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AUGMENTED REALITY
FOR LOCATION-BASED
ADAPTIVE MOBILE LEARNING

BY

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ABSTRACT

Augmented Reality (AR) has become a popular interactive technique in the last few years. One of the critical challenges is to identify the real-life objects. Further, how to fully exert the advantages of the AR technique under the limited resources available on the mobile devices is another critical challenge. To resolve the above issue, firstly this thesis reviewed the real-life object tagging and identification techniques. Secondly this thesis studied the Human Computer Interaction (HCI) Interface and the environmental sensors on the mobile phones. Lastly this thesis implemented a Multiple Real-life Object Identification Algorithm along with the development of the Multi Object Identification Augmented Reality (MOIAR) application. Subsequently, the MOIAR application has been implemented in the location-based mobile learning environment, where the Legislative Assembly of Alberta is included as an example real-life learning object. This MOIAR implementation has applied the tagging and identification technique review as well as the HCI and sensors study, to prove the usability and practicability of the MOIAR application.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter I. Introduction

1.1 Research Background

In the past few years, learning process has evolved from face-to-face learning, distance learning, and now to mobile learning which uses portable devices for learning while the learners are on the move. Development of computer and network technologies also brings challenges and opportunities for the daily life. In fact, computing devices have become ubiquitous in today's academic environment as well. From notebook computers to wireless phones and hand-held devices, the massive infusion of computing devices and rapidly improving Internet capabilities have altered the nature of higher education (Green, 2000). Computer assisted learning has proliferated tremendously in the past few years with the use of Internet, email, multimedia technology, and intelligent tutoring system in academia.

Now with the emergence of new functionality in mobile devices, mobile learning can be conducted anytime and anywhere. From the pedagogical perspective, the advantages of mobile learning could not be fully exploited and demonstrated if the mobile learning is only conducted by using the mobile browser to access learning contents without using the native functions and features of the mobile devices. Currently, there are more and more location-based experiences occurring in our daily lives, such as location-based information services, location-based games, and location-based ubiquitous learning (Benford, et al., 2005 ; Hwang, 2006). In fact, mobile devices with built-in Global Positioning System (GPS) receivers and A-GPS services are becoming increasingly popular. Utilizing a mobile device's location awareness capability within mobile learning applications has now become a reality (Tan, Huang, & Jeng, 2009). One of the emerging research emphases is to utilize the location-awareness functionality of the mobile devices to further strengthen mobile learning. Previous research (Patten, Sánchez, & Tangney, 2006 ; Michie, 1998) have also indicated that the combination of location-awareness and a contextual learning approach can enable learners to better construct meaningful contextualization of concepts.

Alongside mobility, development of positioning technologies makes it possible to keep track of the learners and provide them with tailored learning contents based on their real-time locations. Furthermore, location-based e-learning provides a personalized learning experience and helps in keeping the learners engaged in the learning activities and enhancing their effectiveness. For example, in terms of ubiquitous learning applications, (Chen, Li, & Chen, 2007) proposed a personalized context-aware ubiquitous learning system with ability to exploit appropriate context based on learners' location, leisure learning time, and individual abilities to adapt learning contents towards learners for promoting the learning interests and performance. Situational learning approach proposed by (Hornby, 1950) indicated that context is an important factor in the learning process and it can enhance learners' learning interest and learning effectiveness. These examples suggest that meaningful knowledge is constructed primarily when the learning process integrates with social culture and life-context. The research in this thesis therefore adopts four types of contextual information as proposed by (Dey, 1999), namely **Identity**, **Time**, **Activity**, and **Location,** for building context-aware applications to provide the most relevant information in the right format, at the right time and at the right place to the right person.

With the emergence of Ubiquitous-Virtual Reality (U-VR), the interactions of learners with contents and services have also been changing radically (Kim, Suh, Lee, & Woo, 2006). The aim of U-VR is to increase the quality of human life by providing learners with personalized services and contents according to social human activity in mixed reality environments (Lee, Oh, Shin, & Woo, 2009). The contents in U-VR environments also have been evolving with intelligence, realism and mobility (Kim, Oh, Han, & Woo, 2009). Moreover, a lot of prior research has been trying to realize a new interaction method by combining context-awareness and Mobile Augmented Reality (MAR). The first generation of MAR using context-awareness was based on laptops and mainly used location information as a context (Höllerer, Feiner, Terauchi, Rashid, & Hallaway, 1999 ; Bauer, et al., 2001). Afterwards, the convergence of context-awareness and MAR started to shift to lightweight platforms such as PDAs, Ultra Mobile Personal Computers (UMPCs) and mobile phones (Henrysson & Ollila, 2004 ; NOKIA Mobile Augmented Reality Applications Project ; Schmalstieg & Wagner, 2007). Subsequently, researchers focused on using a domain knowledge and behavior model to improve interactions in MAR (Barakonyi & Schmalstieg, 2006 ; Lee, Seo, & Rhee, 2008).

Ubiquitous learning offered through the Mobile Augmented Reality Systems (MARS) requires well engineered system/software architecture in order to deliver on-demand instructional services. Target applications generated from the architecture require instructional capabilities for understanding individual learning strengths while tailoring empirically evaluated pedagogical techniques to enhance learning performance. In order to significantly impact learning, a MARS e-learning tool needs to consistently measure learning progress and continuously update information about the learner for the duration of the learning interaction. Hence, a MARS e-learning tool may continually process learning data associated to a given context for a given learner.

1.2 Research Issue

Augmented Reality (AR) has become a popular display technique in the past few years. It can be defined as a technique to display virtual contents superimposed upon different real-life objects. On the other hand, the purpose of the location-based adaptive mobile learning is to provide adaptive learning content according to different location-based learning objects in a real-life learning scenario. The research in this thesis has identified that as an emerging content display technique; AR techniques can improve and enhance the current learning content display approaches as well as the interactions between the learner and the learning content.

However, one of the critical challenges is to properly identify the real-life objects, and this is the main research issue tackled in this thesis. As mentioned above, AR aims to define a new way of displaying content. The main purpose of the AR is to identify what real-life object is the learner currently seeing on the device’s screen, or in other words, what real-life object is the camera lens currently facing, and then to display the virtual content that relates to the identified object. The AR technique must have the ability to identify the real-life object in order to provide the right content at the right time.

As mentioned above, the extensive popularity of mobile devices as well as the increasing location-based experiences has been occurring in academia and our daily lives. From the pedagogical prospective, it is better to utilize the native functions and features of the mobile devices if we want to fully exploit and demonstrate the benefits of mobile learning. Furthermore, context is an important factor in the learning process and it can enhance the learners’ learning interests and outcomes, and help in improving the construction of meaningful knowledge. Therefore, to take full advantage of the mobility aspect of mobile learning and the immersiveness of location-based and context-awareness learning, optimization and improvement of the way current location-based mobile learning is being conducted, becomes an important issue.

The research in this thesis aims to integrate the AR technique into the location-based adaptive mobile learning scenario. In order to fully exploit and demonstrate the benefits of mobile devices in mobile learning scenarios, it is important to utilize the native functions and features of the mobile devices. Hence, the second issue of investigation is: what kind of built-in human computer interface on the emerging mobile devices, especially smart phones, can provide the real-life object identification ability.

Lastly, AR applications in general, require a decent amount of computing resources. For example, image processing types of AR require constant connection to the server database for image matching, object recognition and identification; or in the absence of image processing; they require multiple additional markers to attach on each real-life object. For image processing, it also takes a lot of work to build up the image database.

Therefore, the final issue tackled in this research is: how to fully exert the advantages of the AR technique as well as to adapt the limited resources on the mobile devices, in order to develop an AR mobile learning application that requires lesser resource usage, redundant human/device interaction, lower information communication frequency and bandwidth, and least additional hardware for providing adaptive learning contents?

1.3 Research Objective

To resolve the three above research issues, three research objectives are accomplished in this thesis. The first research objective is to study various AR real-life object tagging and identification techniques, divided in two parts. In the first part, various real-life object tagging and identification techniques are reviewed. The second part defined and classified three different approaches to identify the real-life object. The three approaches, namely Learner-Assisted Identification, Manual-Device Identification, and Auto-Device Identification, are classified based on the level of human assistance. The second research objective reviewed the Human Computer Interaction (HCI) interfaces and the environmental sensors available on the emerging mobile devices, especially the smart phones, in order to utilize the mobile devices' native functions and features. This research objective defined and analyzed the mobile devices' HCI interfaces and the environmental sensors, in order to understand what features and abilities can assist the AR application to identify the real-life learning objects. The last research objective proposed and implemented a Multiple Real-life Object Identification Algorithm, based on the finding of the above two objectives. The algorithm aims to identify the real-life learning objects according to the predefined location information and current location and orientation of the mobile device. Further, the algorithm can identify the same RLO even if the learner is at different location and orientation, and provides the basic guidance ability. In order to further improve the learning contents adaptability, the research in this thesis also utilized a 5R adaptive mechanism that can not only assist in identifying the real-life learning object of interest, but also provide the content of interest.

In order to apply the finding of the above conceptual research objectives to prove the usability and the practicality of the Object Identification Algorithm, a system called **Multi Object Identification Augmented Reality (MOIAR)** has been developed, which integrates the Real-life Object Identification Algorithm and the 5R Adaptive Mechanism (Chang, Tan, & Fang, 2010 ; Chang & Tan, 2010). A location-based mobile learning scenario has been realized using the MOIAR system, containing the **Legislative Assembly of Alberta** as a real-life learning object, to prove the usability and the practically of the MOIAR system. The MOIAR system has accomplished the following objectives:

(1) The MOIAR system utilized the Augmented Reality technique to improve and enhance the way of displaying the learning content, as well as the interaction between the learner and the content.

The MOIAR system aims to not only provide the learning content, but also allow the learner to interact with the Real-life Learning Objects (RLO) in the simplest and most intuitive way. Further, with the collaboration of AR, location-based service, adaptability, and mobility, the MOIAR system has the potential to eliminate some of the learning limitations and disadvantages that exist in the prior traditional learning experiences.

(2) The MOIAR system utilized the Multiple Real-life Object Identification Algorithm.

In location-based and adaptive mobile learning scenarios, learners may have to study learning content or to accomplish learning activities and tasks within several real-life learning objects. The MOIAR system can identify multiple real-life learning objects according to the predefined location of each real-life learning object and current location and orientation of the mobile device. Current location and orientation of the mobile device are expected to change constantly during the learning process.

(3) The MOIAR system has the basic learning objects guidance ability in the real-life learning scenario.

The MOIAR system has the location-based real-life learning object guidance ability, which also takes advantage of the AR display technique to guide the learners through multiple real-life learning objects in different learning scenarios.

(4) The MOIAR system not only identifies the Object of Interest, but also provides the Content of Interest.

Further, in order to provide learning content tailored for each learner, a content adaptive mechanism proposed by Tan (2009) is implemented to the MOIAR system, namely the **5R Adaptive** mechanism that aims to provide the Right Contents at the Right Time at the Right Place for the Right Device to the Right Person.

1.4 Thesis Organization

The rest of the thesis is organized as follows. Chapter II provides a comprehensive literature review of Mobile Learning, AR, Location-based Service, the Location-based Service with AR in Mobile Learning and Adaptive Mobile Learning. Chapter III introduces the Real-life Object Identification techniques behind the scene of the Mobile AR, which include the extended definition of the Augmented Reality, the Object Tagging and Identifying techniques, and the study of the Emerging Mobile Device HCI Interfaces and environmental sensors for assisting the AR. In Chapter IV, the complete MOIAR system design is discussed, including the MOIAR system and scenario design, the system functionality which refers to the research objectives, and the system development methodology along with the system framework and development process. Chapter V describes the complete MOIAR system development and implementation with the help of screenshots. The research conclusions and future work are discussed in the last chapter.

Chapter II. Literature Review

2.1 Learning contents in Mobile learning

There have been significant advancements in wireless and mobile technologies in recent years. Now people live in more or less mobile age. With the new paradigm “anytime and anywhere computing”, a shift from “Electronic” to “Mobile” services has begun (Lehner & Nösekabel, 2002). The impact of wireless and mobile technologies has also started to be seen in education. M-learning has been defined as e-learning through mobile and handheld devices using wireless transmission (Bhaskar & Govindarajulu, 2008). M-Learning combines individualized (individual or personal) learning with anytime and anywhere learning. The learning is facilitated by the use of Internet, small portable computing devices and e-learning. These computing devices include Smart Phones, Personal Digital Assistant (PDA) and other similar wireless and handheld (W/H) devices. With a W/H device, the relationship between the device and its owner becomes one-to-one, always on, always there, location aware, and personalized (Wood & Homan, 2003). The place independence of W/H devices provides several benefits for e-learning environment, such as allowing students and instructors to utilize their spare time while traveling in a train or bus to finish their homework or lesson preparation (Virvou & Alepis, 2005). Similar arguments have been made in the business world on how a W/H device can improve time management efficiency by converting workers' dead-time into a productive activity (BenMoussa, 2003). The key features of using a W/H device for e-learning include its personalization capability and extended reach; this has potentially attracted more and more learners, especially adult learners. W/H devices have the potential to change the way learners behave and interact with each other and with the learning environment. A typical scenario is that of a learner who is enrolled in an e-learning class, while waiting for his/her flight at the airport, the learner can access class materials or interact with classmates and instructors or download an assignment.

However, mobile learning with W/H device still has issues regarding contents limitations. As in the example mentioned above, learners are able to receive learning contents in order to study or do assignment anytime and anywhere, resulting in convenience and time saving from the contents delivery point of view. The performance may not be as positive as the convenience because of the noise from the "mobile learning environment", which may distract learners from the learning contents because most of contents may not be related to the surrounding environment. Learning on W/H devices will probably not replace traditional classroom or other electronic learning approaches. However, if leveraged properly, mobile technology can complement and add value to the existing learning models such as the social constructive theory of learning with technology (Brown & Campione, 1996). The constructive learning model states that a learner has to act and reflect in an environment. Action could be a task of solving a problem and reflection could be abstracting from the derived solution and accumulating in one's experiential knowledge.

Contents that relate to nearby objects and are delivered based on learners' location, and are also adapted to learners' profile and preference, have the potential to increase the opportunities of interaction with the environment and decrease the distraction. As in the example mentioned above, a learner who is waiting for flight at the airport, and assuming that the e-learning class he/she is taking is English, delivering "How to check-in at the airport English" instead of "Introduction to Business English" would be more helpful in improving learning performance and gaining better attention, interest and motivation of the learner. Applications of mobile technology in education can provide benefits to both learners and instructors. Mobile technology provides greater flexibility. With mobile devices, educational materials are not only readily available to learners but they can also be delivered to learners based on their needs and preferences (Foster, 2005 ; Chen & Kinshuk, 2005).

Furthermore, research into new mobile technologies that enhance instructional activities will continue to help the educational community as it embraces the idea of anytime, anywhere learning. M-learning is not just about readily accessible information; it opens up the possibility for the delivery of multimedia information, interactive learning and assessment according to the abilities and features of different devices.

2.2 Augmented Reality

Augmented Reality (AR) has become one of the most popular topics in academic research fields and the state-of-the-art interface design of innovative mobile learning application system development. The widely accepted definition of Augmented Reality is given by (Azuma R. T., 1997 ; Azuma, et al., 2001):

“Augmented Reality allows the user to see the real world, with virtual objects superimposed upon or composited with the real world. AR supplements reality, rather than completely replacing it.”

Which means it would appear to the user that the virtual and real objects coexisted in the same space. Moreover, AR requires much more accurate position tracking combined with precise orientation tracking. It can provide a powerful user interface along with adaptive contents display for mobile location-aware environment, to interact directly with the electronically enriched world around us.

AR is thought to present certain advantages over more traditional ways of accessing information (Anastassova, Burkhardt., & Mégard, 2007). The co-existence of the real and the virtual could enhance productivity by facilitating comprehension of the tasks to be performed in various fields, such as in industry, medicine or education. In education specifically, AR has been praised for its potential in the comprehension of physical phenomena, as demonstrated by the European "Connect" project (Horn, 2006).

In addition, as the user is assisted by supplementing the existing world instead of creating a new one, the limited level of immersion is thought to provoke fewer problems of cyber sickness. Cyber sickness is a term that describes motion sickness experienced by users of head-steered Virtual Reality systems. In a typical Virtual Environment, users often view moving scenes while they remain physically stationary. This situation can cause a compelling sense of self motion (called vection). Examples of cybersickness symptoms include nausea, eye strain, and dizziness. Applications have so far been developed in the domains of military and medical training, urban planning and architecture, as well as for industrial maintenance work (e.g. in automotive and aerospace industry), entertainment and lately also for cultural heritage (Damala, Marchal, & Houlier, 2006).

2.2.1 Mobile Augmented Reality

A Mobile Augmented Reality System (MARS) that provides on-demand instruction as well as context-aware services requires reusable, interoperable, scalable, and robust system/software architecture. MARS combines research in AR and mobile/pervasive computing, in which a wearable see-through heads-up display and increasingly small computing devices to communicate over wireless networks in order to allow users to freely perceive real world objects superimposed with digital annotations

(Hollerer & Feiner, 2004). MARS provides flexible mobility and a location independent service without constraining the individual to a specific area. By doing so, this technology holds the potential to revolutionize the way in which information is presented to people and has enormous potential for on-demand, context-aware, and collaborative training (Höllerer, Feiner, Hallaway, & Bell, 2001).

MARS applies the AR interface concept into truly mobile settings. In fact, it demands some specific technologies coming together in making this feasible: mobile computing, mobile displays, built-in camera, the location-based technologies like GPS, wireless communication and services. There are many applications in various fields that have been developed by implementing AR to create the innovative interaction, for example, assembly and construction, maintenance and inspection, navigation and path finding, tourism, architecture and archaeology, urban modeling, geographical field work, journalism, entertainment, medicine, military training and combat and personal information management and marketing (Hollerer T. H., 2004).

MARS in Mobile learning applications provides the intuitive human-computer interface while carrying the advantages of flexibility, portability, mobility and context-aware instruction to innovatively provide personalized and location-based adaptive contents for individual learners to interact with the real mobile learning environment (Doswell, 2006). The context-aware requirement of MARS learning includes the ability to deliver instructional information based on location, the learner's learning strengths (e.g., tactile, auditory, visual, etc.), time of the day, emotional state of the learner, previous knowledge of the learner, and cognitive capabilities of the learner (e.g., adapted to cognitive disabilities). The architecture should also be designed as an extendable and flexible infrastructure to support additional contextual data without impacting the core of the system/software architecture design and to consistently deliver pedagogically correct instructional content independent of an individual MARS display.

