Enabling an Augmented Reality Ecosystem: A Content-oriented Survey

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ABSTRACT

Augmented Reality (AR) is an emerging technology that provides a user experience of augmenting the real world with virtual objects, and allows the user to interact with the virtual objects in real time and space. An AR ecosystem brings content providers, users, AR application developers, AR device manufacturers, and researchers together, making the whole AR environment sustainable. As technology (e.g., sensor tracking, ad hoc routing, computer vision and mobile computing) for supporting AR applications is developing rapidly, content is emerging as a key issue to focus on. In this paper, the state of art in AR from the content generation perspective is reviewed, and three key steps are introduced, namely data collection, content fusion, and content display. Some AR systems and current trends are also briefly discussed.

Categories and Subject Descriptors

H.4 [**Information Systems Applications**]: Miscellaneous

General Terms

Human Factors, Experimentation, Design

Keywords

Augmented Reality; Ecosystem; Content Generation; Survey; Trends

1. INTRODUCTION

Augmented Reality (AR) has become an emerging technology in daily life. With accurate location information, virtual objects can be integrated with the real world, which allows users to interact between the real and virtual world. In the work of Azuma in 1997 [3], three characteristics of AR are identified:

- Combine real and virtual objects in a real environment;
- Run interactively in both 3D and real time;
- Align real and virtual objects with each other.

AR technologies, both hardware and software, have been rapidly developed in the past several years [24], and the market has driven the development of more commercial AR applications (e.g., Layar, Google goggles, and Wikitube). We envision an AR ecosystem which, with content as the core, brings together content providers, users, AR application developers, AR device manufacturers, industrial and academic researchers, and completely changes the current AR landscape (like the way iTunes has changed mobile application distribution). The AR ecosystem framework is shown in Fig.1. Content providers will aggregate data from third party companies such as Google or Wikipedia, local broadcasting sources, environmental sensors, and users, generate AR content, and export general APIs to support a large range of AR applications. Users will not only consume AR content and services but also will generate their own content (e.g., locations or local information), thanks to sensing ability of their smart devices. They will also contribute to the system in a crowd-sourcing approach, like the current YouTube model. AR device manufacturers focus on hardware design such as GPS, sensors, displays, or integration like smartphones or AR glasses. Researchers can contribute by inventing advanced techniques in tracking, computer vision, ad hoc and opportunistic data/content delivery and dissemination, mobile computing, display, energy efficiency, etc. With the ecosystem, AR application developers do not need to collect data, design their AR devices, or propose their own tracking algorithms. Instead, they can use standard APIs to get data packages from content providers, and embed existing AR-related algorithms into their devices made by third party manufacturers. Meanwhile, users can contribute through interaction with the ecosystem. Each

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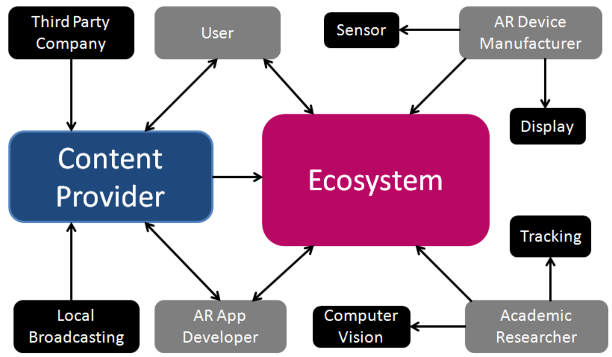

Figure 1: AR Ecosystem Framework

party in the ecosystem plays its own role, improves the efficiency of the whole AR environment, and makes it more sustainable and extendable.

Recent advances in hardware and software for AR have been reviewed in several survey papers [3, 2, 24, 20]. Localization and calibration have been the most difficult challenges since AR was first proposed in the 1960s. Current sensor networks apply multi-sensors system and cooperative localization algorithm to overcome them [22]. With the rapid development of wireless communication such as 3G and WiFi, the communication and data exchange between each components of the AR ecosystem are easy to implement. Ad hoc and opportunistic communication further provides a scalable way to deliver AR content to users, especially in the current era of mobile data explosion. The maturity of mobile computing along with the development of AR-related algorithms lays a good foundation for the AR ecosystem in both hardware and software. However, a natural challenge is how to generate the content for AR. Therefore, a core component of the AR ecosystem would be content generation [6]. Content providers aggregate data from multiple sources, process and generate structured content which will be displayed to the users by AR devices, and thereby enable the interaction with virtual objects.

