing a way to aim the aircraft's weapons. For example, the chin turret in a helicopter gunship can be slaved to the pilot's HMS, so the pilot can aim the chin turret simply by looking at the target. Future generations of combat aircraft will be developed with an HMD built into the pilot's helmet [10].

Augmented Reality technologies are also applied in satellites. The Autonomous Vision System on TeamSat (AVS) [11] is a fully autonomous star tracker and vision system. The objectives of the AVS were to verify, in space, multiple autonomous processes intended for spacecraft applications such as autonomous star identification and attitude determination, identification and tracking of non-stellar objects, imaging and real-time compression of image and science data for further ground analysis. The object tracking techniques are employed in the project.

Object Tracking

Accurately tracking the user's viewing orientation and position is crucial for AR registration. Two major components can be distinguished in a typical object tracker. Target representation and localization is mostly a bottom-up process which has to cope with changes in the appearance of the target. Filtering and data association is mostly a top-down process dealing with the dynamics of the tracked object, learning of scene priors, and evaluation of different hypotheses. The way the two components are combined and weighted is application-dependent and plays a decisive role in the robustness and efficiency of the tracker.

Object tracking techniques can be divided into two main streams: marker-based object tracking [12], [13], [14] and marker-less-based object tracking [15]. General tracking technologies include mechanical arms and linkages: accelerometers and gyroscopes, magnetic fields, radio frequency signals, and acoustics. Tracking measurements are subject to signal noise, degradation with distance, and interference sources. Active tracking systems require calibrated sensors and signal sources in a prepared and calibrated environment. Among passive tracking approaches, computer vision methods can determine pose as well as detect, measure, and reduce pose tracking errors derived by other technologies. The combined abilities to both track pose and manage residual errors are unique to vision-based approaches.

Several different approaches for object tracking exist. Comaniciu [16] proposed a new approach toward target representation and localization of the central component in visual tracking of nonrigid objects. The feature histogram-based target representations are regularized by spatial masking with an isotropic kernel. The masking induces spatially-smooth similarity functions suitable for gradient-based optimization; hence, the target localization problem can be formulated using the basin of attraction of the local maxima.

Oron [17] proposed an algorithm for multi-object tracking method for video images. This algorithm is based on motion estimation and image difference techniques. It provides an improved capability for object tracking, especially for cases of non-stationary background conditions due to radiometric changes, camera motion instability and motion of different objects within the images.

Natural feature tracking is another challenging topic. Natural feature tracking algorithms detect and track target objects in the scene automatically without any pre-defined figures or objects. In [18], a natural feature tracking algorithm is proposed. Natural scene features stabilize and extend the tracking range of augmented reality pose-tracking systems. Point and region features are automatically and adaptively selected for properties that lead to robust tracking.

3. ARCADE

Augmented Reality Computing Arena for Digital Entertainment (ARCADE) is an environment to develop and execute Augmented Reality applications targeted for digital entertainment. The computing arena is the collection of software tools, algorithms, designs, and configurations within a highly automated execution environment for Augmented Reality entertainment applications. Figure 2 shows the logical framework of ARCADE.

Since Augmented Reality entertainment applications will be executed across different hardware platforms, and some of the hardware may be proprietary, ARCADE intends to ease the hurdle of applying Augmented Reality technology for digital entertainment sectors through this generic logical framework.

ARCADE aids developers in deploying Augmented Reality entertainment experience and applying Augmented Reality technology for content creation. We deliver the architecture design of the ARCADE along with a fully tested implementation including the following components:

1. Video Object Tracking Engine (VOTE)
2. Video Object Tracking Techniques
3. Pilot Augmented Reality Entertainment Applications

We describe these components in detail.

Video Object Tracking Engine (VOTE)

Video Object Tracking Engine (VOTE) is the core technology of ARCADE. VOTE is a generic software framework to support different video object tracking algorithms. It facilitates two services. They are (1) tracking video object with different accuracy and performance level for different application needs, and (2) automatic rendering of computer animated virtual images. The architecture of VOTE is illustrated in Figure 3.