2.3 Location-Based Service

The main origin of location-based service (LBS) was the E911 (Enhanced

911) mandate, which the US government passed in 1996 (Bellavista, Küpper, & Helal, 2008). The mandate was for mobile-network operators to locate emergency callers with prescribed accuracy, so that the operators could deliver a caller's location to Public Safety Answering Points. Early LBS was reactive, self-referencing, single-target, and content-oriented. This started to change with the maturation of low-power positioning technologies (such as assisted GPS), LBS middleware technology, and 3G mobile networks. Initial versions of these services were based on cell-ID positioning using triangulation techniques, which suffered from low accuracy and were soon replaced by GPS. With the emergence of GPS-capable mobile phones, users started to write small applications passing location data to a central server to make their location available to other users. Soon, these early initiatives turned into professional businesses that created a broad range of proactive and multi-target services—such as for mobile gaming, marketing, health and education.

In fact, there are four major revolution perspectives of LBS which make LBS a powerful functionality for learning applications. **From reactive to proactive**, where reactive LBSs are explicitly invoked by the user, for example, a user might request a list of nearby points of interest manually, and proactive LBSs, on the other hand, are automatically initiated when a predefined event occurs, for example, if the user approaches or leaves a certain point of interest or another target/object. **From self- to cross-referencing**, it is important to distinguish between the user, who requests and consumes an LBS, and a target, whose location is requested for LBS provisioning. Self-referencing LBSs are services in which the user and target coincide, while cross-referencing LBSs exploit the target location for service-provisioning of another user, thus requiring stronger privacy protection. In particular, targets should be able to restrict access to their location data to a limited and well-defined group of users. **From single- to multi-target**, another relevant classification concerns the number of targets participating in an LBS session. In single-target LBSs, the major focus is on tracking one target's position, which is usually displayed on a map or in relation to nearby points of interest. In multi-target LBSs, the focus is more on inter-relating the positions of several targets among each other. Nowadays, LBSs detect the proximity of multiple targets (Cupper, Treu, & Linnhoff-Popien, 2006). **From content- to application-oriented**, where content orientation occurs when LBSs aim to deliver relevant information depending on users' locations. Examples include a list of points of interest, maps, or information about nearby sightseeing. Today's LBSs offer applications tailored to the user and delivered dynamically on the basis of current location and execution context. The delivery of such dynamic applications is impromptu, which provides a more powerful and richer interaction model (Bellavista, Küpper, & Helal, 2008).

2.3.1 Location-Based Learning

Location-based m-Learning systems provide the learners with the learning contents based on their real-time locations while learners are on the move. They facilitate the learning activities by integrating the learning contents with the physical world and selecting only the most relevant information. Examples of scenarios that could work with location-based m-Learning systems can be found in museums, botanical gardens, national parks, campuses and so forth.

(1) Location-Based Content Delivery:

The most important functionality of a location-based m-learning system is to provide the learning contents according to the learner's current location. The relevant learning contents in his/her vicinity will be presented to him/her by the system automatically while learners walk in the learning area. This involves the following steps: (1) estimating the current location of the learner by a lone or a composite positioning approach; (2) performing location-dependent content queries to retrieve the relevant learning contents in the vicinity; (3) composing the location-dependent learning contents into a personalized presentation; and, (4) delivering the presentation to the learner (Zhou & Rechert, 2008).

(2) Guiding Ability:

In addition to delivering the learning contents according to the learners' locations, location-based m-learning systems are able to provide learning tours and guide the learners through the tours, which may be predefined or dynamically generated on-the-fly. For the beginners, who have no idea about the learning area, the system provides a predefined introductory tour and guides them through the tour, so that they can get a basic understanding of the learning area. Afterwards they can go to the specific places that they are interested in. Those learners who have specific learning goals, they can specify what they want to learn. Based on their specification, the system generates the specialized tours on-the-fly and guides the learners through the tours. When the learners walk in the learning area, the system provides them with the nearby learning contents. After the presentation of learning contents for a specific learning topic, the system recommends the next learning topic and is able to guide the learners to the learning contents related to that topic. (Zhou & Rechert, 2008)

2.4 Location-Based Service with Augmented Reality in M-Learning

The ability to combine digital media/information and augment the physical world is commonly referred to as Augmented Reality (AR). Moreover, this ability to fuse digital media within the physical world gives way to the potential for AR learning which creates the ideal conditions for locative, contextual and situation-based learning scenarios. Recent advances in mobile technologies are the primary reasons for the AR learning scenarios to emerge. "The incorporation of various rich sensors into new phones such as GPS location, wireless sensitivity, compass direction, accelerometer movement as well as sound and image recognition is enabling new ways in which we are able to interact with the world around us." (Nokia Research Center, NRC., 2009) Furthermore, the tools (software) and technologies (hardware) are more evenly distributed and are at our disposal to deploy mixed reality learning scenarios that deliver rich and immersive AR content which could potentially re-shape how individuals and groups approach learning and education.

Majority of the prior research about applying AR into education has indicated that the intuitive interaction of AR has greatly improved learning efficiency, motivation, and overall performance. For example, a research (Chen & Tsai, 2010) proposed a novel game-based English learning system with context-aware interactive learning mechanism which can appropriately provide a corresponding game-based English learning scene to the learner’s handheld device based on the learner’s location context. The proposed system aims to construct a mixed reality game learning environment that integrates virtual objects with real scenes in a university library. The preliminary experimental results reveal that the proposed learning mode provides likely benefits in terms of promoting learners’ learning interests, increasing learners’ willing to learning English. A research (Liu, Tan, & Chu, 2007) constructed a learning system called HELLO (Handheld English Language Learning Organization). It consisted with 2D barcode and handheld AR which has 3D animated virtual learning partner (VLP) over the real world. The student can complete the context-aware learning process by talking to the VLP and to learn in the designed game-based pedagogic scenario to improve students' English level. Another research (Juan, Beatrice, & Cano, 2008) presented an AR system for children of the Summer School of the Technical University of Valencia for learning about the interior of the human body. In addition, they presented two AR interactive storytelling systems that use tangible cubes for the same students as mentioned above to learn with the 8 different ends of the Lion King story (Juan, Canu, & Giménez, 2008). A research by (Wagner & Barakonyi, 2003) proposed a piece of educational software that uses collaborative AR on fully autonomous PDAs running the application which is laid out as a two player AR computer game, together with an optical marker-based tracking module to teach learners the meaning of kanji symbols. Another research by (Kaufmann, 2003) developed a collaborative AR application, called Construct3D, specifically designed for mathematics and geometry education. Construct3D is based on the mobile collaborative AR system "Studierstube" within the greater context of immersive virtual learning environments.

2.5 Adaptive Mobile Learning

The concept of adaptation has been an important issue of research for learning systems in the past few years. Research has shown that the application of adaptation can provide a better learning environment since learners perceive and process information in very different ways (Lee M.-G. , 2001). So, the adaptive educational systems provide effective alternative to the traditional teaching; they can be considered to be the next generation of e-learning. These systems attempt to be adaptive by building a model of the goals, preferences, level of knowledge, and so forth of each individual student, and using this model throughout the interaction with the student in order to adapt to his/her needs. There are two levels of adaptation in the adaptive e-learning systems, depending on who takes the initiatives: the system or the student. These terms lead to two different forms of adaptation: **Adaptivity** and **Adaptability** (Kay, 2001). Adaptivity refers to the capacity of a system to adapt its presentation according to the student characteristics in a system-controlled way, whilst adaptability refers to the capacity of the system to support end-learner modifiability. The term adaptive is often confused with adaptable. Systems that adapt to the learners automatically based on the system's assumptions about learner needs are called adaptive. Systems that allow the learner to change certain system parameters and adapt their behavior accordingly are called adaptable (Oppermann, Rashev, & Kinshuk, 1997). In designing the adaptive e-learning systems, a critical issue is how to find balance between these two levels of adaptation (Papanikolaou, Grigoriadou, Kornilakis, & Magoulas, 2003).

A lot of prior research works have indicated that implementing suitable adaptive engine into mobile learning will significantly improve the learning motivation, interest and performance. For example, CAMCLL, a context-aware location-independent learning system, teaches Chinese to the students whose language levels are not enough to make conversations in Chinese, by providing appropriate sentences to different learners based on contexts **(AL-MEKHLAFI, HU, & ZHENG, 2009)**. The CAMCLL context includes time, location, activities and learner levels. Adaptive engine of CAMCLL is based on ontology and rule-based matching. TenseITS teaches English language to foreign students through meeting their demands **(Cui & Bull, 2005)**. Learner model in TenseITS is designed based on four context factors: location, interruption/distraction, concentration and available time. Appropriate learning materials for different learners are selected based on the information represented in learner model. Furthermore, a full adaptive learning system should include all the components of the learning process: representing the content, implementing the instructional strategy and providing a mechanism for assessing the student's learning progress **(Modritscher, 2007)**. On the other hand, many adaptive systems focus the adaptation efforts on the assessment (both, exams and self-assessments) instead of on content presentation. For example, SIETTE emulates oral exams and infers student's knowledge through adaptive tests, by putting questions to the student adapted to his/her current knowledge (Guzmán, Conejo, & Pérez-de-la-Cruz, 2007 ; Conejo, et al., 2004). Besides, self-assessment tests done with SIETTE can offer hints with the question or provide feedback with the answer, focusing on cognitive diagnosis.

Chapter III. A Study of Mobile AR Technology

3.1 The Extended Definition

In mobile AR, one of the most important topics that need to be studied further is the **Real-life Object Identification Methodologies and Technologies** that are behind the content augmentation. One of the most widely accepted definition of AR is as follows (Azuma R. T., 1997): "Augmented Reality allows the learner to see the real world, with virtual objects superimposed upon or composited with the real world. AR supplements reality, rather than completely replacing it, which means it would appear to the learner that the virtual and real objects coexisted in the same space."

The purpose of this research is to investigate real-life object identification techniques with particular focus on mobile devices. An extended definition of AR is used in the research presented in this thesis that is based on the original definition, yet more focused on the object identification techniques with the mobile devices:

Firstly, AR tags the Object Of Interest (OOI) in real-life with information that is attached to it, such as name or location. Secondly, AR identifies the tag information by utilizing different media devices, such as webcam, PDA, or mobile phone. Thirdly, according to the tag identification information, AR retrieves contents that are attached to specific real-life objects, for which the contents are already predefined in the database. Lastly, by using different superimposing and augmenting display techniques, AR allows the learners to see the real world on the media device through the camera lens with virtual contents superimposed synchronously.

According to the extended definition above, AR is an emerging display technique that requires collaboration of multiple information technologies, such as location-based sensors, camera, and other HCI interfaces to accomplish the process.

AR is a combination of information technologies that have different features and purposes no matter whether they are emerging or existed previously, and functioning with an innovative display idea that brings virtual contents augmented with the reality scene to the learner. In this thesis, the processes of achieving AR are divided into four steps as follows:

(1) Real-life Object Tagging:

Before AR can be started, in order to specifically identify different real-life objects that have different characteristics, each object of interest must be attached with one or more identification tags, which are used to let the learner and the application system clearly identify which object is going to be augmented with what contents through the media device. Tags could also be attached to the real-life object, or even the real-life object itself could be one of the tags. More details about the real-life object tagging and identifying system are discussed in the next section.

(2) Tag Identification:

Once the object of interest tagging process is finished, the learner can further utilize different media devices, such as webcam, PDA or Smart Phone, to identify different tag information that is attached to a specific object of interest, and then send the tag identification information to the application system. For example, if there is a building as an object of interest, the possible tag identification information could be as follows:

- ✓ Name Tag: Alberta Legislature.
- ✓ Location Tag: 53 32’20”N, 113 30’29”W.
- ✓ Serial Number Tag: AB001.
- ✓ Image Tag: An image of the building.

Also, the tag identification process could be conducted by the learner manually, or by the media device itself with or without learner’s assistance and then sent to the application system through the HCI interface on the media device. More details about tag identifying system are discussed in the third section.

(3) Real-life Object Identification:

In the augmented reality process, object identification process comprises of a series of tag identification information matching in the database. According to the tag identification information received from the client media device, the application system matches it with the tag information that has already been predefined in the database. The application then utilizes the matched result to find contents that are attached to the identified real-life object, and then augments the real-life scene with superimposed contents displaying through the media device.

For example, if the tag identification information received from the media device is “Alberta Legislature”, the application system will match the “Alberta Legislature” tag with attributes in the database that are predefined as “Alberta Legislature” to access contents that are attached to the Alberta Legislature. For example, events of the Alberta Legislature, the architectural style of the building, and other associated contents will be augmented upon the real-life scene through the media device.

(4) Content Augmented Display:

Once the application system has finished the real-life object identification and has retrieved the contents, it utilizes different positioning and displaying techniques to display contents of interest superimposed on the real-life scene on the media device.

3.2 Real-life Object Tagging Techniques

3.2.1 Descriptive Tag

Varieties of different objects exist in real life. These real-life objects are usually referred to as natural objects, such as territories, mountains, lakes, animals, and plants; or artificial objects, such as borders, cities, countries, roads, buildings, rooms in buildings, and even small objects such as computers and mobile phones. In order to clearly identify different objects in real-life to communicate with other people, navigating, deliver mails, or deliver messages, humans create different types of identifications and attach them to the specific objects, such as name, serial number, or special identifiers. In this thesis, the descriptive identification is called **Descriptive Tag.** In most cases, descriptive tag usually refers to the object's specific characteristic, for example, "Laptop" means a computer that is able to be used on top of the lap. No matter how, but once a descriptive tag is attached to an object, it will not be changed to another descriptive tag frequently, which means that descriptive tag incorporates the features of **Object Identifiability** and **Tag Consistency.** It is also easy to read and understand by humans. Following are examples of descriptive tags:

- ✓ **Name Tag:** Alberta Legislature.
- ✓ **Serial Number Tag:** AB001.

3.2.2 Location-based Tag

A location-based Tag identifies the object's location and geographic orientation within a set of geographic based tag information . Because of the widespread popularity of location awareness technologies, location-based tags are getting more and more popular in recent years. In this thesis, the location or orientation information attached to each real-life object is called **Location-based Tag**. The location-based tags can be classified according to the feature of Geographic-Scale, the Large Geographic-Scale location-based tags cover larger geographic space, and the distance between the real-life objects is wider. This type of location-based tags is mostly applicable for outdoor scenarios, for example, utilizing GPS coordinate information to identify two different buildings. On the other hand, Small Geographic-Scale location-based tags cover smaller geographic space, and the distance between the real-life objects is narrow. This type of location-based tags is mostly applicable for indoor scenarios, for example, utilizing the WiFi Access Points to identify the printer and the scanner in an office room.

Due to the feature of Geographic-Scale, different real-life objects could have similar or identical location-based tags. For example, the GPS coordinate 32’20”N, 113 30’29”W refers to the Fort Edmonton Park. If there are three landmarks located in the Fort Edmonton Park which are close to each other, there is a chance that the three landmarks will have similar location-based tags. On the other hand, because the location-based tags are attached to the real-life object's location and orientation instead of the object itself, such tags provide much greater flexibility and variability. For example, once the real-life object's location or orientation is changed because of different scenario or environmental conditions, the location-based tag information will automatically change. There are a lot of different location-based tags that are applicable for the mobile AR scenarios, as discussed below:

(1) Geographic Coordinates: GPS Tag (Latitude, Longitude, Altitude)

Geographic coordinate system allows learners to identify real-life objects by their latitude, longitude, and altitude on the earth. The tag information refers to the object's Absolute Geographic Location on the earth, which means the representation of the tag information itself will not change along with any environmental factors or conditions. For example, 53 32'20"N, 113 30'29"W represents the location of latitude in 53 degrees North and the longitude in 113 degrees West. The real-life objects on the location could be different because of the environmental change. For example, the original building on a certain location may have been torn down and replaced with another new building.

Currently the most common and intuitive way to retrieve GPS tag information is to utilize the GPS sensor. In this thesis, the geographic coordinate system tag is called the **GPS Tag**. Due to the Absolute Geographic Location feature of the GPS tag**,** the GPS sensor can receive better signal strength in the outdoor environment. The GPS tag is mostly applicable to identify outdoor buildings, landmarks or any other large-scale real-life objects. As mentioned above, the distance between each real-life object is wider and the objects at the location do not change frequently. On the other hand, the GPS tag can be used as a tag filter. For example, one GPS tag could cover several real-life objects, which helps the application system to narrow down the possible contents when matching and identifying the object's tag information in the database.

(2) Geographic Orientation (N, S, E, W): Compass Tag

The geographic orientation tag information is used to identify the real-life object's Absolute Geographic Position at a certain location. In daily life, the basic geographic orientation tags refer to East, West, South and North, and with further detailed information such as orientation degree, they can identify the real-life object's geographic orientation precisely, for example, object A is facing 256 degrees South West.

The common way to retrieve the geographic orientation is to utilize a compass**.** The geographic orientation tag is called **Compass Tag** in this thesis. The compass tag is applicable for both indoor and outdoor scenarios without any signal strength limitations while identifying the real-life objects. Besides, the compass tag can also be extended to indicate the Relative Geographic Position within one and the other real-life objects. For example, the "real-life object A" is located at the absolute orientation "East", and the "real-life object C" is located at the absolute orientation "South East", which means that the relative geographic position of " real-life object A" that based on the "real-life object C" will be "North" or "North West".

(3) Cellular Tower ID (Cell-ID)

Cellular Tower ID is a global cellular tower identifier. Every cellular tower has its unique Identification (ID), Location Area Identity (LAI) and Cell Identity (CI). A complete Cell-ID includes Mobile Country Code (MCC), Mobile Network Code (MNC), Location Area Code (LAC) and CI. Cellular Tower ID tag information indicates a certain cell tower that is closest to the object of interest. On the other hand, the cellular tower ID tags the real-life objects according to the cell tower signal coverage radius, which means the objects that are covered under a certain cellular tower signal will be tagged with the same cell tower ID. The locations of cell towers are available in massive cover Tower Geographic-Location databases, which can be referred to identify the location of a specific cell tower.