In this paper, we will mainly review recent developments of AR, from a content-oriented perspective. Tracking and registration techniques are only briefly introduced but we will focus on the content generation pipeline. Three main questions will be considered: how to collect, combine, and display content. The rest of the paper is organized as follows. Section 2 describes data sensing and collection methods. Section 3 focuses on content fusion, and Section 4 discusses content display. Several AR systems are described in Section 5, and current trends and issues are discussed in Section 6. Section 7 provides a conclusion.

2. DATA COLLECTION

In AR systems, content providers render content to users or applications in various ways. In other words, content can be collected from local sensors, deployed sensor networks, or cameras. At the same time, AR devices can reach rich sources from the cloud by open APIs via wireless infrastructures or ad hoc networks. In the following part, we will briefly introduce data collection from two prospectives, through local devices or cloud servers.

2.1 Local Devices

2.1.1 *Sensors*

Sensors play an indispensable role in AR systems. Even in the earliest AR display system in the 1960s, a head sensor was installed to measure the location and orientation of the user's head. Now increasingly advanced sensors are being used and can be divided into the following classes.

- *Direct-field sensor:* sensors that measure the strength of direct field, such as magnetic sensors or gravitational sensors. They are usually small, inexpensive, light-weight and long-ranged. Even though such sensors are widely used in AR, they act more sensitively to electronmagnetic distortion and their accuracy degrades with distance.

- *Inertial sensor:* sensors that are based on a given axis or given position, such as gyroscope sensors or accelerometers. Usually three sensors are placed so that their measuring axes are orthogonal to each other. They are usually light and no reference is needed. However, errors can accumulate by the integration of rotation axis and accelerometer.

- *GPS:* Global Positioning System (GPS) that uses 24 satellites to provide global location information and is widely used in AR systems. It has extremely long range but can experience signal loss in urban areas or indoors. Moreover sometimes its accuracy still cannot meet the requirement for AR applications.

The following are some drawbacks of these sensors:

- They are easily distorted by interference;

- Some of them such as GPS are very energy intensive;

- When sampling rate varies, some of the sensors result in high latency.

Collaboration between multiple sensors to form a sensor network can improve the accuracy of the data. We will describe more details in the next section.

2.1.2 *Cameras*

A camera is another way to gather data in AR. While a few AR applications have been made through senses such as haptics and audio, most utilize vision-based sensors. First captured by a camera and later processed, such image information is utilized in two ways. One is for vision-based tracking which identifies the location and orientation of AR devices. Another is for the background information upon which virtual objects in AR system are added.

Some desirable properties of wearable cameras in AR are listed below:

- Have long battery lifetime for sufficient power;

- Capture specific information and discard useless data as early as possible;

- Be able to transmit captured images to a local device or the cloud.

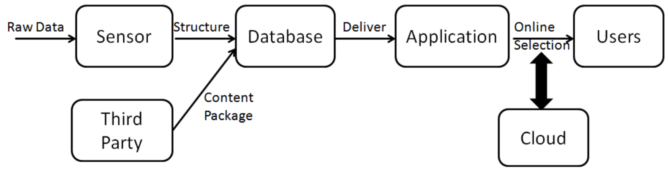

Figure 2: Content Fusion Pipeline

2.2 Cloud Server

In AR systems, local computing power and database memory are often not powerful enough to provide sufficient content. Therefore data exchange between an AR device and a cloud server is necessary. A local AR device usually first uploads its content inquiry along with its location information, and then uses open APIs to get uniform format of content package from third party companies or local broadcasting sources. In [18], an outdoor AR system is proposed for mobile phones that continuously sends its location to the server via a wireless network (ad hoc or infrastructure) and gets highly related information from the server.

Following are some limitations of servers as content providers:

- The formats of packages are usually made by third party companies, and thereby come with much redundant information.
- Since AR requires users to communicate with virtual objects in real time, it cannot tolerate high transmission latency or long inquiry processing time.