As shown in Figure 3, VOTE includes a generic video format converter to accept various digital video input formats. The low level visual information, including colors, lighting, edges, regions, and camera parameters, will be extracted and analyzed. With predefined information and knowledge about the object markers and object characteristics, high level object tracking and identification can be obtained. Consequently, a 3D environment matrix calculation will be performed to acquire accurate tracking information of the object, including its size, position, orientation, movement, lighting, shadow, color prospect, and other environmental aspects. Besides the tracking, VOTE will calculate a 3D environment matrix for the objects tracked in the video. The information calculated will be used for other rendering engines in the subsequent digital composition tasks.

A consistent and standard implementation of VOTE will be developed for five different platforms and software modules:

1. Microsoft's DirectShow filter. DirectShow filters are used for video processing.
2. Video Information Processing (VIP) modules of Video2MMS^{TM} for mobile video environment. Video2MMS^{TM} is an automatic video information processing and conversion system for MMS and mobile Internet developed by the Chinese University of Hong Kong. Video2MMS^{TM} will serve as a server to process the client tracking requests by the mobile devices/handsets via:
   (i) Standard web services interface for VOTE API.
   (ii) Interface to the MMS for mobile device/handset without programming capability
3. Mobile device/handset VOTE API for major devices/handset environments: Symbian and PocketPC.
4. Plug-ins or external processing units for popular animation software to enable video object tracking capabilities.

Video Object Tracking Techniques

To facilitate accurate and real-time video object tracking, two additional techniques will be developed: 3D surface marker, and human head and face tracking.

3D surface marker— 3D surface markers are specially designed color patterns that can be applied to the surface of physical objects. Figure 4 illustrates a possible pattern of 3D