The Cellular Tower IDs are not as much affected by the limitations of signal strength as the GPS tags. They are therefore applicable for both indoor and outdoor scenarios, similar to Compass tags. Since the Cellular Tower ID indicates the location of a certain cellular tower that is closest to the object of interest instead of the object's absolute location, the Cell Tower ID tag is more applicable as a scale type of tag.

(4) WiFi Access Point

WiFi Access Point tag utilizes the signal strength and the unique Media Access Control (MAC) address of a specific wireless network router to tag objects of interest. In WiFi Access Point tag information, the meaning of the MAC address is similar to the Cell Tower ID tag. The mobile device will first sense the WiFi signal from a specific object's location, and then it will retrieve the source of the WiFi signal and the MAC address from the source router and its corresponding location information. The purpose of the signal strength is to sense different WiFi signal strengths in order to identify the object's location within the coverage.

The wireless network routers are typically small, easy to implement, and low cost, and the signal coverage in indoor environment is great. This method of tagging is therefore applicable for indoor scenario object identification, for example, a printer in the "meeting room 1121", or a scanner in the "office room 1100" on the "11th floor" in a building. However, the meaning of the WiFi Access Point tag may differ due to the changes in the environmental conditions. For example, if a wireless network router was located in "Room B on the 11th floor", that would mean each object under the signal coverage will be attached with the Wifi Access Point tag that indicates a certain location in room B on the 11th floor. However, if that router is moved to the "Room A on the 12th floor", the same MAC address tag and the signal strength tag of the router will refer to different objects (the objects in room A on 12th floor), and objects that were previously tagged with the WiFi Access Point tag “Room B on the 11th floor” will lose the original meaning.

(5) Bluetooth Signal

In the prior research about positioning, several applications and systems utilized the Bluetooth signal in different ways as a positioning approach. The most common way to utilize Bluetooth signal as a tagging approach in the mobile augmented reality is through the Unique Address of each Bluetooth device, and then referring to specific Bluetooth device’s information or location through the Unique Address, which is predefined in the database to identify the real-life objects.

3.2.3 Motion-based Tag (Relative Tag)

When the learner changes the camera lens’ orientation on the media device to get different real-life scene, the motion detected by the media device is called **Motion-based Tag**, which is also a type of Relative Tag. In mobile AR, when the location of the media device does not change, the learner can casually change the camera lens’ orientation to identify different real-life objects and retrieve virtual contents, such as facing the camera lens to front view or ground view. In this thesis, this type of tag, which relates to the motion of the camera lens instead of the real-life object's location is called **Relative Tag**.

Mobile devices typically have very limited screen space, and relative tag and mobile AR can improve the way information is displayed on the mobile devices' limited screen space. For example, if a learner is at the Alberta Legislature, the application system can provide architecture information about the building on the media device when the camera lens is facing straight at the Alberta Legislature. However, when the camera lens turns left, political stories could be displayed on the media device, and navigation information could be displayed when the camera lens faces down to the ground. Thus, space around the object of interest can be used properly to provide more information by simply changing the camera lens' orientation in order to extend the limited screen space of the mobile devices.

(1) Acceleration

To retrieve the motion while the learner is using the mobile device, the simplest way is to sense the acceleration. The emerging mobile devices are generally equipped with built-in **Accelerometer**.

3.2.4 Image Process-based Tag

In this thesis, the tag that identifies the real-life objects through image processing is called **Image Process-based Tag**. This tag is further sub-categorized as **Real Object Image** and **Additional Optical Marker** based on the feature of the image.

(1) Real Object Image Tag

Real Object Image refers to the image of the real-life object itself, and it is necessary to provide immediate real-life scene in mobile AR. The object identification through real object image tag refers to the image matching process between the immediate real-life object image that is captured by the camera, and the image related to the object of interest that is predefined in the database.

(2) Additional Optical Marker Tag

In addition to the image of the real-life object itself, another way is to attach **Optical Marker** on the real-life object as a tag, and scan the optical marker through the camera on media device and then deliver the scanned image to the application system for image processing. The tag identification is achieved by using the camera and scanning the optical marker that is attached to the real-life object. The distance available for interaction between the learner and the real-life object is limited in such scenario. Following are the most common optical markers in the mobile AR:

i. AR Toolkit Marker

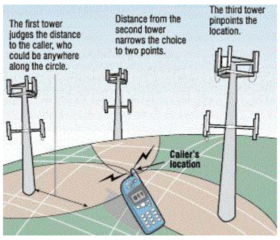
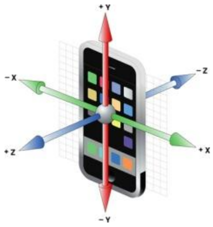
AR Toolkit Marker is the most original marker used in AR applications. This marker is composed of a square frame with a simple symbol inside it, both of which are binary images. The AR Toolkit algorithm identifies the symbol in the square frame and calculates the distance between the camera lens and the marker, and then displays the virtual contents upon the image of the symbol in the square frame on media device screen. Basically, the AR Toolkit Marker facilitates the display of contents at the right place on the media device screen.

ii. 1D Barcode and 2D QR Code

1D Barcode and 2D QR Code are essentially different in terms of the type of information they can hold; 1D Barcode can only store contents containing simple numbers, whereas 2D QR Code can store more complicated contents such as text or URL. In the mobile AR, depending on the situation, both 1D Barcode and 2D QR Code can be attached on the real-life objects to store a series of tag identification information related to the object of interest.

Table 1 provides a comparison of the varioustagging techniques.

Table 1. Comparison of Tagging Techniques

Technology	**Range (m)**	**Scenario**	**Setup**	**Identification Approach**	**Images**
Name / Serial	10	Indoor / Outdoor	Additional	Learner-Assisted	N/A
A-GPS	Open	Outdoor	Built-in sensor	Auto-Device	
Magnetic Compass	Open	Indoor / Outdoor	Built-in sensor	Auto-Device	
Cellular Tower ID	Open	Indoor / Outdoor	Built-in sensor	Auto-Device	
RFID	10	Indoor	Additional	Manual / Auto-Device	
Accelerometer	1000	Indoor / Outdoor	Built-in sensor	Auto-Device	
Real Object Image	50	Indoor / Outdoor	Image Database	Manual-Device	

AR Toolkit Marker	10	Indoor	Additional	Manual-Device	
Barcode / QR code	10	Indoor	Additional	Manual-Device	

3.3 Real-life Object Identification Approaches

As mentioned in the first section of this thesis, there are three ways to accomplish AR. The first one, **Real-life Object Tagging** has been introduced in the above section. Once the **Real-life Object Tagging** process is finished, the next process is the **Augmenting Reality**, which includes two steps, namely **Tag Identification** and **Real-life Object Identification**. The following section will discuss the different approaches to identify tags and real-life learning objects, classified according to the level of the learner assistance.

3.3.1 Learner-Assisted Identification

Learner-Assisted Identification means when the learners see the objects of interest, they identify the real-life object tag information by themselves. After the learners see a real-life object, they identify the tag information according to their personal background knowledge, or their observation of the object, for example, the name of the real-life object or other assisting tag information such as serial numbers. The learner will enter the tag identification information in the application system through the media device in order to identify the real-life object.

In this approach, the system completely relies on the learner to identify the tag information to accomplish the object identification process. The media device is not involved in any of the tag information identification process. Hence, tag information in the **Learner-Assisted Identification** approach must be in human readable and understandable form, such as the Descriptive Tag. For example, after a learner sees a building, according to the learner's background knowledge of the building, he/she may know that the building he/she is facing is named Alberta Legislature, or there may be an additional tag attached to the building with serial number (such as

AB001), or he/she may realize that the building is the first object in the scenario, and so on.

In the **Learner-Assisted Identification** approach, it is learner's responsibility to recognize the tag information that is attached to the real-life object. After that, the learner will input the tag identification information through the HCI interface of the media device. Then the system will deliver the tag identification information to the application system. Therefore, the media device is not involved in the object tag identification process. The media device is only responsible for providing input/output interface and to deliver the tag identification information to the application system server. After the application system has identified the real-life object and returned the contents, the media device will display the contents through augmented display techniques.

3.3.2 Manual-Device Identification

In **Manual-Device Identification**, after the learners see the real-life objects, they manually utilize the HCI interface on the media device to interact with the real-life object and to identify the tag information on the object. Unlike Learner-Assisted Identification, instead of the learner, the media device is responsible for identifying the tag information in this approach. Although learner's assistance is still required, it is limited only to assist the media device in launching and operating the functionality that is needed to identify the tag information. User does not get involved in any tag identification process. The responsibility of the media device is relatively higher than the learner in the **Manual-Device Identification** approach.

Manual-Device Identification is usually used to identify images or passive scanning-based tag information, such as real-life object self-image, marker, or 1D/2D barcode, which refers to the Optical Marker-based Tagging and Real Object Self Tagging. Passive RFID tag is applicable for **Manual-Device Identification** as well. For example, after the learners see a certain real-life object, they can use the camera on the media device to capture images or to scan the tag that is attached on the real-life object, which is then delivered to the application system.

3.3.3 Auto-Device Identification

Auto-Device Identification enables the media device to a**utomatically** interact with the real-life objects through the HCI interface, and then sense and identify the tag information of the real-life objects when learners hold the media device near a real-life object's location or space. Compared to the **Learner-Assisted Identification** and **Manual-Device Identification**, this approach no longer requires learner assistance. The media device will automatically sense the real-life object's tag information, and then deliver the information to the application system server in order to identify the real-life object.

Therefore, **Auto-Device Identification** is mostly used to identify automatic sensing or awareness types of tags, such as GPS coordinate, geographic orientation and cellular tower ID. It refers to the location-based tagging, and active RFID tag is applicable for **Auto-Device Identification** as well. For example, if a learner is located in front of a building, and the GPS sensor on the media device automatically senses the GPS coordination tag information of the building, it will deliver the identification to the application system to identify the real-life object.

3.4 Mobile HCI and Sensor interface in Mobile Augmented Reality

In each process of the mobile AR, mobile device plays an important role of media for humans to interact with the real world. This section will discuss the utilization of different HCI and sensor interfaces on the emerging mobile devices during each process of the mobile AR.

3.4.1 Input Components

(1) Keyboard (Physical / Virtual)

From the earliest generations of the physical Nine-Squares-Dialer keyboards and the physical mini-QWERTY keyboards, evolved further to the virtual Nine-Squares-Dialer and mini-QWERTY keyboards, the keyboard is the most basic and important HCI interface on the mobile devices. In the **Object Tag Description** process, keyboard is an important interface for enabling learners to input the tag information into the mobile device. In the **Learner-Assisted Identification** approach, when learners are identifying the tag, such as name or serial number, they can directly input the tag information through the keyboard, for example, by typing in the name tag "Alberta Legislature", or the serial number tag "AB001". Learners can also interact in the **Content Augmented Display** process through the keyboard with the augmented contents that is related to the real-life object, such as for answering questions.

(2) Optical Trackball

Optical Trackball can help learners in selecting objects, commands or options on the mobile device interface. Learner can scroll the optical trackball in different directions to move the menus, check boxes or cursor, or push it to confirm the selection and commands. Compared to the traditional five directions keyboard, optical trackball provides more convenient and smooth HCI interface. In mobile AR, optical trackball is mostly used in the interaction between learner, application menus, and contents.

(3) Touch Screen

Along with continuous advancements and improvements in the mobile devices, most of the emerging mobile devices are equipped with Touch Screens, that provide learners with a more intuitive HCI interface. On Touch Screens, besides having virtual keyboards mentioned above, learners can also directly touch any menus, options, or space on the screen while looking at the real-life scene display to interact with the real world.

In the **Object Tag Identification** process, besides manually typing in the tag information through the physical/virtual keyboard, or selecting through the optical trackball, learners can also directly touch the tag information or option that is related to the object of interest through the Touch Screen to identify the real-life object. For example, when a learner is facing the Alberta Legislature, and there are several tags on the touch screen, “Alberta Legislature,” “Edmonton City Hall,” and “Edmonton City Center Mall”, learner can directly touch the “Alberta Legislature” tag on the touch screen to interact with the real world intuitively. Furthermore, in **Content Augmented Display** process, learner can also interact with the augmented contents that are related to the object of interest. For example, learner can touch a text box to retrieve more detailed contents or answer a question by touching the real-life scene on the screen.

(4) Microphone

Besides providing a means to interact with the real world through HCI interface, most of the emerging mobile devices are also equipped with microphones, which provide a different way for learners to record voice and any other audio to interact with the real world.

In **Object Tag Description** process, learners can orally describe the tags of real-life object instead of manual typing or clicking. Moreover, in

Content Augmented Display process, learners can also interact with the augmented contents through their voice. For example, in a mobile AR English learning application, learners can read the augmented contents, and the microphone can record the audio and deliver it to the application system for voice recognition to help learners' English speaking skills.

(5) Camera

A Camera is the most indispensable component in AR. It provides the most basic element of AR, the **Reality View**. The camera has to keep working during entire AR process in order to help learners in browsing the real-life objects in the real world. While the learner is browsing the reality view, application system is able to retrieve raw images of the reality view stream video captured by the camera, which are then used for image processing. Hence in the **Object Tag Description** process, learner can either manually capture images of any objects of interest, or the application can automatically deliver the streamed video images to the system for image processing and object identification, which is referred as **Image Process-based Tag Description**.

3.4.2 Output Components

(1) Screen

In recent years, screens of the mobile devices have evolved with huge improvements. From traditional black/white 1 inch screens that were used for simple text-based communication, or for displaying contacts or text contents, screens have evolved to multi-color display capabilities, and further to the Touch Screens. The screen size has also received upgrades up to 3.5 inches and more, providing more space for the HCI interface. In both traditional AR and mobile AR, the screen is as important as the camera. Leaving the touch ability aside, the most important ability of the screen is to display contents. In mobile AR, the screen has to simultaneously display Reality View from the camera superimposed with the Augmented View provided by the AR application. Moreover, there are various formats of contents, such as text, web page, multimedia audio/video or even 2D/3D animation that are contained in the Augmented View.

(2) Speaker

Using audio through the audio HCI interface on the mobile device is another way to enable learners to interact with the real world. Besides the audio input interface through microphone, another interface responsible for audio is speaker. In mobile AR, for example, if a learner is located in a Dinosaur Historical Museum, the mobile AR navigation or learning application can provide an idea of what a dinosaur might have sounded like when learners are browsing the fossils.

(3) Vibratory Motor

In mobile device HCI interface, the vibratory motor is traditionally used to provide common feedback and notification functionality. For example, text message and call notifications, touch screen feedback, and body sense feedback in mobile games are all provided by a vibration response. In mobile AR, for example, when a learner is facing a specific object, he/she can be informed through the vibratory motor notification whether he/she is facing the right object or not. Another example may be when the learner is answering a question; he/she can be informed through the vibratory motor whether the answer is right or wrong.

3.4.3 Context Sensing and Communication Component

(1) GIS-based Context Sensing:

1) A-GPS

A-GPS chip is one of the most common and popular GIS based sensors on the emerging mobile devices. The main purpose of A-GPS is to receive a GPS signal and help learners in retrieving latitude, longitude and altitude of the mobile device. In the mobile AR applications, learners can utilize the A-GPS sensor to automatically sense the GPS tag information around the scenario to confirm whether there are any real-life object contents related to the GPS tag in the database.

2) Digital Compass

Similar to the A-GPS chip, a digital compass is also very common and popular in the emerging mobile devices. In mobile AR applications, learners can utilize the digital compass to sense the orientation tag information the camera lens is facing, and to confirm whether there are any real-life object contents related to the compass tag in the database.

(2) Motion-based Context Sensing:

1) Accelerometer

As discussed in the **Motion-based Tagging** section, an accelerometer has the ability to sense the acceleration from different motions while the learners are using their mobile devices, which can then be used by the applications to change the display mode or content format according to the different acceleration. In mobile AR applications, the application system can determine different camera lens orientations to provide related augmented contents by sensing the acceleration through the accelerometer while the learner is turning the camera lens.

(3) Communicating Component

1) Cellular Network

Due to the rapid evolution and improvement of wireless communication techniques in recent years, not only cell phones but also other mobile devices such as tablet PCs and many laptops now have the ability to connect to the cellular network. In mobile AR applications, besides GPS signal, the cellular network connectivity ability on the mobile devices provides another location-based tag description interface, by retrieving the ID of the cell tower that the mobile device is connected to, and then calculating the learner’s location by inquiring the location of the relative cell tower ID.

2) WiFi

Another general communication interface on the mobile device is the WiFi network connection ability. In mobile AR applications, by connecting to different WiFi Access Points, and then determining the learner location through analyzing the MAC Address and signal strength, applications can confirm whether there are any real-life object contents related to that particular WiFi Access Point tag in the database.

3) Bluetooth

Another common communication component on the mobile devices is the Bluetooth connection ability. As discussed in the **Location-based Tagging** section, mobile AR applications can utilize the Bluetooth communication interface of the mobile devices to communicate with other Bluetooth devices available in the real world scenario, retrieve the unique address of the Bluetooth device, and then confirm whether there are any real-life object contents related to that particular unique address tag in the database.

Chapter IV. MOIAR System and Scenario Design

In this chapter, the Multi Object Identification Augmented Reality (MOIAR) system that is designed for the location-based and adaptive mobile learning scenarios is discussed. The definition of the Multi Real-life Learning Object Oriented scenarios is discussed followed by a description of the design of the system. Then the system development environment is described, including hardware and software environment and the 6 degrees of freedom (DOF) sensing ability of iOS devices used in this research. The system development methodology, namely Model-View-Controller (MVC) is then discussed. This is followed by the system framework design, including three modules and six data models along with the complete system develop process.

4.1 The Multi Real-life Learning Object Oriented Scenarios

MOIAR is a mobile learning application system which is designed based on the location-based and adaptive mobile learning scenarios. The **location-based adaptive mobile learning scenarios** in this research are defined as the learning scenarios that constitute multiple real-life learning objects in both indoor and outdoor environments. The **Real-life Learning Objects (RLO)** refer to any objects in real world that contain learning contents that can enhance and improve learners' knowledge. Based on different real-life learning objects, the instructor can provide different learning activities and tasks corresponding to different course requirements or learning scenario design.