3. CONTENT FUSION

After gathering enough data from content providers, an AR system will integrate multiple data streams that represent the same real-world object, keeping the captured information consistent, accurate, and informative. Content fusion plays an important role.

For the content fusion pipeline, we can refer the three-tier model proposed by Reitmayr and Schmalstieg [14, 17]. The first tier is a database, where data is acquired from third party companies. The second tier is delivery, where the data in the database is restructured to meet the specific use of the applications. The third tier is for different applications to use, which belongs to the online content recommendation. The pipeline is shown in Fig.2.

A large amount of information is available online. However, display screens of AR systems are usually small and narrow. Therefore effective methods are necessary to determine what to display on the screen. Limited by the computing power of local devices, current AR systems usually implement content fusion offline, select highly related information, and store it in the database in advance [26]. However, since AR systems operate interactively between real and virtual objects in real time, the online content selection would be a main approach to help users get the most relevant information [21, 22, 23].

3.1 Offline Data Preprocessing

Information integration in the database can be regarded as offline content selection or data preprocessing. Usually AR application developers do not execute the function of content providers at the same time. They will download standardized format content packages from third party companies such as Google, Wikipedia, Yelp, etc. Therefore highly related and structured information is selected and assembled by these websites in advance. However, some AR application developers still want to personalize their AR system content by using their own expertise. Zhu et al. [26] propose an AR shopping assistant providing dynamic contextualization to customers. Product context is utilized and complementary products are aligned with each other in the database in advance. When customers are interested in some specific items, the shopping assistant automatically provides recommendations for closely related products as well.

3.2 Online Content Selection

For online fusion, information is automatically selected in real time, depending on the particular location, orientation, and user's preference. In 2000, Julier et al. [9] introduced the concept of information filtering to automatically select content to users. They also specified some characteristics and desirable prperties of online content selection procedures.

- Any object, of any type, at any point in time, can become sufficiently important when it passes the filtering criteria.
- Certain objects are important to all users at all times.
- Some objects are only important to the particular users.
- All things being equal, the amount of information shown to a user about an object is inversely proportional to the distance of that object from the user.

Filtering criteria helps to evaluate whether a certain object is important enough for a specific users. Based on the filtering criteria, there are three kinds of information filtering methods.

- *Distance-based filtering:* It thresholds an object's visibility based on its distance from the user. If the distance is larger than a pre-set threshold, information about the object would be invisible to the user. However, some soft-threshold methods are proposed as well. One example is the Touring Machine [8], the brightness of augmented labels decreases as they are further far away from center.
- *Visibility-based filtering:* The visibility of virtual objects depends on whether the real objects are visible to user at the current time. It will automatically prevent extra information of invisible objects from being displayed on the screen.
- *Advanced filtering:* Benford et al. establish a spatial model, using focus and nimbus to determine the importance of objects [7]. [9] proposes hybrid filtering, which combines a spatial model and logic rules together with knowledge of the user's objectives.

Currently more advanced techniques are being used for online content selection. When the goal of the user is well defined, location is often one of the most important criteria for content selection. [21] proposes a touring system to help reconstruct archaeological sites using wearable and mobile computers. Based on the different locations, computers will automatically download related information, providing archaeological sites and audio narration. The in-car intelligent system [22] updates surrounding traffic information for drivers in real time to avoid possible accidents. Specifically, social messages from other drivers such as "Follow Me" or warnings from the sensor systems of other cars such as "Distracted Driver" are augmented to the current driver through the intelligent system, improving car-to-car communication. [11] proposes an AR education system, with an automatic content selection procedure. Through mobile devices and positioning systems, learners have access to relevant information as they arrive at certain locations.

Sometimes when the purpose or the preference of the customers are uncertain, designing such a content selection criteria can be more challenging. Plenty of historical data is stored and much calculation is required to better understand a user's preference. The shopping assistant in [26] provides personalized item recommendations based on customer preferences by using the collaborative filtering algorithm. The most related items are recommended as customers walk around. [23] further extends the idea into multi-dimensional recommender systems and proposes a graph-based algorithm to automatically recommend AR users some places of interest, based on the time, location, user history, and social network information.