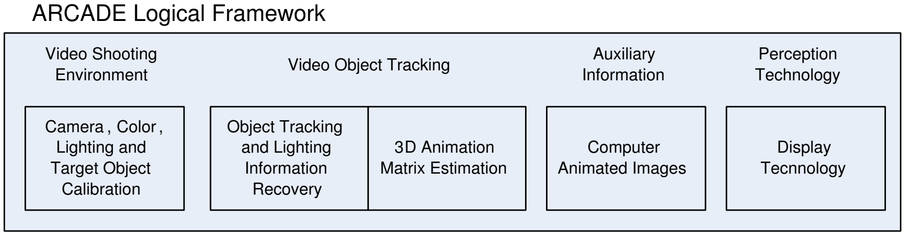

Figure 2. The Generic Framework of ARCADE

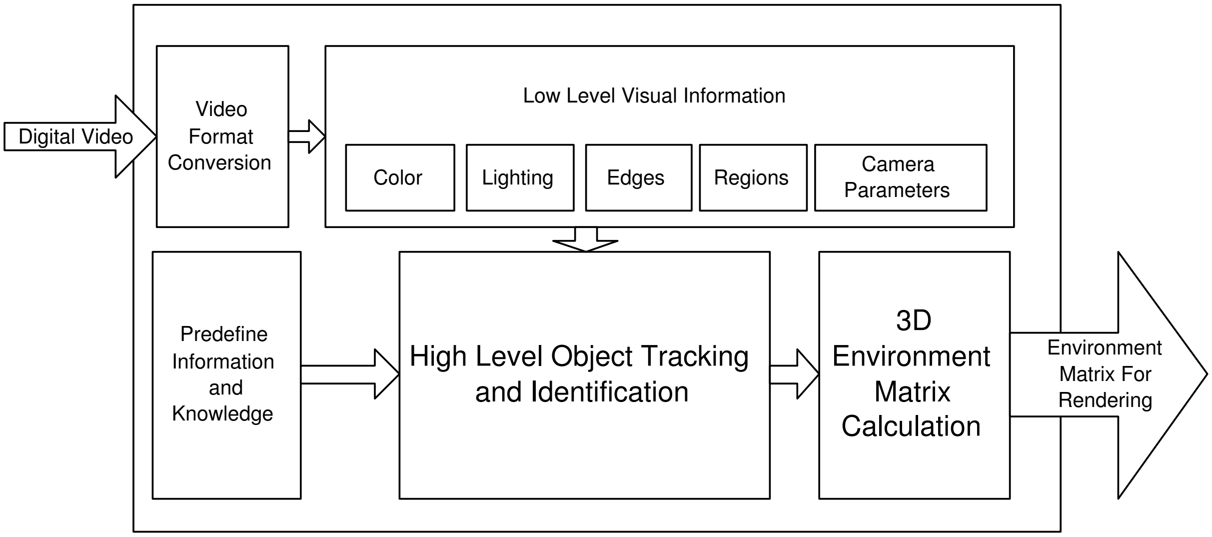

Figure 3. The Architecture of Video Object Tracking Engine (VOTE)

surface markers.

Figure 4. A sample 3D surface markers

By tracking the markers, the 3D environment matrix of the objects can be obtained and computer-animated virtual objects can be superimposed with the right position and orientation in a digital video. The 3D surface markers help the automatic calibration work required in the digital composition of the real scene. The 3D surface markers also achieve acquisition of the lighting condition of the physical object received. The performance of the 3D surface markers is the target for non-real-time applications with high precision that can fulfill the requirements for digital composition need.

Human head and face tracking—Human head and face may arguably be the most frequent objects appearing in videos. A human head and face tracking algorithm aimed for entertainment use will be developed. The performance of the human head and face is the target for near-real-time applications but with medium accuracy. The accuracy is scarified for performance which is of higher priority in an interactive entertainment setup.

The object detector described below has been initially proposed by Viola et al. [19] and improved by Lienhart et al. [20]. Viola et al. have proposed a multi-stage classification procedure that reduces the processing time substantially while achieving almost the same accuracy as compared with a much slower and more complex single stage classifier [19].

First, a classifier (namely a cascade of boosted classifiers working with Haar-like features [19]) is trained with a few hundred sample views of a particular object (i.e., a face or a car), called positive examples, that are scaled to the same size (say, 20x20). Negative examples, on the other hand, are arbitrary images of the same size.

After a classifier is trained, it can be applied to a region of interest of the same size as used during the training in an input image. The classifier outputs a ”1” if the region is likely to show the object, and ”0” otherwise. To search for the object in the whole image, one can move the search window across the image and check every location using the classifier. The classifier is designed so that it can be easily ”resized” in order to be able to find the objects of interest at different sizes, which is more efficient than resizing the image itself. Therefore, to find an object of an unknown size in the image, the scan procedure should be done several times at different scales. The basic classifiers are decision-tree classifiers with at least two leaves. Haar-like features are the input to the basic classifiers. Some samples of the feature are shown in Figure 5.

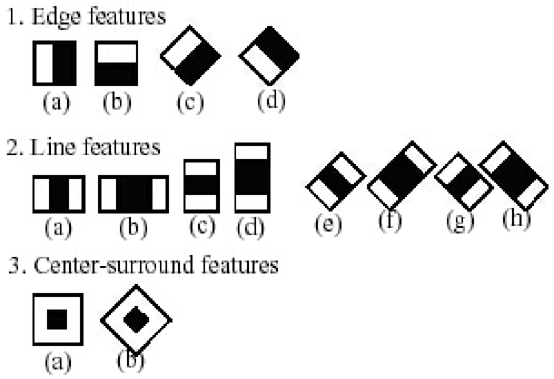

Figure 5. Sample feature for the classifiers

The feature used in a particular classifier is specified by its shape, (such as 1a, 2b, etc., in Figure 5), position within the region of interest, and the scale. This scale is not the same as the scale used at the detection stage, though these two scales are multiplied. We apply the above object detection algorithm for face human head and face tracking. Figure 6 shows the result of face and eye detection.