Furthermore, in the location-based and adaptive mobile learning scenarios, learning activities and tasks of each real-life learning object might be interconnected based on the different course requirements and learning scenario design, as indicated in figure 1. For example, in an office scenario, in order to understand the overall Internet printer set up process, first the learner has to study the basic knowledge about the printer itself (let us assume it is object A), and then study the knowledge of the computer server (let us assume it is object C). Then the learner will need to complete some setting tasks from the both objects, which might be in the order "A_1 -> A_2 -> C_1 -> C_2 -> A_3 -> C_3", which means that there are learning associations between the object A and object C. The learner has to get part of the knowledge from the object A before he/she can accomplish the tasks from the object C, and vice versa. The learning guidance ability is designed based on this learning scenario.

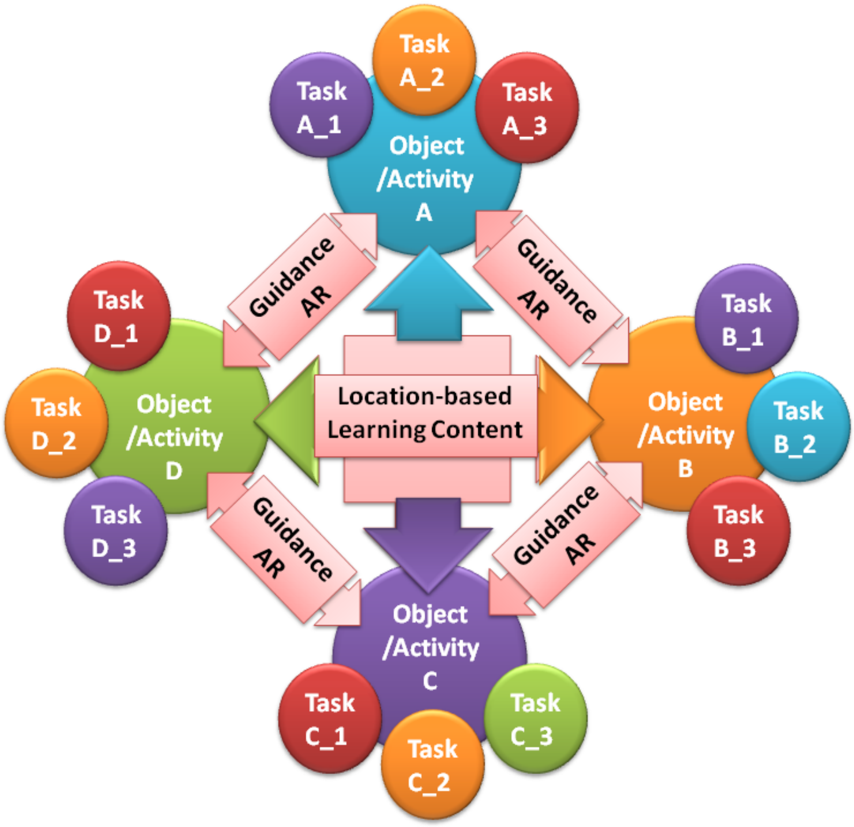


Figure 1. MOIAR system conceptual learning scenario

4.2 System Functionality

In location-based adaptive mobile learning scenarios, in order to improve the presentation of the content as well as the quality of the content, the MOIAR system is designed with two major functionalities with corresponding objectives.

(1) **Augmented Reality:** ***Content Display*** *and* ***Interaction***.

For the outdoor learning scenarios in this research, such as the Alberta Legislature, the RLOs included in the scenario are usually large and the distance within the RLOs is wider, such as the Alberta Legislature Building and the Fountain. The RLOs in the outdoor scenario are easily identified through the GIS type of location-based tags because of the feature of geographic-scale. Hence, for the **Real-life object Tagging** step, the GPS Tag and the Compass Tag are utilized in this research for the outdoor scenario RLO identification. The GPS tag information includes latitude, longitude and altitude coordinates, which refer to the object's **Absolute Geographic Location**, and the Compass tag information indicates the object's geographic orientation, which refers to the **Absolute Geographic Position** at a certain location. Another reason to utilize the GPS Tag and Compass Tag for outdoor scenario is that the MOIAR system is designed for the location-based and adaptive mobile learning scenarios, which means that all of the RLOs that are included in this research are location-based. However, the most convenient and precise way to identify the location of a certain object in outdoor scenario is through the GIS coordination information, since the locations of the RLOs in outdoor scenario do not change frequently.

For the next step of **Object Tag Identification**, this research utilizes the **Auto-Device Identification** approach because both GPS Tag and Compass Tag can be sensed automatically through the **GIS-based Context Sensors** on the mobile device, such as A-GPS chip and digital compass.

For indoor learning scenarios such as laboratory, research lab, or museum, the RLOs involved in the scenario are usually small, and the RLOs are much closer to each other (less than 5 meters), for example, printer, scanner, or artworks. In fact, there are several types of tags that are suitable for indoor RLOs, such as **Descriptive Tag, WiFi Access Point Tag, Bluetooth Signal Tag, and Image Process-based Tag.** The tagging information of both WiFi access point tag and Bluetooth signal tag is based on the signal strength, MAC Address, or Unique Device ID, which means it is not easy to identify each RLO specifically and precisely because there might be more than one object connected to the same WiFi access point or Bluetooth device.

On the other hand, the image process-based tagging is the most popular approach in AR applications and research because of the highly precise results due to directly processing the Real Object Image Tag and the Additional Optical Marker Tag, which can later be attached to the real-life object. However the real object image tag processing requires constant

Internet connection in order to deliver the real object image to the server for image processing, which also costs more computing resources than other tags. The real object image tag is also easily influenced by different environmental conditions, such as light, shadow, and different viewpoints. On the other hand, the additional optical marker tag requires the learner to manually scan the tag, which limits the distance in which the learner can interact with the RLO.

Therefore, the optimal tag for the indoor RLOs is still the **Descriptive Tag** along with the **Learner-Assisted Identification** approach. There are different ways in which the learners can provide input, such as text typing, voice recording, and using buttons. It is therefore important to limit the identification information, for example, if an RLO has a name tag "Object one", then the learners should identify the tag based on what information exactly they see on the object tag, such as typing in the text "Object one", or saying "Object one", or clicking on the "Object one" button. Moreover, in order to eliminate the limitation of the screen space on the mobile devices, **Motion-based Tag** can also be applied to extend the screen space to provide more contents.

The research in this thesis mainly focuses on the outdoor learning scenario. The indoor learning scenario is one of the study contributions and part of the system design, but is not actually implemented in the MOIAR application.

(2) **Location-based Learning Guidance: *Content Orientation***.

The location-based learning guidance feature is accomplished based on the augmented reality, compass tags, and motion-based tags. When learners turn the camera lens to the real-life ground view, the MOIAR system will provide guidance information based on the objects' location and orientation tags. The guidance information will lead learners to find the real-life learning objects around them in AR display. When learners are learning, they only need the learning contents on the screen. On the other hand, when they are looking for another real-life learning object, they only need the guidance information. They generally do not need both types of information at the same time. Therefore, the interactive AR tag in this research is designed in the way that, when learners launch the MOIAR application, they will first see the identification tag view that shows the name of the identified real-life object as well as the distance of the object from the learners' current location. When learners click on one of the identification tags, it will flip to the content view to show detailed information and learning content of the real-life object.

4.3 System Development Environment

(1) Hardware Environment

The MOIAR system is a client-server based mobile learning application system. The server side is developed on Apple Macbook 2009 with Intel Core 2 Duo P7500 CPU 2.26GHz and 4GB of RAM. On the client side, the MOIAR system is designed and developed based on Apple iPhone 3GS or later models. The reason why at least an iPhone 3GS is required is because of the built-in hardware requirements to launch the MOIAR application, which include camera for AR view, A-GPS chip for sensing location, electronic compass and accelerometer for learning guidance ability and 5R adaptive mechanism, as well as full cellular network and WiFi network connection ability.

(2) Software Environment

In the software development environment, both server and client side applications are developed on Apple Macintosh OSX 10.6 Snow Leopard, and the programming environment is based on Apple's official Integrated Development Environment (IDE) Xcode 4.0 along with the official iOS Software Development Kit (SDK) 4.0. The main programming language used in this research is the object oriented programming language, Objective C 2.0. The database is developed on SQLite framework which is suitable for developing embedded mobile device applications. The client application requires iOS 4.0 or later versions.

(3) The six degree of freedom (6 DOF) Sensing Ability on the iOS and iPhone

By sensing the position of axis X, Y, Z, and the orientation of roll, pitch, and yaw angles from the camera lens on the mobile device, the MOIAR system can decide which pre-defined location-based adaptive learning contents for the real life learning objects should be displayed on the screen. With the sensory data, the MOIAR system can also instruct the learner to complete activities and tasks within the real life learning objects and provide location-based adaptability in any mobile AR learning scenario. The 6 DOF sensing ability is a critical feature that enables AR interactive learning in the MOIAR system. Figure 2 shows the 6 DOF information on the iOS and iPhone, as adapted from previous research (Simon, Kunczier, & Anegg, 2007).

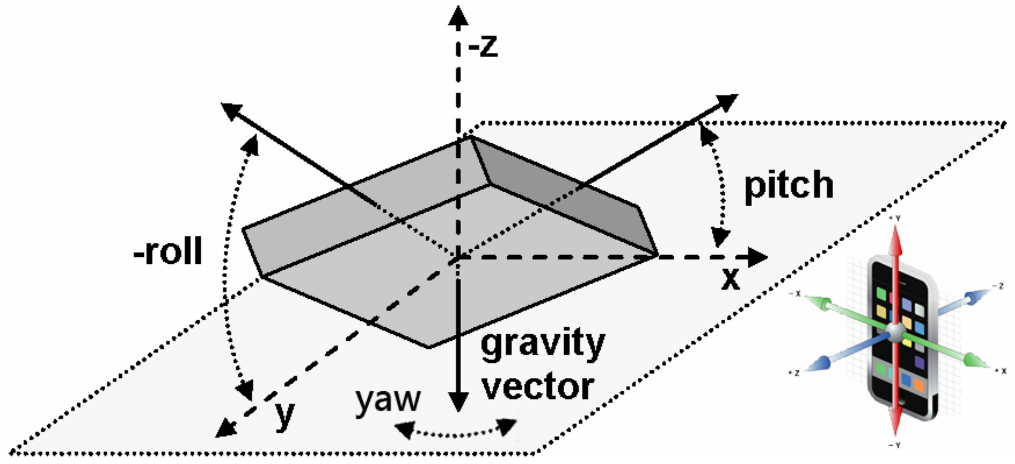


Figure 2. The 6 DOF Information on iPhone and iOS

First, the MOIAR system utilizes iPhone's built-in A-GPS to receive the positioning data, including longitude, latitude, and altitude. Then it receives X, Y, and Z coordinates of the 6 DOF from digital compass and accelerometer. Axis X corresponds to the motion **Roll**, or rotation around the axis that runs from the iPhone's home button to learner's earpiece, with values from 0.5 (rolled all the way to the left) to -0.5 (rolled all the way to the right). Axis Y represents the motion **Pitch**. If the learner places the iPhone horizontally and a horizontal line could be drawn about half-way down the screen, it would be the axis around which the Y value rotates. Values for pitch vary from 0.5 (the headphone jack straight down) to -0.5 (the headphone jack straight up). Axis Z represents the motion **Face up and Face down** of the iPhone**.** Actually, axis Z value does not correspond to the motion yaw. It refers to whether the iPhone is facing up (-0.5) or facing down (0.5). When iPhone is placed on a side, either the side with the volume controls and ringer switch, or the side directly opposite, the axis Z value equates to 0.0.

4.4 System Development Methodology

The MOIAR system is an iPhone based mobile learning application that is developed using Apple Xcode IDE 4.0 with Objective-C programming language. In order to meet the Object-Oriented programming principles of the Apple iOS application development, the Model, View, and Controller (MVC) design architecture has been adopted.

(1) The Data Model

In the MVC design architecture, the Model layer consists of objects that represent the data managed by the application, such as learner profile, real life objects location, learning progress, learning contents, 6 DOF information and so forth. Objects in this layer should be organized in the way that makes the most sense for the data, such as the six data model mentioned above. External interactions with data model objects also occur through a well-defined set of interfaces, whose job is to ensure the integrity of the underlying data at all times.

(2) The Interface View

The View layer defines the presentation format and appearance of the client application. This layer consists of window, views, and controls in the MOIAR client application, for example, the Login View, Register Table View, Personal Main Page View, Camera View and AR View. These different views could be standard system views, for example, Functions View that consists of features such as Launch MOIAR, Get Contents and Back to Personal Main Page, or custom views, for example, the Navigation AR and Learning Contents AR. The MOIAR system configures both types of views to display the data from the data model objects in an appropriate and adaptive way to the learner. In addition, the view objects need to generate notifications in response to events and learner interactions with that data.

(3) The Controller

The Controller layer acts as the bridge between the Data Model and Interface View layer. It receives the notifications generated by the view layer and uses them to make the corresponding changes in the Data Model. For example, if the data in the data layer changes for some reason (e.g., because of some internal computation loop), it notifies the appropriate controller object, which then updates the views. For example, in the system, when the learner changes his/her location from A to B, the location information will be updated in the data model and be matched with another learning object. Then the data model will send a notification to the Controller to ask the Interface Views to display the new AR contents.

4.5 System Framework

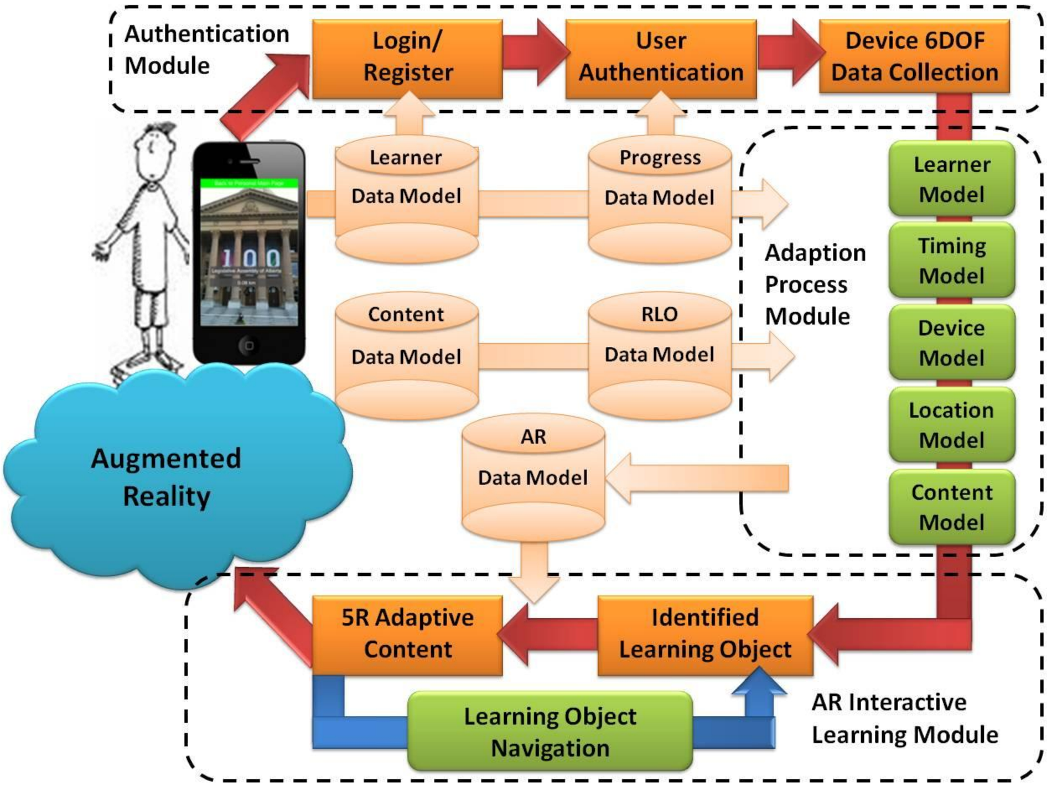


Figure 3. The MOIAR System Conceptual Architecture Design

(1) The Authentication Module

After learners launch the client application installed on their iPhone devices, they will be asked to login to the MOIAR system with a specific ID number (Student ID number, for example) and password. The server will then access the Learner Data Model to retrieve personal information, such as learners' name, program, grade, course ID, and previous knowledge level to accomplish the learner authentication process. After the authentication process is successfully completed, learners will be directed to a personal main page that contains all the information mentioned above, divided into three parts, namely *Profile*, *Progress* and *Last Evaluation Result*. If the system does not already have the learner registered in the system, system will guide the learner through register progress and request to provide his/her personal information. Once logged in, the learner will launch the instruction process by pressing the AR button on the bottom of the personal main page, and the system will start to access learner's location information to accomplish the 6 DOF progress for the **5R Adaptive Module**. The 6 DOF progress is discussed in the next section.

(2) The 5R Adaptive Module

The 5R adaptive module in the MOIAR system includes five objectives, which are to provide **Right Contents** at the **Right Time** at the **Right Place** to the **Right Device** for the **Right People**. In this module, after accessing the learner data model for personal information and receiving learners' 6DOF information from the device, the system will start to recognize the learning scenario according to the information.

i. Timing Adaptive:

The Timing Adaptive Model indicates two features. First one relates to the contents that are available only in certain time periods. For example, the Alberta Legislature opens from 10:00 AM to 4:00 PM. So, if a student of law launches the application before or after this time period, the MOIAR system will not lead the learner to the Alberta Legislature and will not provide any contents even if the learner is standing right at the Alberta Legislature, because the content that student needs is inside the building.