In all, content fusion plays an important role in AR systems. Offline data preprocessing deals with large amounts of data in cloud servers with high speed and the data is stored with a predefined structure. After that the online content selection is processed by local AR devices as real-time data is collected from devices. However, computational power or memory can be limitations that prevent complex algorithm implementation. Therefore sometimes crowd-sourcing or cloud computing is applied to address the limited computing power of local devices.

4. CONTENT DISPLAY

Data often becomes structured and useful through fusion, organized in a consistent and informative way. Afterwards, content is displayed to users for interaction.

Previously, the simplest AR system was a 3-dimensional head-mounted-display(HMD), and displays remain a fundamental technology in AR. Based on the method of carriage, displays for merging virtual objects and the real world can be classified into the following categories: head-mounted, projection-based, and handheld.

4.1 Head-mounted Displays

Head-mounted displays are the most traditional displays in AR. Users wear this kind of display on their heads, like glasses, and see the world through it. Basically there are two categories of HMD: optical see-through HMD and video see-through HMD.

- *Optical see-through:* a semi-transparent mirror is used, through which users can see the real world. At the same time, a display overlays virtual objects onto the real world as well. The advantages of optical see-through displays include easy implementation, high resolution, safety, and no eye offset.

- *Video see-through:* a video camera is used to capture the background of the real world, combine it with virtual objects together, and directly display it on the screen like a video. Therefore fusion of virtual objects and the real world is needed in local devices. Compared with optical see-through displays, the advantages of video see-through displays include high flexibility in composition, wide field-of-view, consistency in luminance, and high delay tolerance.

Previously HMDs were large, heavy, and not easily portable while recently HMDs have become lighter, smaller, and much more user-friendly. Google Glass is one of the newest HMD products. They are smaller than real glasses, and the field-of-view of its camera is no less than human eyes.

4.2 Projection Displays

Projection displays generally use projection technology to augment three-dimensional objects in the real world by projecting graphics onto their visible surfaces. It does not require users to wear anything and thus operates with minimal intrusiveness. It also has low latency because projectors and the augmented objects keep relatively still in most cases. However, several users have to share one augmented object at the same time. Luminance compensation is needed to overcome uneven surfaces. Moreover multiple projectors are sometimes used from different directions to coordinate. This brings a greater requirement for calibration and registration compared with a single display source. Recently Mine et al. [13] propose a projection-based AR system applied in a Disney Theme Park. Besides the challenges mentioned above, they also mention the real-time masking problem, which refers to the ability to selectively project or not project on parts of a scene. Dynamic tracking of objects is often applied to overcome this difficulty.

4.3 Handheld Displays

Recently AR experiences have begun to be displayed by mobile devices such as Tablet PCs, PDAs, or smartphones. This is the current trend for AR systems because tablets and smartphones are becoming increasingly popular. The maturity in mobile computing and wireless communication technology is further supporting the development of mobile AR. Many navigation-based applications [18] have been proposed in handheld displays. In addition, [16] proposes a handheld AR system for underground infrastructure visualization. Compared to the other two displays, handheld displays are light, convenient, and increasingly popular since smartphone use is becoming ubiquitous. However, limited computing power and battery life are still open challenges for handheld displays.

5. CURRENT AR SYSTEMS

Currently AR systems are still immature and most applications are in their prototype stage. However, they have shown a new way to make use of virtual information, augmenting the real world.

5.1 Specialized Field

AR systems are widely used in many specialized fields such as manufacturing, medicine, and the military. [16] presents an AR system to help field workers of utility companies in outdoor tasks such as design, maintenance, or repair. [25] describes an AR system applied to automotive spot welding inspection. The location of spot welds and operation description sheet information are augmented, making it easier for technicians to locate the spot welds. Medical AR systems are usually based on HMD, freeing the hands of surgeons. Accurate calibration and time synchronization are significant issues in this area, and even incorrect depth perception can lead to serious consequences. Specifically, [19] presents an AR system for oral or maxillofacial surgery, providing 3D virtual presentations of osseous structures and soft tissues in the patient's body.