Pilot Augmented Reality Entertainment Applications (Pilot AREA)

Three pilot applications will be developed with the support of ARCADE to illustrate the new entertainment experience made possible by applying Augmented Reality technology to digital entertainment.

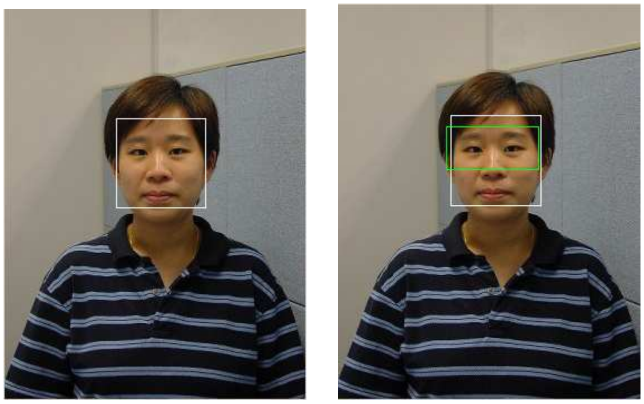
(a) (b)

Figure 6. Face and eye detection

ARProps—ARProps is a plug-in or external processing unit of popular animation software for replacing objects with 3D surface markers by computer-animated objects. The 3D surface markers help the automatic calibration work required in the digital composition of the real scene. The 3D surface markers also achieve acquisition of the lighting condition of the physical objects. With the lighting information obtained, the animation process can further be automated and ‘replacement’ of the real objects by computer-animated virtual objectss can be fully computerized. Figure 7 illustrates the possible result of a video object replaced by different computer-animated virtual objects in the same video clip to create various scenes.

If ARProps is used during the shooting of a TV program, different versions of computer-animated virtual images of the corresponding commercial products can be inserted into the video during the post-production editing of the TV program. For example, if the TV program is sold to Mainland China, a localized version showing Chinese Characters of the commercial products can appear. Using the current technology, if it is done manually, the additional revenue generated may not cover the cost of the post-production animation effort. The automation capability provided by the VOTE and ARCADE, therefore, provides a justification for the localization of the commercial production for TV programs for distribution to different regions as the cost of the post-production animation can be lowered significantly.

Apart from entertainment, ARProps can be used for robot path planning. When the robot works far away, such as on another planet, it would be difficult to communicate with the robot as delays of the communication link would be very long [9]. One of the solutions is for the user to plan and specify the robot’s action by manipulating a local virtual version in real time. The results are then directly displayed in the real world. With our ARProps and 3D surface markers, the robot path planning would become very powerful. The 3D markers are placed on the robot and ARProps is able to augment the action of the robot according to the user’s planning as shown in Figure 8. The action of the robot is augmented on the scene and the user is able to plan the path of the robot accordingly.

Figure 7. Replacement of a 3D marker by different animated objects

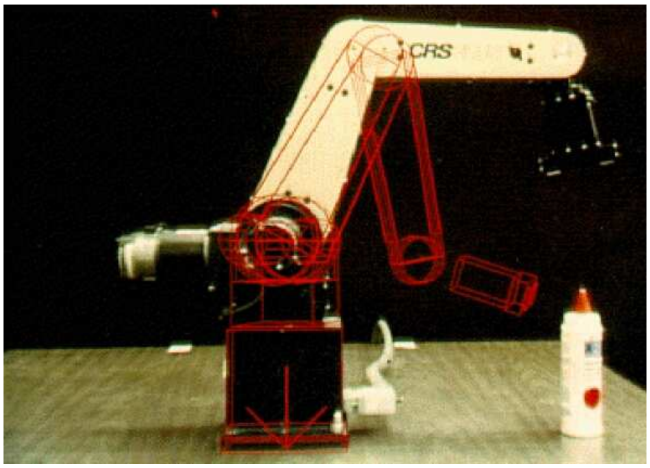

Figure 8. Virtual lines show a planned motion of a robot arm (Courtesy David Drascic and Paul Milgram, U. Toronto.) [9]

Figure 9. Replacement of a 3D marker by different animated objects

ARMirror— This is a kiosk-based entertainment setup to replace a human head and face for entertainment purposes. Besides overlaying an artificial image in front of the human head, various effects such as adding a virtual hat and other accessories are also possible. Figure 9 shows a picture to illustrate a possible effect for an animated face mask in a real background scene, provided in a real-time environment.