The second feature relates to the individual learning progress of each learner. Contents will be provided according to each learner's different learning progress. For example, learner Will who is currently progressing through unit one and learner Danny who is in unit two, will receive different contents, even if they both are at the same location.

ii. Place Adaptive

A place in the 5R Adaptive mechanism consists of all the 6 DOF information related to the learners and the real life learning objects. The6 DOF information is one of the most important information for the location-based adaptive mobile learning. The learning contents are selected based on the learners' 6 DOF information related to the learning scenario, such as learners' geographic coordinates, the orientation and acceleration of the learners' device and the real life learning objects. Only the contents related to the real life learning objects in learner's vicinity will be displayed.

iii. Device Adaptive

Different mobile devices have different operating systems, screen sizes, software, and capabilities, such as web browser or media player, which create differences in the learners' learning experience. Therefore, it is important to adapt the presentation of the learning contents to the individual devices to ensure effectiveness of learning. The common solution is to map the combinations of features of the mobile devices to a few stereotypes and present information according to the appropriate stereotype. In the MOIAR system, content adaptation is broken down into three basic stereotypes: text, multimedia and web page. Contents are provided to the device based on the available functionality to present certain type of contents.

iv. Learner Adaptive

The Learner Adaptive Model represents the adaptation for different knowledge levels of the learners. In the MOIAR system, learner's knowledge level is evaluated in two ways. Learners are asked several questions when they first time participate in the learning scenario of each real life learning object. Each learning object consists of three knowledge levels, and learners have to answer questions in the form of challenges. If the learner passes a challenge, the system continues to the next knowledge level challenge. If the learner fails a challenge, the system provides contents related to that particular knowledge level. Furthermore, when the learner passes a challenge, the MOIAR gives a grade from "A plus" to "D minus" according to the difficulty of the question, depending on the correctness of the answer and the time taken to answer the question. The second way learner's knowledge level is evaluated when the learner finishes a complete topic or unit. The system requires the learner to take several quizzes covering overall topic or unit in order to assess their knowledge level in that specific topic or unit.

v. Content Adaptive

The Content Adaptive Model is the last model of the 5R Adaptive mechanism. In this model, the MOIAR system starts to query and filter the 5R data model in order to retrieve contents according to all the adaptive results achieved in the previous four models and provides those contents to the learner.

(3) The AR Interactive Learning Module

In this module, the server starts to utilize the AR technique to display different learning contents on the learners' iPhone device according to the 6 DOF information, the personalized real-life learning object list and the adaptive result from the 5R Adaptive module. The interactive learning process is accomplished in several ways. One of them is the knowledge level evaluation mentioned above. In addition, when the learner launches the MOIAR application, it will start to identify the real-life learning objects around the learner and display an identification tag upon each real-life object scene. When the learner clicks on the tag that he/she is interested in getting more learning contents, the tag will flip to a full screen semi-transparent view to display detailed contents about that real-life object. The semi-transparent display is used so that the learner can see the contents and the real-life object scene at the same time.

4.6 System Development Process

The whole MOIAR system development process and architecture contain 11 main processes, which are divided into three modules as described in the system framework design (figure 4).

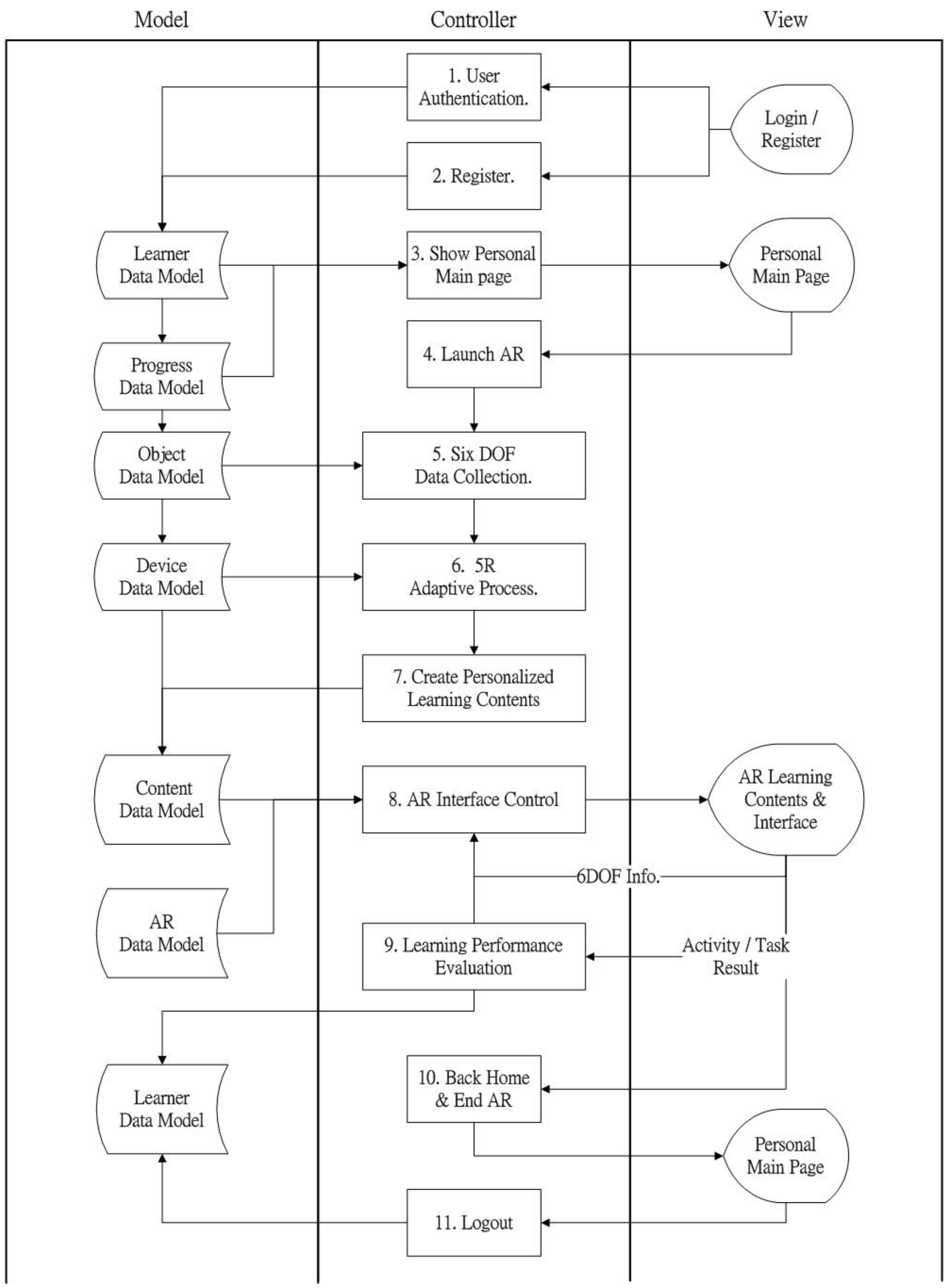


Figure 4. System Development Process

(1) The Authentication Process:

According to the 5R Adaption mechanism that aims to provide the right contents at the right time at the right place for the right device to the right person, the learners must first log-in/register in the system through the client application on their iPhone device and provide detailed personal profile, such as student ID, program, learning interests, enrolled courses and so forth. For this purpose, when the client application is launched, the first View layer displays the main interface that contains options for Login and Register.

Previously registered learners can login directly by typing in their learner ID and password. *Process 1: Learner Authentication* will send a notification containing login information to the Learner Data Model to match the learner ID as a key in the data model and retrieve specific learner profile. On the other hand, for the new learner, *Process 2: Register,* will ask the Interface View to show a registration interface as mentioned above. Then the new learner profile will be saved and the Controller will send a notification to the Model Layer to update the Learner Data Model. Both *Learner Authentication* and *Register* processes lead to *Process 3: Show Personal Main Page* on the View layer. The learners will see their personal information, learning progress, their current location, as well as two buttons, namely Launch AR and Logout, displayed on their iPhone devices.

(2) The 5R Adaption Process:

In order to accomplish the goals of the MOIAR for location-based adaptive mobile learning, the 5R Adaptive Progress contains three critical processes. After the learner clicks on the Launch AR button and starts *Process 4: Launch MIOAR*, the first adaptive process begins. In *Process 5: Six-DOF Data Collection*, the MOIAR system receives GPS information as the first step to retrieve current location of the learner, and then utilizes digital compass to sense the learner’s current orientation and accelerometer to sense the acceleration. The MOIAR system can provide location-based learning contents based on the 6DOF process. Furthermore, the system utilizes the 6DOF information to support and accomplish *Process 6: 5R Adaptive*. In this process, the Controller sends a notification to ask for the learner’s profile from the Learner Data Model, and then matches the personal information with suitable location-based learning objects and contents that are accessed from the Object Data Model and the Content Data Model. After that, the MOIAR server creates a personalized real-life learning object list containing learning objects and learning contents that are related to that particular learner. The 5R Adaptive Data Model then finishes the adaptive processes with *Process 7: Create Personalized Learning Contents*.

(3) The AR Interactive Learning Process:

After completing all of the adaptive processes, the MOIAR system starts to provide personalized and interactive AR learning contents through *Process 8: AR Interface Control*. In this process, there are two possible ways for the learners to learn with the MOIAR. First, if the learners put the camera lens as the Front View, they will see two AR tag boxes containing the real-life learning object's name and distance from the learner's current location. Furthermore, each real-life learning object's tag box is an interactive button. If the learner is interested in getting more detailed learning contents about the specific real-life learning object, he/she can simply click on any tag box. The controller will receive the touch event and send a notification to the Interface View layer and flip up the detailed contents view in order to display more 5R adaptive learning contents based on the learner's learning progress.

During the learning process, the learner has to interact with each real life learning object by successfully completing the challenge through a series of questions. This challenge mechanism is designed for evaluating the learners' knowledge levels to perform the 5R Adaptation mentioned above. After learner finishes activities and tasks for each learning object, the results are sent to the Controller of *Process 9: Learning Performance Evaluation* (Future Development). If the results meet the goals defined by the course instructor, the system will go back to the AR Interface Control process and lead the learner to the next learning object. Otherwise, the AR Interface Control process will provide the same learning contents to the learner for remedial study until the goals are met. At the end of the AR interactive learning progress, all of the learning information and evaluation results are stored in Learner Data Model, in order to enhance the performance of the 5R Adaptive Progress. Learners can also terminate the AR interactive learning and go back to the personal main page by click on the Back Home button. In that case, the View Layer will send a notification to the Controller and ask for process 3. The users can then Logout to complete the whole interactive learning progress.

Chapter V. System Implementation

This chapter discusses the MOIAR system implementation along with the core elements and algorithm. As mentioned in the system design, the MOIAR system has three modules, namely Learner Authorization, 5R Adaptive, and the AR Interactive Learning. In the first section of this chapter, an overview of the MOIAR system operations is provided with particular focus on how the three modules work with each other. This is followed in by the details of the data model, the 5R adaptive mechanism, as well as the query, in the second section. The third and final section discusses the outdoor location-based real-life learning object identification algorithm.

5.1 MOIAR System Process Overview

AR provides an intuitive learner interface for visualization in a mobile computing application. The learner's view is augmented with location based information at the correct spatial location, thus providing an intuitive way of presenting such information (Reitmayr & Schmalstieg, 2004). In the research presented in this thesis, the MOIAR system is a mobile learning application that focuses on identifying location-based outdoor real-life learning objects. The MOIAR can also provide learning contents that are adapted to different personal learning status through AR display technique. For outdoor mobile AR, especially on mobile phones, a built-in A-GPS and a digital compass are used as the major tracking components, sometimes assisted with secondary sensors such as an Inertial Navigation System (INS), for example motion sensors (accelerometers) and rotation sensors (gyroscopes) to continuously track learner's movements without the need for external references.

However, for most of the location-based service applications, the 6DOF information may not be required. If precise enough, 2 dimensions (2D) of location such as latitude and longitude, and 1 dimension (1D) of viewing direction such as orientation of the true north provided by A-GPS and digital compass may suffice to display clues of point of interest (POI) information on learners' mobile devices. This research presents a method to improve the location-based mobile AR position and orientation (2D location, 1D orientation and 1D motion) obtained by an A-GPS, a digital compass, and an accelerometer. This method is practical because of utilizing the easy-to-generate information extracted from the built-in mobile device components, and is computationally less expensive. Figure 5 shows complete MOIAR system architecture diagram.

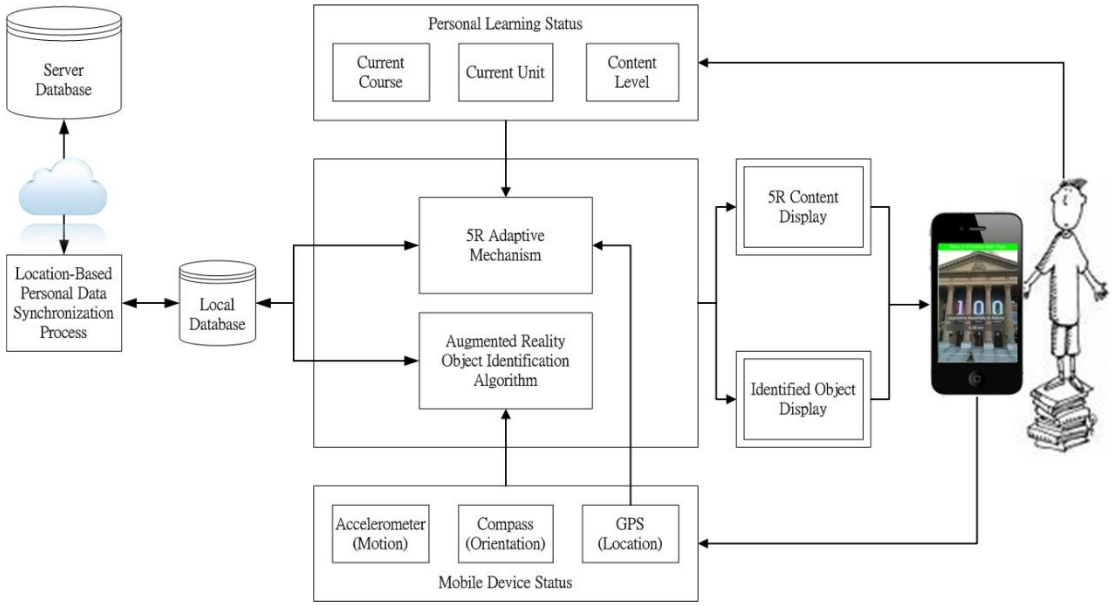


Figure 5. System Architecture Diagram

In the system architecture diagram, the Data Synchronization Process is not yet implemented and will be included in the future research, which means the MOIAR system is functioning with an off-line local SQLite database. The reason is that current research aims to focus on the AR technique, location-based object identification, as well as content adaptation. Also, MOIAR is designed based on the client mobile software design principles mentioned in (Tan & Kinshuk, 2009), which suggest that the built-in local database requires less resource usage, small data communication bandwidth and no redundant human/device interaction.

In the research scenario developed to demonstrate the application, learning contents are available for three programs, as well as locations of couple of real-life learning objects and profiles of students are stored in the local database. More detail of the data model will be discussed in the next section. When a learner logs in the MOIAR application, the system authenticates the learner’s profile according to the database record and brings out his/her personal learning status, such as the course and unit he/she is currently enrolling in, as well as associated knowledge level. Then, according to the personal learning status, the system generates an AR data model containing all of the objects and related contents that should be displayed on the screen. After that, the 5R adaptive mechanism process is finished.

When the learner clicks on the Launch MOIAR button, the application launches the real-life object identification algorithm. First, the program obtains the mobile device’s current status information, namely location, orientation and motion, through built-in A-GPS, digital compass, and accelerometer. According to the device status information and the real-life learning objects’ location information stored in the RLO data model, the algorithm identifies the objects around the learner and displays the identification tags that contain the objects’ names and the distances from the device’s current location. As and when the learner moves to another location or change the orientation, the algorithm recalculates the orientation related to the mobile device and the distance, which means that only objects in a specific location and orientation will be displayed on the screen. Otherwise, the tags will fly out of the screen space. The details of the algorithm are discussed in the third section.

To sum up, the MOIAR system has two major outcomes. First outcome includes the Objects of Interest, where only those objects that are related to the learner's learning status are extracted from the database and stored into the AR data model. Further, those objects along with related contents are displayed only when the mobile device is in a reasonable distance from the real-life learning object and is facing the right orientation. Second outcome includes the Contents of Interest, proposed in this research, which is also the rationale behind implementing the 5R Adaptive mechanism. When the learners click on one of the object identification tags, the view flips and displays detailed contents about that particular object. The important concept regarding the Contents of Interest is that not only the displayed content is related to the real-life learning object but is also related to individual learner's learning status. For example, when facing a specific real-life learning object, learners enrolled in different programs, at different units, and at different knowledge levels, will get different learning contents. The details of the concept of Contents of Interest are discussed in the next section.

5.2 5R Adaptive Mechanism

This section will first discuss one of the key concepts proposed in this research, namely Contents of Interest, which is the rationale behind implementing the 5R Adaptive mechanism. Then the Personal Learning Status, the 5R adaptive data model, and the Query Mechanism will be discussed.

5.2.1 Contents of Interest in LBS and AR

Location-based Service (LBS) in collaboration with AR applications has been very popular and rapidly growing phenomenon in recent years. In fact, emergence of the Points of Interest (POI) is one of the critical reasons behind such success of the LBS-AR applications. The concept of POI is follows: when a learner is located in a particular area, the application automatically brings up information about various objects that the learner might be interested in, for example, restaurants, tourist spots, and so on.

In academia, location-based learning has been taking advantage of POI concept as well. For example, when students go on a field trip to an historic relic, the application can provide learning contents that are based on the real-life learning object's location. However the problem is, in location-based learning, students might not be interested in some of the learning contents due to various reasons, for example, the contents may not be related to the current program or course they are currently enrolled in, or some of the contents might be overwhelming for their current knowledge level, making it difficult for the students to understand.

The concept of Contents of Interest (COI) and the 5R Adaptive mechanism proposed in this research aim to minimize the problems mentioned above. In other words, the MOIAR application not only automatically identifies the real-life learning objects that the learner will be interested in, but also tailors the learning contents according to learners' personal learning status so that they will be interested in the learning contents as well.

5.2.2 Personal Learning Status

The personal learning status is one of the most important elements in the 5R Adaptive mechanism. According to the learner's different learning status, such as programs, courses, units, and knowledge level, the 5R Adaptive mechanism identifies not only the real-life learning objects but also the related contents that the learner will be interested in and comfortable learning with. Furthermore, for the same real-life learning object, learners with different personal learning status can get completely different learning contents. Even when they are enrolled in same course and are working on same unit, learners will get different contents if they have different knowledge levels. This is accomplished through the Contents of Interest concept mentioned above.