5.2 Everyday Use

In addition to AR systems in specialized fields, there are a number of applications for everyday use such as multimedia services, advertisements, remote meeting, touring, navigation, entertainment, etc. [10] proposes an AR remote conferencing system, allowing remote users to view and interact with virtual objects using a shared virtual white board. In [21], an AR system is used to add archaeological sites into the real world, producing the feeling of the past for tourists. A number of mobile applications such as Layar and Wikitude have been introduced to help users to navigate with extra information provided. A similar project is Google Glass. Its goal is to integrate mobile phone, notebook and GPS together. [13] uses AR techniques to create 3D graphics, enhancing the theme park experience. A number of mobile games produced by Total Immersion and Metaio are also based on basic AR technology, augmenting the real world with virtual graphics. Recently, the concept of an AR in-car system is proposed, with which an intelligent car can help drivers visually perceive data streams from other cars [22].

6. CURRENT TRENDS AND ISSUES

6.1 Tracking and Registration

Tracking has been one of the most difficult challenges in this area since the 1960s when AR was first proposed, and it still remains a challenging problem [24]. Sensor-based tracking methods are limited by accuracy, while vision-based tracking methods are limited by their scope and power consumption. The development of sensor networks could help to combine tracking data and improve localization accuracy. Sensor networks, however, demand a new method of fusion. Individual tracking of hundreds or thousands of devices can be problematic, especially when data from many devices have different formats and accuracy. Furthermore, devices may be partially out of operation due to unobservable and dynamic environments. Therefore, how to reconstruct the location from incomplete data is another challenge in sensor networks.

6.2 Content Fusion

Information precision is becoming one of the most important issues when users encounter unstructured data. Therefore, data selection and content fusion using artificial intelligence and machine learning techniques are needed to structure the data and simplify the content. Online processing usually needs a powerful device and large memory to support complex algorithms. In some cases, algorithms have to be modified to fit the need of mobile devices for online processing, or they can be run in the cloud or even offline. [5] is some recent work in this area. The proposed AR mobile system delivers personalized and location-based restaurant recommendations to tourists by continuous analysis of social media streams such as tweets. With the application, users can see the social media comments as well as the location of restaurants through the advertisement. Also the restaurant list can be sorted by distance, preference, social media comments, etc. It is a combination of recommender system and AR mobile system.

6.3 Energy-efficiency and Cloud Computing

Mobile AR systems have become increasingly popular in recent years. However, mobile devices are limited by their computational power and battery life. Therefore, cloud computing may become an important direction in AR for energy conservation. In 2012, Kosta et al. [12] proposed the ThinkAir, by dynamic resource allocation and parallel execution in the cloud for mobile code offloading, to enhance the power of mobile cloud computing and significantly reduce energy consumption. Moreover, the concept of cloud sensing is raised, which collects sensor data from a large number of mobile users, enhancing user-generated content and saving resources in large ad hoc networks [4]. For example, when a user drives to a specific place using an AR navigation system, the cloud will collect data from local users and make an estimate of local traffic at the same time [22].

6.4 Security and Privacy Issues

Sometimes new technology is not readily accepted by society when it is immature. Roesner et al. [15] conducted a survey on security and privacy issues in AR with respect to input, output, and data access. Input validation, output conflicts, and access control are some of the main issues for privacy preservation. Acquisti et al. also raise a privacy issue resulting from AR [1]. They develop a real time demo on a mobile device, overlaying information obtained from third party websites such as Facebook over the image of an individual's face. This successful demo, combining available information both online and offline, exposes some significant risks involving privacy issues in AR. For example, individuals may not be comfortable if strangers in the street could determine their names, interests, or possibly even SSNs through AR devices or applications.

7. CONCLUSION

This paper provides a survey on the state of art in AR from a content-oriented perspective. The general concept and main components of the AR ecosystem are described, and a core component of the AR ecosystem, the content component, is introduced. Three main steps are how to collect, aggregate, and display content. Finally, we conclude with a brief discussion of trends and issues with current AR systems. Data fusion is widely used for more accurate tracking and calibration to meet application requirements. The concept of content fusion is brought into AR, with the application of artificial intelligence technology. Limited by computational power and memory, efficient algorithms and cloud computing are applied to reduce energy consumption. Moreover, social impact and privacy preservation are other emerging issues in AR as the technology matures.

8. ACKNOWLEDGEMENT

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