These technologies can be applied to the aircraft pilot training. Replacement is not limited to face, but also applicable to other objects and addition of some information on the scene. A pilot is one of the suitable applications. When the pilot is trained in a virtual panel, the virtual scene can be augmented, providing different training scenarios for the pilot.

Aircraft manufacturing is another applicable area. Augmented Reality can put more information directly in front of the engineers designing aircraft and the manufacturing workers who build them. With AR technologies, pertinent diagrams and instructions can be put before the eyes of manufacturing staff. Figure 10 shows an external view of a researcher employing a prototype AR system to build a wire bundle.

ARMobile— This is a mobile video processing system to replace human head and face for entertainment purposes . Today more and more handsets are equipped with video cameras; consequently, mobile application developers can make use of the video camera in providing enhanced and personalized entertainment experiences to the end users. After the users shoot a video clip with their handsets, they can upload the video to a processing server. The video object in the clips will then be identified by the VOTE engine and computer-animated virtual images can be added to the video clips. The augmented video clips can then be sent back to the users or to other users for entertainment purpose. If the human head and face tracking is applied to the video, the effect of replacing one's head and face can be achieved, as illustrated in Figure 5 previously.

4. ARCADE APPLICATION

Augmented Reality (AR) is an emerging technology area. The applications of AR technology are still not fully unveiled. AR technology enhances a user's perception of and interaction with the real world. The virtual objects display information that the user cannot directly detect with his or her

Figure 10. A researcher demonstrates Boeing's prototype wire bundle assembly application. (Courtesy David Mizell, Boeing)[9]

own sense. The information conveyed by the virtual objects helps the user to perform real-world tasks. This new form of human-computer interaction can be applied to different industry areas. Currently six potential markets of applying AR technology have been identified. They are:

1. Medical visualization
   (i) Virtual internal organ can be overlaid with real images for pre-surgical planning and diagnostic
   (ii)Medical readings such as blood pressure can be presented in the view of a doctor to avoid attention distraction
2. Maintenance and repair
   (i) Assembling parameters such as voltage and current can be presented in the view of engineers to free their hands for other work
   (ii) Virtual objects can illustrate the repairing procedures by overlaying on top of real objects
3. Navigation system
   (i) Traffic information can be presented in the view of a driver aligned with head motion
4. Training and simulation
   (i) Military and police combat training
5. Education
6. Entertainment
   (i) Revitalizing the digital composition of animation with real scenes
   (ii) New entertainment experience
7. Aerospace industries
   (i) Robot path planning [9]
   (ii) Pilot training
   (iii) Aircraft manufacturing [9]

5. CONCLUSIONS

We foresee that Augmented Reality (AR) technology would be one of the major technologies to revitalize the digital composition of animation with real scenes and to bring new digital entertainment experience to the viewers. We propose to apply Augmented Reality technology for digital entertainment by building an enabling environment called "Augmented Reality Computing Arena for Digital Entertainment (ARCADE)" to support the development of Augmented Reality entertainment applications. The objectives of ARCADE are to ease the hurdle of applying the Augmented Reality. Through the introduction of ARCADE, we will bring in the new business opportunity enabled by Augmented Reality technology for digital entertainment sectors and provide necessary development tools and environment to execute the Augmented Reality entertainment applications. We believe the project can make new services possible for animation and entertainment business, ease the hurdle of applying AR technology to digital entertainment sectors, provide them with cost effective technology for daily use in content creations, and generate innovative, brand new entertainment experience for the end users.

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