5.2.3 5R Data Model and the Query Mechanism

The MOIAR system contains six critical data models. The Learner data model stores the learner's personal profile, such as student ID and name. The Personal Learning Status data model stores information about the courses that the learner is registered in under a particular learner ID, as well as progress details for each registered course, such as unit ID and the related knowledge level. The progress data model stores details of every single unit and knowledge levels that each course has. For example, the "Introduction to English" course has six units, and each unit has three levels. The "Introduction to Politics" course has five units, and each unit has two levels. The RLO data model stores the names of the real-life learning objects and their two dimension location information, namely latitude and longitude. The Content data model stores learning content that are related to every real-life learning objects, and includes different learning profiles. The last data model, which is the output of the 5R Adaptive mechanism, is the AR data model. Figure 6 shows the Entity–Relationship (ER) Diagram of the MOIAR system.

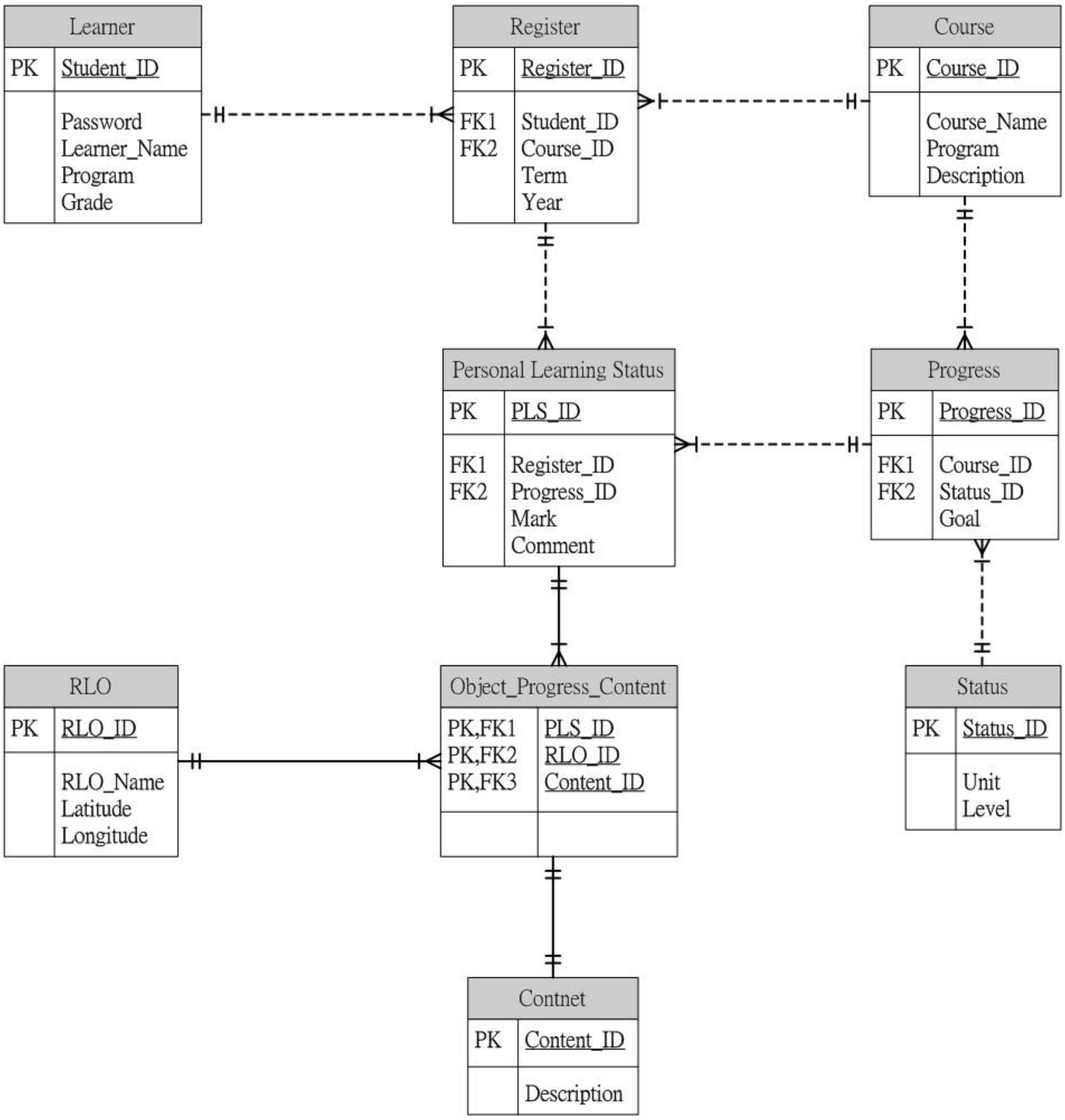


Figure 6. ER Diagram of the MOIAR system

When a learner logs in the MOIAR system, the 5R Adaptive mechanism query first selects the learner’s profile table and the course register table to find out what courses the learner is currently taking. Then it selects the personal learning status according to the course register ID in order to find out learner’s progress in each course the learner is currently registered in.

According to the Personal Learning Status (PLS) ID, the mechanism then matches and selects the objects that are related to the progress ID and the learning contents that are related to both the progress ID and the object ID. The key table in the 5R adaptive data model is the “Object_Progress_Content” table as it holds the other three tables together.

For example, in the research scenario created for demonstration of MOIAR system, learner Will’s student ID is “2937838.” At first, the 5R adaptive mechanism selects all of the columns, which include learner’s profile, progress, real-life learning objects, and contents that are needed. Second, in order to get the specific progress ID, which in this scenario will be “60411”, according to the student ID number that was input from the login text field interface, the 5R Adaptive mechanism starts to match the learner’s personal learning status, namely course, unit, and knowledge level. Third, the mechanism starts to match Real-life Learning Objects IDs that contains the progress ID “60411”. In this scenario, they will be RLO_A, RLO_B and RLO_C. Then according to the progress ID and Real-life Learning Objects IDs, the mechanism then matches the content IDs that are related to the progress ID and the Real-life Learning Objects IDs. In this example, they will be RLO_A_60411, RLO_B_60411 and

RLO_C_60411. When the mechanism is finished, the results of 5R Adaptive mechanism are stored into the AR data model.

5.3 MOIAR: Object Identification Algorithm

For outdoor location-based AR mobile learning scenario in this research, the MOIAR application first utilizes the geographic coordinate information to identify the mobile device and absolute location of real-life object, both of which are retrieved by the built-in A-GPS sensor. The MOIAR then utilizes the geographic orientation information to retrieve the absolute orientation, which is detected by the built-in digital compass. The MOIAR then calculates the relative orientation between the mobile device and the real-life learning object, which is accomplished by the Object Identification algorithm.

Besides the 5R adaptive learning contents, another main purpose of the MOIAR application is to display learning contents related to the real-life learning objects superimpose upon the real-life scene on the mobile device's screen. This means that the learner carrying the mobile device has to be at a location that is nearby the real-life learning object, and the learner has to face the mobile device's camera lens towards the real-life object, so that the contents can be seen superimposed upon the real-life learning object on the screen.

In fact, in the outdoor scenario, the location of real-life objects does not change frequently, and it is not necessary to describe the object's geographic orientation. When the learner carrying a mobile device is standing nearby a real-life object, it is impossible and would not make sense to turn the object to face the learner by changing object's orientation. On the other hand, it is easy and would make sense for the learner to change his/her current orientation and face the camera lens to the real-life object. Particularly when the object is located in an open space, which means there are no other objects close by or right next to it, the learner can walk around the object as long as he/she is close enough or nearby the object's location, and has mobile device facing the object. Hence, the learner's orientation related to the real-life learning object becomes very important.

The Object Identification algorithm utilizes the concept of the Relative Orientation, which is also proposed in this research and is discussed in the following section. This algorithm utilizes two dimension geographic coordinate information, namely latitude and longitude, as well as the one dimension geographic orientation information, to calculate the distance between the learner and the real-life learning objects. The algorithm also calculates the angle between the learner to the true north, and the angle between learner and the real-life learning object, and both of these angles are then used to decide whether the identification tags and the 5R adaptive learning contents should be displayed on the screen or not.

5.3.1 Mobile Device Status

The mobile device status is another important element for accomplishing the 5R adaptive mechanism and the Augmented Real-life object Identification algorithm. This section discusses how the mobile device status, location, orientation, and motion are used in the MOIAR system, as well as the role of human computer interfaces on the mobile device.

(1) Location: A-GPS

Mobile device's location, which refers to the learner's current location, is very important in the MOIAR application. The 5R adaptive mechanism first utilizes the mobile device's two dimension location information, namely latitude and longitude, to show the learners where they are after they have logged in to the personal learning status page. Then the Real-life Object Identification algorithm utilizes the mobile device's location to calculate the distance between the learner and real-life learning objects and the Azimuth.

The Azimuth is the angle between the learner to the geographic north, and the learner to the real-life learning objects, which are used to decide whether the object identification tags should be displayed on the screen or not. The details of the Azimuth are discussed in the next section. Through the built-in A-GPS, the MOIAR application can easily retrieve and track the mobile device's location and update continuously.

(2) Orientation: Digital Compass

Mobile device's orientation, which refers to the learner and the camera lenses' current heading, is one of the most important elements in the Real-life Object Identification algorithm. In the MOIAR learning scenario, learners change their location and orientation continuously. Learners can see different real-life learning objects at different locations with different orientation, or at the same location but different orientation. As mentioned above, the algorithm calculates the Azimuth of each real-life learning object that is around the learner's current location. After that, according to the learner's current heading, the algorithm further calculates the subtended angle to decide whether the passed-in object identification tags are in the Viewable Range of what the camera can see. For example, when the learner is standing in front of the Alberta Legislature building and facing the South, the object identification tag will be displayed on the screen as it is within the subtended angle of the camera's Viewable Range. If the learner keeps standing at the same location but facing the camera lens to the East, the object identification tag will fly out of the screen as it is outside of the Subtended Angle of the camera's Viewable Range. Through the built-in digital compass, the MOIAR application can easily retrieve and track the mobile device's orientation and update continuously.

(3) Motion: Accelerometer

The motion of the mobile device in the MOIAR system plays a similar role as the orientation, except when the learner is facing the camera lens up to the sky or down to the ground, the object identification tags will not be displayed on the screen since there will be no real-life learning object in the screen. Furthermore, when the learner turns the mobile device's orientation itself, which means either from Portrait to Landscape or vice versa, the MOIAR application has to make some adjustment, because normally the built-in digital campus calculates the device's geographic orientation based on where the head of the device is facing in Portrait mode, where the head of the device is usually the headphone. For example, a learner is currently holding the mobile device in portrait mode and facing to the North. If the learner turns the device from portrait to landscape-right, it would technically mean the device is currently facing to the East instead of the North. So the application will deduct 90 degrees to adjust the orientation. On the other hand, the mobile device's motion can be used in various scenarios, for example, when the learner is facing the camera lens down to the ground, the system can provide detailed navigation information, and so on.

5.3.2 Azimuth

Azimuth is a word from the Arabic language. Its literal translation is "direction." Azimuth is an angular measurement used in spherical coordinate systems, such as those found in geospatial calculations. The azimuth is the angle between the projected vector and a reference vector on a well-defined reference plane. For example, let us consider the MOIAR application in which there is a point of interest, in this research it will be one of the real-life learning objects. If we would like to know which direction the learner needs to face to be pointing toward this real-life learning object, the object identification algorithm in the MOIAR application might compute the azimuth of that object from the North Pole. The object identification algorithm would draw (figuratively) a perpendicular plane from the learner's current position to the North Pole, and a second perpendicular plane from the real-life learning object through to sea level (or an equal plane under our position). In Figure 7, the angle between the two planes is the azimuth.

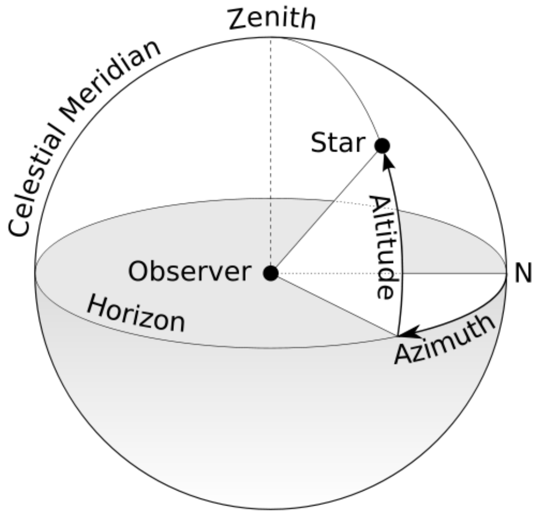


Figure 7. The definition of Azimuth

5.3.3 Relative Object Identification Algorithm

In the MOIAR learning scenarios, there will be multiple real-life learning objects related to the learner at any particular time. In order to effectively utilize the limited screen space on the mobile device, as well as to meet the purpose of the 5R content adaptation, only a certain number of real-life object identification tags and content should be displayed at a certain place and time. In the MOIAR application, only objects that match the learner's personal learning status are included into the AR data model as Objects of Interest, and the real-life object identification tags of only those objects are displayed on the screen. In fact, in the MOIAR learning scenario, even with different location and orientation, learner can still see the same real-life learning object. In other words, the right contents are displayed on the screen only when the learner is at the right location and facing the camera lens to the right orientation to the real-life learning object. Based on different locations of the learner, the orientation related to the real-life learning object can be different, which becomes very important issue. The learner might be standing on the different side of the real-life learning object, which would require the learner to turn the camera lens to a different direction in order to get the content of interests to be displayed on the screen properly.

Hence, a Relative Object Identification algorithm is proposed in this research. The relative object identification algorithm is designed to compute the orientation subtended from the learner's current location to each real-life learning object. As mentioned above, the mobile device's current Azimuth, each real-life leaning object's Azimuth, and the angle subtended between the two Azimuths, are the critical elements to accomplish this algorithm. The

MOIAR utilizes two coordinate systems to implement the algorithm. The first coordinate system is the original geographic coordinate systems, known as the Polar coordinate system, which utilizes the latitude, longitude, and the North Pole based orientation. Based on the Polar coordinate system, each real-life learning object's location is indicated as [LAT_o, LON_o] as a **known parameter**, which is predefined and stored in the RLO data model. The learner's current location is indicated as [LAT_m, LON_m] as a **sensor parameter**. The "$_o$" means real-life learning object's location, and the "$_m$" means the mobile device's location, which also refers to the learner's current location. The mobile device's current Azimuth is indicated as θ_m, which is also a **sensor parameter** and is measured in Radian, discussed in the later paragraph. Another coordinate system is the MOIAR coordinate system that based on the Cartesian coordinates, which computes the Azimuth of the each real-life learning object that is subtended to the learner's current location and the North Pole. In the MOIAR coordinate system, the learner's current location is indicated as the coordinate origin.

The first procedure of the algorithm is to compute the distance from the learner's current location to each real-life learning object. The calculation is based on the following Great-Circle Distance formula:

$$d = R * \arccos[\sin\phi_1 * \sin\phi_2 + \cos\phi_1 * \cos\phi_2 * \cos(\lambda_2 - \lambda_1)]$$

The distance is measured in meters. The ϕ_1 and ϕ_2 indicate the latitude of the learner and the real-life learning object's location, the λ_1 and λ_2 indicate the longitude, and the R is the radius of the earth. The latitude and longitude have to be converted into Radian in order to get the best accuracy. Based on the different distances, the MOIAR can filter out the real-life object identification tags that are not within a proper distance from the learner's current location, in order to efficiently utilize the limited screen space and keep the screen uncluttered.

The second procedure is to compute the two Azimuths mentioned above. The MOIAR coordinate system contains two key variables. ϕ and λ which respectively indicate the computed West to East axis and North to South axis variables that are subtended from the learner's current location to each real-life learning object's location. The formula for calculating the $[\Delta\phi, \Delta\lambda]$ is shown as follows:

$$\Delta\phi = \phi_o - \phi_m \quad \text{(1-1)}$$

$$\Delta\lambda = \lambda_o - \lambda_m \quad \text{(1-2)}$$

In the MOIAR system, every real-life learning object's two dimension location information are predefined and stored in the RLO data model. The ϕ_o and λ_o each indicates the latitude and longitude of each real-life object. On the other hand, the learner carrying the mobile device can always change current location while learning with the MOIAR application. The ϕ_m and λ_m each indicates the mobile device's current latitude and longitude, which are sensed by the built-in A-GPS sensor on the mobile device. The concept of the Azimuth in the MOIAR learning scenario is shown in figure 8.

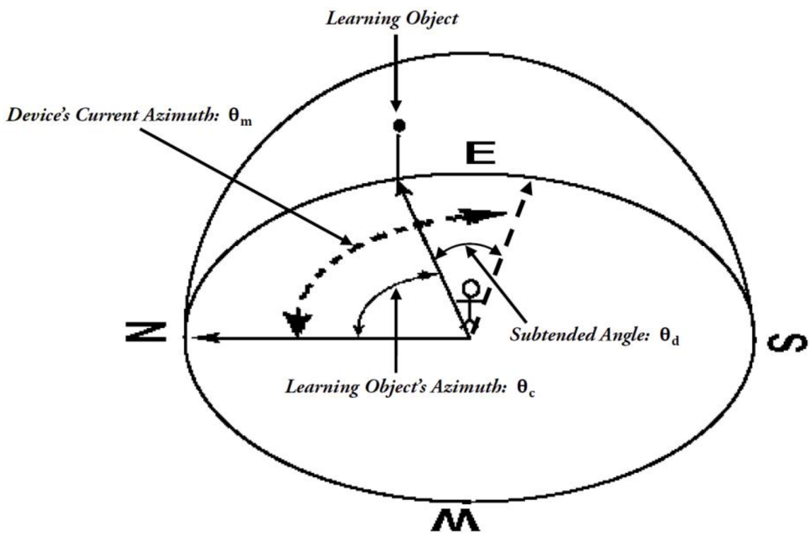


Figure 8. The concept of the Azimuths in the MOIAR learning scenario

After $[\Delta\phi, \Delta\lambda]$ is computed, which indicates the new coordinate variable between the real-life learning object and the learner's current location, the Polar coordinate system is then conceptually converted into the MOIAR coordinate system, which utilizes the learner's current location as the coordinate origin. As mentioned above, in order to identify the right real-life object and display the right content when the learner is facing the mobile device on the right orientation to each real-life learning object, and to further guide the learner regarding which direction to face the camera lens, the Azimuth of the learner's current orientation and the Azimuth of each real-life learning object is computed. The concept of the Azimuth in the MOIAR coordinate system is shown in figure 9 and the computing formula to further calculate the Azimuth θ_c is presented as follows:

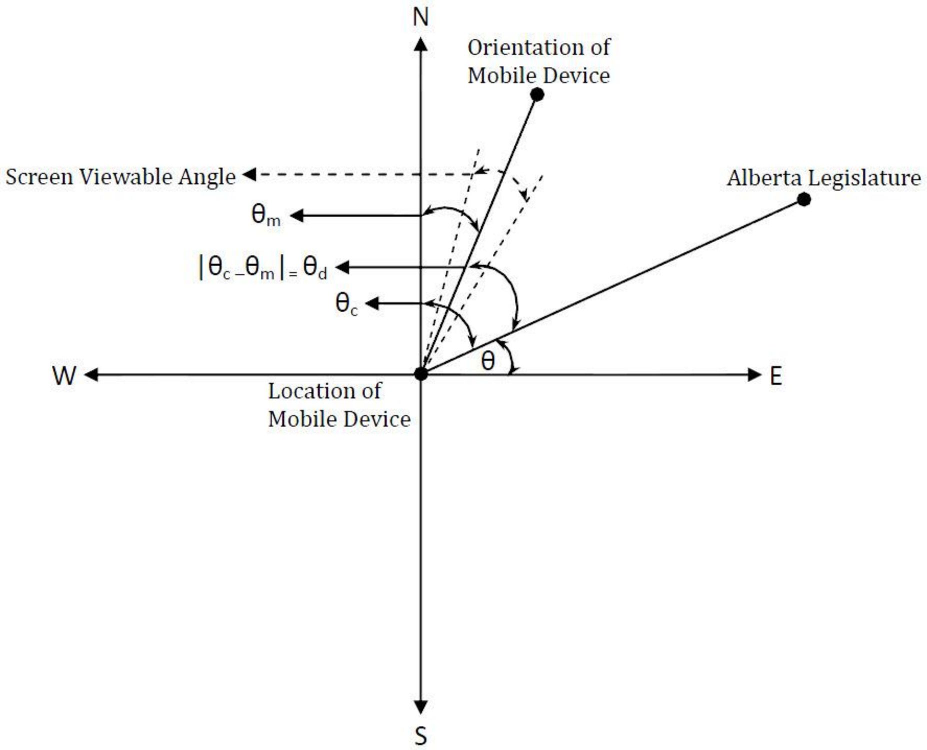


Figure 9. The concept of the MOIAR coordinate system in the Algorithm

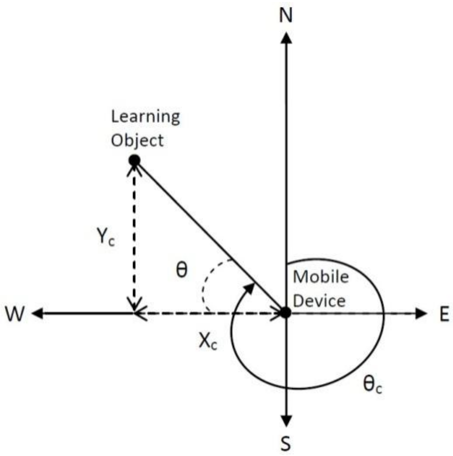
$$\tan\boldsymbol{\theta} = \left|\frac{Y_c}{X_c}\right| \quad \text{...(1-3)}$$

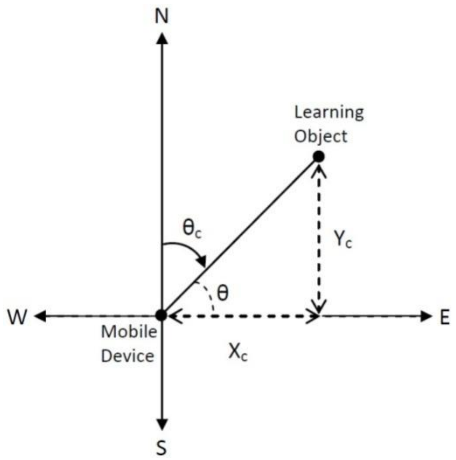
$$\boldsymbol{\theta} = \tan^{-1}\left|\frac{Y_c}{X_c}\right| \quad \text{...(1-4)}$$

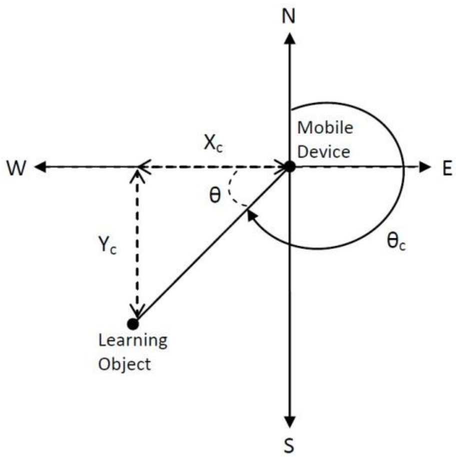
$$\boldsymbol{\theta_c} = \mathbf{90° \text{ or } 270° \pm \theta} \quad \text{...(1-5)}$$

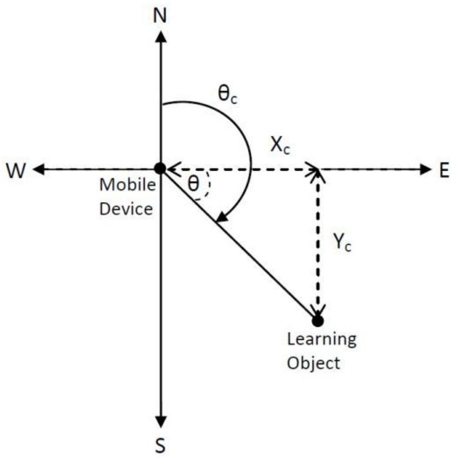
In the MOIAR coordinate system, the horizontal line from the coordinate origin to the North Pole and the horizontal line from the coordinate origin to [$\Delta\phi$, $\Delta\lambda$], become an angle θ_c, which refers to the Azimuth. In order to compute θ_c, the angle θ between the learner, the real-life learning object, and the $\Delta\phi$ axis have to be computed first by using the Tangent Trigonometric Functions. Further, according to [$\Delta\phi$, $\Delta\lambda$] that locates the quadrant in the MOIAR coordinate system, the complete Azimuth θ_c will be found. When $\Delta\phi$ is positive and $\Delta\lambda$ is positive, it means the real-life learning object is located in the first quadrant and θ_c will be $90° + \theta$. When $\Delta\phi$ is positive and $\Delta\lambda$ is negative, it means the real-life learning object is located in the fourth quadrant and θ_c will be $90° - \theta$. When $\Delta\phi$ is negative and $\Delta\lambda$ is negative, it means the real-life learning object is located in the third quadrant and θ_c will be $270° - \theta$. When $\Delta\phi$ is negative and $\Delta\lambda$ is positive, it means the real-life learning object is located in the second quadrant and θ_c will be $270° + \theta$. Table 2 displays different cases when Azimuth θ_c is located in each quadrant.

Table 2. Azimuths in different quadrants of the Algorithm.

<table>
<tr><td colspan="2">Mobile Device Coordinate</td><td colspan="2">Mobile Device Coordinate</td></tr>
<tr><td>$\Delta\phi$</td><td>$\Delta\lambda$</td><td>$\Delta\phi$</td><td>$\Delta\lambda$</td></tr>
<tr><td>-</td><td>+</td><td>+</td><td>+</td></tr>
<tr><td colspan="2">Real-life Learning Object Coordinate</td><td colspan="2">Real-life Learning Object Coordinate</td></tr>
<tr><td colspan="2">North West: Second Quadrant


$\theta_c = 270° + \theta$</td><td colspan="2">North Ease: First Quadrant


$\theta_c = 90° - \theta$</td></tr>
<tr><td colspan="2">Mobile Device Coordinate</td><td colspan="2">Mobile Device Coordinate</td></tr>
<tr><td>$\Delta\phi$</td><td>$\Delta\lambda$</td><td>$\Delta\phi$</td><td>$\Delta\lambda$</td></tr>
<tr><td>-</td><td>-</td><td>+</td><td>-</td></tr>
<tr><td colspan="2">Real-life Learning Object Coordinate</td><td colspan="2">Real-life Learning Object Coordinate</td></tr>
<tr><td colspan="2">South West: Third Quadrant


$\theta_c = 270° - \theta$</td><td colspan="2">South East: Fourth Quadrant


$\theta_c = 90° + \theta$</td></tr>
</table>

Once Azimuth θ_c is computed, the last step is to compute the subtended angle. The subtended angle is computed according to the difference between Azimuth of the learner's current orientation, which is sensed by the built-in digital compass on the mobile device, and the Azimuth of each real-life learning object θ_c. Further, the object identification algorithm can determine whether the object identification tags and the 5R adaptive contents of interest should be displayed on the screen or not, according to the formula below:

$$\boldsymbol{\theta_d = |\theta_m - \theta_c| \leq R\ (ex: R = 5°)} \quad \textbf{..(2)}$$

In the formula, θ_d refers to the angle difference between the Azimuth of the learner's current location and each real-life learning object. Variable R refers to the Rule in the algorithm that is used to determine how many degrees of difference should the MOIAR system be displaying the object identification tags and the 5R adaptive contents. The reason to compute θ_d as an absolute value is that the MOIAR system should display the object identification tags and the 5R adaptive contents no matter whether the real-life learning object is on the left side or right side of the learner. For example, if θ_m is 45° and θ_c is 40°, the original θ_d is +10, which means the object is slightly left to the learner. On the other hand, when θ_m is 45° and θ_c is 50°, the original θ_d is -10, which means the object is slightly on the right side of the learner. If we set the rule as 5°, after computing θ_d with an absolute value, the MOIAR system will display the object identification tags and the 5R adaptive contents in both cases.

5.4 MOIAR Scenario Implementation

This section describes how the MOIAR works in the research scenario created for the purpose of demonstration, with appropriate screenshots. There are three students in the scenario. Will is currently enrolled in the English program, and he is taking course 604 "Traveling English," the progress is on unit one with knowledge level one. Jimmy is currently enrolled in the Politic program, and he is taking course 704 "Politic Science," the progress is on unit one with knowledge level one. Alex is currently enrolled in the Architecture program, and he is taking course 604 "Introduction to Architecture," the progress is on unit one with knowledge level one. The default real-life learning object is the Alberta Legislature building.

5.4.1 Learner Authentication Interface

The learner authentication interface contains two parts of information, the personal learning status and the learner's current location. The screen shots are shown in figure 10.

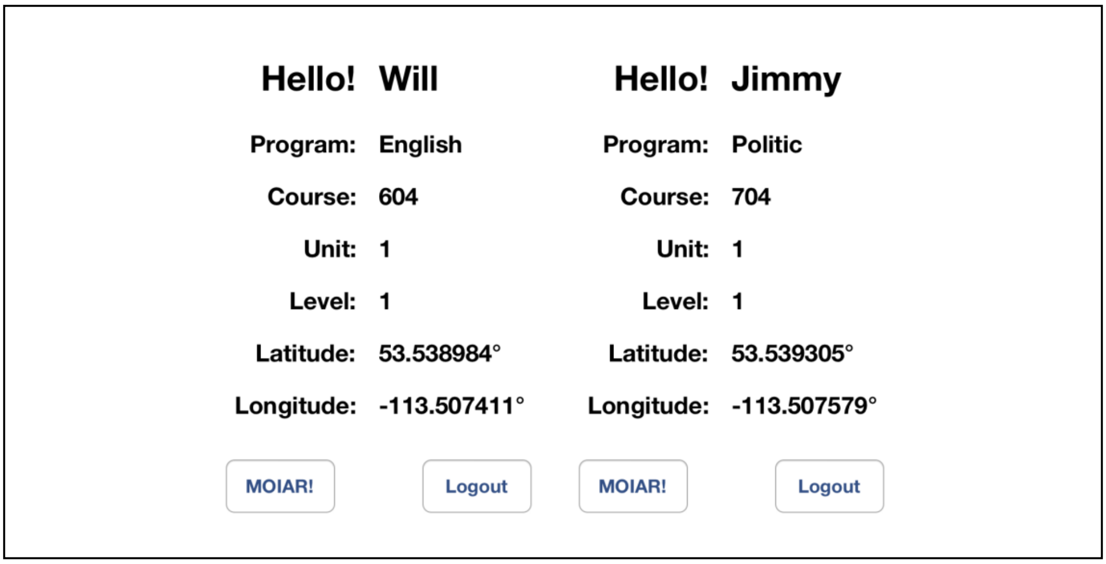
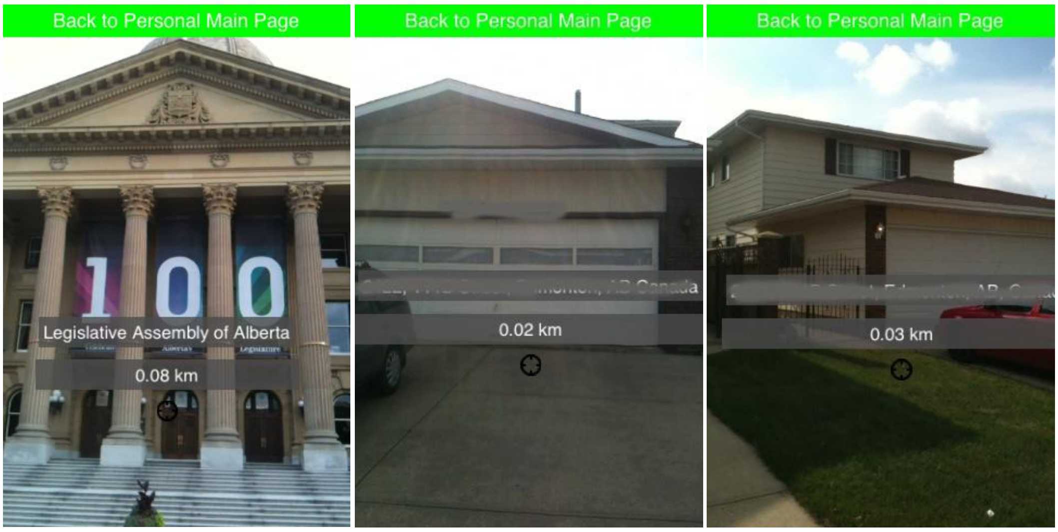


Figure 10. Personal Learning Status

At first, system shows to the learners which course and unit they are currently learning with the MOIAR application, and what knowledge level of content they will be getting. Second the system obtains the device's current GPS location information so that the learners will have idea about where they are.

5.4.2 Location-based Reality Learning Object Identification

When the learner clicks the MOIAR button, the application will launch the Object Identification algorithm to start identifying the real-life learning object around the learner's current location and display the location-based object identification tags as shown in figure 11.



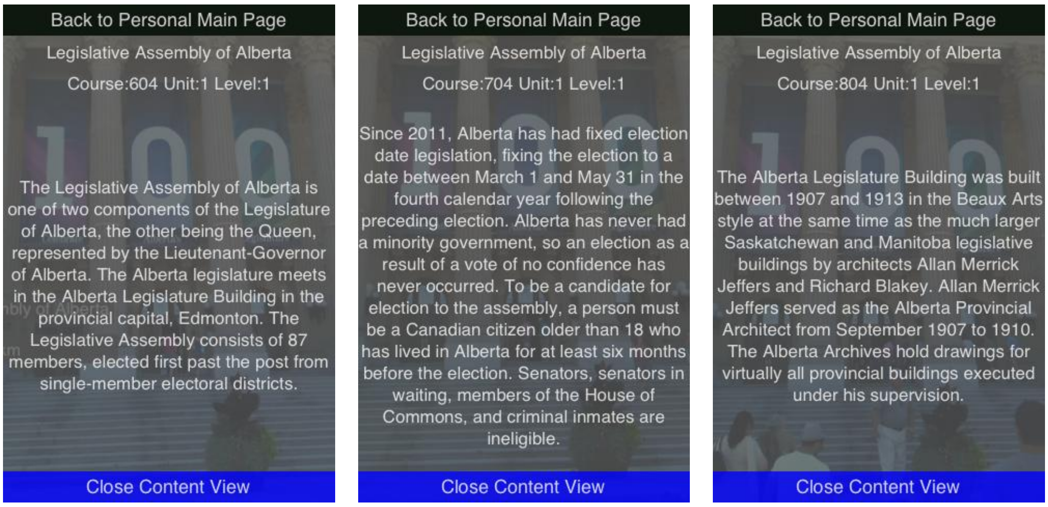
(11 - A) (11 - B) (11 - C)

Figure 11. Location-based Reality Learning Object Identification Tags

The screenshot (11 - A) shows that the MOIAR application successfully identified one of the real-life learning objects, the Alberta Legislature Building, with the object’s name and the distance displayed upon the screen. The screenshots (11 - B) and (11 - C) show that the MOIAR can display tags at that same location according to different orientations and motions. In screenshot (11 - B), the learner was standing in front of a house that is located at the address 2422 111B Street (which is recorded as a real-life learning object in the database), where the house was 0.02 km away from the learner. When the learner faced to the house right next to it, the tag still shows the correct address, but the distance from the learner is now shown as 0.03 km (screenshot 11 - C). Further, the MOIAR system will change the size of the object identification tags according to the distance; the closer the object is to the learner the bigger the tag will be, and vice versa.

5.4.3 5R Adaptive Learning Contents

In the MOIAR application, all of the object identification tags are touchable buttons. In fact, the learner has to click the tags in order to get to the detailed learning contents view. The reasons for the design is first to enhance the interaction between the learner and the MOIAR application, and second that the MOIAR application can identify multiple learning objects at the same time, but the screen space on the mobile device is limited. So it is better to display only the object identification tags at first because the learners do not need to see the contents until they are directly in front of a real-life learning object and are ready and interested to learn. Figure 12 shows different learning contents based on personal learning status of three learners.



(12 - A) (12 - B) (12 - C)

Figure 12. 5R Adaptive Learning Contents

As mentioned above, with the 5R adaptive mechanism, the MOIAR application can tailor the learning contents according to personal learning status of different learners. There are three parts of contents in the content view. First part on the top shows the name of the learning object, second part below shows the learner's current personal learning status, and the third main part shows learning contents. As shown in figure 12, screenshot (12 - A) is a tourist spot description of the Alberta Legislature Building, which is tailored for the course "Traveling English". Screenshot (12 - B) shows the political history of the building, which is tailored for the course "Political Science". The last screenshot (12 - C) gives the design and architectural style of the building, which is tailored for the course "Introduction to Architecture".

Chapter VI. Conclusion and Future Work

6.1 Conclusion

Augmented Reality (AR) allows learners to see the real-life scene with attached virtual information superimposed upon or composited with the real world. In the location-based adaptive mobile learning scenario, AR can further benefit and optimize the learning experience because it is a highly location-sensitive and real-life object oriented technique. The location-based mobile learning also allows learners to experience the learning content by seeing the objects in real life, so that the learners do not have to match the contents in imagination. With AR, learners not only get to experience the learning objects in real life, but also get to see the learning contents superimposed upon the real-life object on the screen at the same time. This way, learners will not get distracted by matching back and forth between the learning contents and the real-life object, and they do not have to match the learning contents with each of the real-life learning object by themselves.

6.1.1 Academic contribution

The research in this thesis has accomplished both academic and practical contributions. In terms of the academic contributions, an overall literature review of mobile learning applications was conducted with focus on location-based service, content adaptability, and mobile AR technique. Then, chapter three described a study conducted in this research about the real-life object tagging and identification techniques in AR, which resolved the issue of how to properly identify the real-life objects. This study extended the original AR definition and further focused on the object identification process. The first part of the study focused on real-life object tagging and identifying. In order to properly identify the objects in real life, the study indicated that the first important step is to attach each real-life object with appropriate identification tag. The study categorized different types of tags according to their features, for example, descriptive tags are easy to understand by humans, and location-based tag are suitable for open space outdoor scenario. Based on the different features of each real-life object identification tag, the second part of the study proposed three approaches according to the level of human assistance required to identify the tags. The Learner-Assisted Identification requires learners' full involvement in the object identification process, which means learners are responsible to identify the tags. In the Manual-Device Identification and Auto-Device Identification, the application takes the responsibility to identify the tags. The only difference between those two approaches is that the Manual-Device Identification requires the learner to manually scan or take a picture of the tag, while the Auto-Device Identification automatically senses and identifies the tags.

Another study was conducted in this research in order to analyze the human-computer interfaces and their abilities on the emerging mobile devices, especially smart phones, for successfully and efficiently utilizing the three approaches mention above to identify the real-life objects in the location-based adaptive mobile learning scenario.

Then, the 5R adaptive mechanism was implemented to improve the learning contents adaptability, in order to provide the right contents to the right learner at the right time and location for the right device. The 5R adaptive mechanism tailored the learning contents according to the learner’s learning status and the mobile device’s current location status. Comparing the MOIAR approach developed in this research with prior mobile AR learning research applications, most of the prior applications can only provide learning contents based on the textbook or tailored to the object itself. The MOIAR system can not only identify the objects of interest but also provides the contents of interest. The 5R adaptive mechanism helps the learners in constructing more meaningful knowledge because the learning process and learning contents are integrated with societal culture, life-context, and personal learning preferences.

6.1.2 Technical contribution

A system called "Multi Object Identification Augment Reality (MOIAR)" has been developed and implemented in this research. The MOIAR system works on iOS platform and is designed based on the client mobile software design principles. The first practical contribution is that it fully exerts the advantages of AR technique and adapts to the limited resources available on typical mobile devices. Compared the MOIAR system to prior AR learning applications, prior applications for example, require setting up of huge image databases in advance for real-life image processing, continuous Internet connection for instant image streaming, and lots of computing resources for imaging processing and matching. Similarly, optical marker AR requires putting a binary marker on every single learning object. The MOIAR system requires *no additional hardware*; it utilizes all of the built-in components on the mobile device, such as A-GPS, digital compass, accelerometer, and the camera lens. The MOIAR requires only *small data communication bandwidth usage;* it utilizes the local database to develop the system data model, so that the application can be used without any additional Internet connection while identifying real-life objects and retrieving related contents. For the principle of *little resource usage*, the MOIAR system utilizes location-based tags and Auto-Device Identification approach instead of the real life image processing tag and additional assistance Marker, so that the main processing resources are location, orientation, and motion, which can also be accomplished without additional server computing resources. Lastly, for the principle of *little human/device interaction*, it only takes two steps to launch the MOIAR application, the learner login and clicking of the launch button. However, in order to effectively utilize the limited screen space and have the ability to provide an interactive learning experience, the MOIAR application displays only the Object Identification Tags on the screen first, and then the learners can click on the tags they are interested in to get more detailed learning contents.

Next, an Object Identification algorithm is proposed and implemented in this research for the MOIAR application to effectively identify the real-life learning objects based on the calculated Azimuth and the subtended angle, whatever the learners' current location and orientation are, and whenever learners change them. Unlike prior AR learning applications that require learners to stand within a certain distance from the object or focus the camera lens in front of the optical marker, the MOIAR application lets the learners walk around the real-life learning object and still see the identification tags and the adaptive learning contents, as long as the camera lens is facing the real-life learning objects. Further, the MOIAR can also guide the learner to other real-life learning objects located with the object identification tags.

6.2 Research Limitations and Future Work

In the research presented in this thesis, there are three parts that were not implemented and are left for future work. These include the indoor AR learning scenario and application, the distance filter in the Object Identification algorithm, and the server database synchronization and instant object/content update.

REFERENCES

Al-Mekhlafi, K., Hu, X., & Zheng, Z. (2009). An Approach to Contextaware Mobile Chinese Language Learning for Foreign Students. *Eighth International Conference on Mobile Business* (pp. 340-346). IEEE.

Anastassova, M., Burkhardt., J. M., & Mégard, C. (2007). User-Centred Design and Evaluation of Augmented Reality Systems for Industrial Applications: Some deadlocks and breakthroughs. *S. Richir (Editor), VRIC'07, 9th International Conference on Virtual Reality* (pp. 215-224). Laval, France: IEEE.

Azuma, R. T. (1997). A Survey of Augmented Reality. *Teleoperators and Virtual Environments, 6*(4), pp. 355-385.

Azuma, R., Baillot, Y., Behringer, R., Feiner, S., Julier, S., & MacIntyre, B. (2001). Recent advances in augmented reality. *Computer Graphics and Applications, 21*(6), pp. 34-47.

Barakonyi, I., & Schmalstieg, D. (2006). Ubiquitous Animated Agents for Augmented Reality. *Mixed and Augmented Reality, 2006. ISMAR 2006. IEEE/ACM International Symposium*, (pp. 145-154).

Bauer, M., Bruegge, B., Klinker, G., MacWilliams, A., Reicher, T., Riß, S., . . . Wagner, M. (2001). Design of a Component-Based Augmented Reality Framework. *Augmented Reality, 2001. Proceedings. IEEE and ACM International Symposium (ISAR)*, (pp. 45-54).

Bellavista, P., Küpper, A., & Helal, S. (2008). Location-Based Services: Back to the Future. *Pervasive Computing, 7*(2), pp. 85-89.

Benford, S., Rowland, D., Flintham, M., Drozd, A., Hull, R., Reid, J., . . . Facer, K. (2005). Life on the edge: supporting collaboration in location-based experiences. *CHI 2005* (pp. 721-730). Portland: ACM Press.

BenMoussa, C. (2003). Workers on the move: new opportunities through Mobile commerce. *IADIS International Conference e-Society 2003*, (pp. 251-256).

Bhaskar, U., & Govindarajulu, P. (2008). A Design Methodology For Acceptability Analyzer in Context Aware Adaptive Mobile Learning Systems Development. *IJCSNS International Journal of Computer Science and Network Security, 8*(3), pp. 130-138.

Brown, A., & Campione, J. (1996). Psychological theory and design of innovative learning environments: on procedures, principles, and systems. In S. Leona, & G. Robert, *Innovations in learning: new environments for education* (pp. 289-325).

Chang, W., & Tan, Q. (2010). Augmented Reality System Design and Scenario Study for Location-Based Adaptive Mobile Learning. *Computational Science and Engineering (CSE), 2010 IEEE 13th International Conference* (pp. 20-27). IEEE.

Chang, W., Tan, Q., & Fang, W. T. (2010). Multi-Object Oriented Augmented Reality for Location-Based Adaptive Mobile Learning. *Advanced Learning Technologies (ICALT), 2010 IEEE 10th International Conference* (pp. 450-451). IEEE.

Chen, C.-M., & Tsai, Y.-N. (2010). Interactive Location-based Game for Supporting Effective English Learning. *International Journal of Intelligent Information Technology Application, 3*(1), pp. 44-50.

Chen, C.-M., Li, Y.-L., & Chen, M.-C. (2007). Personalized Context-Aware Ubiquitous Learning System for Supporting Effectively English Vocabulary Learning. *Advanced Learning Technologies, 2007. ICALT 2007. Seventh IEEE International Conference* (pp. 628-630). IEEE.

Chen, J., & Kinshuk, D. (2005, January). Mobile Technology in Educational Services. *Journal of Educational Multimedia and Hypermedia, 14*(1), pp. 89-107.

Conejo, R., Guzmán, E., Millán, E., Trella, M., Pérez-DeLa-Cruz, J.-L., & Ríos, A. (2004). SIETTE: A Web-Based Tool for Adaptive Testing. *International Journal of Artificial Intelligence in Education, 14*, pp. 1-33.

Cui, Y., & Bull, S. (2005, June). Context and learner modelling for the mobile foreign language learner. *Science Direct System, 33*(2), pp. 353–367.

Cupper, A., Treu, G., & Linnhoff-Popien, C. (2006). TraX: a Device-Centric Middleware Framework for Location-Based Services. *Communications Magazine, 44*(9), 114-120.

Damala, A., Marchal, I., & Houlier, P. (2006). Merging augmented reality based features in mobile multimedia museum guides. *XXI International CIPA Symposium.* Athens, Greece.

Dey, A. K. (1999). *Providing Architectural Support for Building Context-Aware Applications.* Unpublished PhD Thesis, College of Computing, Georgia Institute of Technology, Computer Science.

Doswell, J. T. (2006). Augmented Learning: Context-Aware Mobile Augmented Reality Architecture for Learning. *Sixth International Conference on Advanced Learning Technologies (ICALT'06)* (pp. 1182-1183). IEEE.

Doswell, J. T. (2006). Context-Aware Mobile Augmented Reality Architecture for Lifelong Learning. *Sixth International Conference on Advanced Learning*

Technologies (ICALT'06) (pp. 372–374). IEEE.

Foster, A. L. (2005). Can You Hear Me Now? *The Chronicle of Higher Education, 52*(12), A32.

Green, K. C. (2000). *Technology and instruction: compelling, competing, and complementary visions for the instructional role of technology in higher education.* http://www.campuscomputing.net.

Guzmán, E., Conejo, R., & Pérez-de-la-Cruz, J.-L. (2007, July-Aug). Improving Student Performance using Self- Assessment Tests. *Intelligent Systems, 22*(4), pp. 46-52.

Henrysson, A., & Ollila, M. (2004). UMAR: Ubiquitous Mobile Augmented Reality. *MUM '04 Proceedings of the 3rd international conference on Mobile and ubiquitous multimedia* (pp. 41-45). ACM.

Hollerer, T. H. (2004). *User Interfaces for Mobile Augmented Reality Systems.* Graduate School of Arts and Sciences, Philosophy. New York, NY, USA: Columbia University.

Hollerer, T., & Feiner, S. (2004). Mobile Augmented Reality. In H. Karimi, & A. Hammad, *Telegeoinformatics: Location based Computing and Services.* London, UK: Taylor and Francis Books Ltd.

Höllerer, T., Feiner, S., Hallaway, D., & Bell, B. (2001, Oct). User Interface Management Techniques for Collaborative Mobile Augmented Reality. *Computers and Graphics, 25*(5), pp. 799-810.

Höllerer, T., Feiner, S., Terauchi, T., Rashid, G., & Hallaway, D. (1999, Dec). Exploring MARS: Developing Indoor and Outdoor User Interfaces to a Mobile Augmented Reality System. *Computers and Graphics, 23*(6), pp. 779-785.

Horn, M. (2006). Wings of learning. *Fraunhofer Magazine*, 18-19.

Hornby, A. S. (1950). The situational approach in language teaching (I)(II)(III). *ELT, 4*(4), pp. 98-104, 121-8, 150-6.

Hwang, G.-J. (2006). Criteria and Strategies of Ubiquitous Learning. *Sensor Networks, Ubiquitous, and Trustworthy Computing, 2006. IEEE International Conference. 2*, pp. 72-77. Taichung: IEEE.

Juan, C., Beatrice, F., & Cano, J. (2008). An Augmented Reality System for Learning the Interior of the Human Body. *Eighth IEEE International Conference on Advanced Learning Technologies (ICALT 2008)*, (pp. 186-188).

Juan, C., Canu, R., & Giménez, M. (2008). Augmented Reality Interactive Storytelling Systems Using Tangible Cubes for Edutainment. *Eighth IEEE*

International Conference on Advanced Learning Technologies (ICALT 2008) (pp. 233-235). IEEE.

Kaufmann, H. (2003). Collaborative Augmented Reality in Education. *Proc. Imagina 2003 Conf. (Imagina03).*

Kay, J. (2001). Learner Control. *User Modeling and User-Adapted Interaction, 11*(1-2), pp. 111-127.

Kim, K., Oh, S., Han, J., & Woo, W. (2009). u-Contents: Describing Contents in an Emerging Ubiquitous Virtual Reality. *International Workshop on Ubiquitous Virtual Reality (IWUVR)*, (pp. 9-12).

Kim, S., Suh, Y., Lee, Y., & Woo, W. (2006). Toward ubiquitous VR: When VR Meets ubiComp. *The 4 international symposium on ubiquitous VR (ISUVR)*, (pp. 1-4).

Lee, J. Y., Seo, D. W., & Rhee, G. (2008, November). Visualization and interaction of pervasive services using context-aware augmented reality. *Expert Systems with Applications: An International Journal, 35*(4), pp. 1873-1882.

Lee, M.-G. (2001). Profiling students' adaptation styles in Web-based learning. *Computers & Education, 36*(2), pp. 121-132.

Lee, Y., Oh, S., Shin, C., & Woo, W. (2009). Ubiquitous Virtual Reality and Its Key Dimension. *International Workshop on Ubiquitous Virtual Reality (IWUVR),* (pp. 5-8).

Lehner, F., & Nösekabel, H. (2002). The role of Mobile devices in elearning– first experiences with a wireless e-learning environment. *Wireless and Mobile Technologies in Education, 2002. Proceedings. IEEE International Workshop* (pp. 103-106). IEEE.

Liu, T.-Y., Tan, T.-H., & Chu, Y.-L. (2007). 2D Barcode and Augmented Reality Supported English Learning System. *6th IEEE/ACIS International Conference on Computer and Information Science (ICIS 2007)* (pp. 5-10). IEEE.

Michie, M. (1998, 11). Factors influencing secondary science teachers to organise and conduct field trips. *Australian Science Teacher's Journal, 44*(4), p. 43.

Modritscher, F. (2007). *Implementation and Evaluation of Pedagogical Strategies in Adaptive ELearning Environments.* Institute for Information Systems and Computer Media (IICM), Doctor of Technical Sciences (Dr.techn.) in Computer Science. Graz, Austria: Graz University of Technology.

NOKIA. (n.d.). *Mobile Augmented Reality Applications project.* http://research.nokia.com/research/projects/mara/index.html.

Nokia Research Center, NRC. (2009, June). Mobile Mixed Reality: The Vision. *Nokia*

Technology Insights series, 1-4.

Oppermann, R., Rashev, R., & Kinshuk, K. (1997). In A. Behrooz, *Knowledge Transfer* (Vol. 2, pp. 173-179). London UK: the School of Oriental and African Studies, University of London.

Papanikolaou, K. A., Grigoriadou, M., Kornilakis, H., & Magoulas, G. D. (2003). Personalizing the interaction in a web-based educational hypermedia system: The case of INSPIRE. *User Modeling and User Adapted Interaction, 13*(3), pp. 213-267.

Patten, B., Sánchez, I. A., & Tangney, B. (2006, April). Designing collaborative, constructionist and contextual applications for handheld devices. *Computers & Education, 46*(3), pp. 394-308.

Reitmayr, G., & Schmalstieg, D. (2004). Collaborative augmented reality for outdoor navigation and information browsing. *Proceedings of the Second Symposium on Location Based Services and TeleCartography* (pp. 53-62). TU Wien.

Schmalstieg, D., & Wagner, D. (2007). Experiences with Handheld Augmented Reality. *Mixed and Augmented Reality, 2007. ISMAR 2007. 6th IEEE and ACM International Symposium* (pp. 3-18). IEEE.

Simon, R., Kunczier, H., & Anegg, H. (2007). Towards Orientation-Aware Location Based Mobile Services. In G. Gartner, & K. Rehrl, *Location Based Services and Telecartorgaphy Lecture Notes in Geoinformation and Cartography* (pp. 279-290). Springer.

Tan, Q., & Kinshuk. (2009). Client Mobile Software Design Principles for Mobile Learning Systems. *International Journal of Interactive Mobile Technologies (iJIM), 3*(1), pp. 32-37.

Tan, Q., Huang, Y.-M., & Jeng, Y.-L. (2009). Location-Based Dynamic Grouping Algorithm in Mobile Learning Environment. *Journal of Education Technology*.

Virvou, M., & Alepis, E. (2005, January). Mobile educational features in authoring tools for personalized tutoring. *Computers & Education, 44*(1), pp. 53-68.

Wagner, D., & Barakonyi, I. (2003). Augmented Reality Kanji Learning. *the Second IEEE and ACM International Symposium on Mixed and Augmented Reality (ISMAR '03)* (pp. 335-336). IEEE.

Wood, K., & Homan, S. (2003, Oct). Taming the mega-lecture: wireless quizzing. *Syllabus Magazine*, 7-8.

Zhou, R., & Rechert, K. (2008). Personalization for Location-Based E-Learning. *The Second International Conference on Next Generation Mobile Applications,* *Services, and Technologies* (pp. 247-253). IEEE.