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Mobile Augmented Reality for Learning

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Table of Contexts

Towards mobile augmented reality

Until recently, augmented reality (AR) applications were mostly available for powerful workstations and high power personal computers. The introduction of augmented reality applications to smartphones enabled new and mobile AR experiences for everyday users. Because of the increasing pervasion of smartphones, AR is set to become a ubiquitous commodity for leisure and mobile learning. With this ubiquitous availability, mobile AR allows to devise and design innovative learning scenarios in real world settings. This carries much promise for enhanced learning experiences in situated learning. In the present article, we will look at different dimensions of mobile AR and exemplify their potential for education. At the end, we want to report on a short experiment that we conducted, called Locatory. It exceeds the current state of art for common mobile AR applications by introducing interactive and collaborative elements as well as gaming mechanisms.

Milgram and Kishino (1994) describe augmented reality (AR) as "relating purely virtual environments to purely real environments". Rice (Shute, 2009) gives an even broader perspective on augmented reality, stating that it should cover any media that is specific to your location and the context of what you are doing. We find these definitions too generic, and in direct conceptual conflict with closely related systems such as context-aware or immersive systems, mixed reality, and personalized adaptation.

For the purpose of this article, at least, we, therefore, want to specify augmented reality as a system that enhances a person's primary senses (vision, aural, and tactile) with virtual or naturally invisible information by digital means. A key defining factor in this is the synchronization that the system requires to perceptually embed the information into the enhanced (re)presentation of the world view – where 'view' also includes other primary human senses.

In this context, examples of virtual information include information artifacts like geo-located meta-information, visual/audio overlays, or 3D enhancements. Naturally invisible information, on the other hand, includes things that the human senses do not register, e.g. compass orientation, invisible light (infrared, ultraviolet, X-rays, etc.), ultrasound, or barometric pressure.

Like context-aware systems, augmented reality applications make it possible to filter information and present information overlays relative to the user's current context (Zimmermann et al., 2005, and 2007). Information in context can be filtered according to location, movement path, facing direction, object in focus, time period or according to meta-information such as the learner's personal interests or profile. As we will demonstrate below in our experiment, Locatory, information can also be filtered in a social context as relative to surrounding peers and their activities. Furthermore, we define mobile augmented reality as a specialization of context-aware systems as there is a close synchronization of existing human senses and perception with the digital information channels presented in augmented reality.

In addition to this conceptual model of AR applications, an engineering perspective is required to understand the technical components and their role in mobile AR systems for learning. In their description of the history of mobile AR, Wagner et al. (2009) have identified the following technical components of mobile AR systems as being important:

- *Flexible Display Systems*: this includes head mounted display systems, camera phones, and hand-held projectors. Display technologies become increasingly more flexible and cheaper to produce. These technologies enable the augmentation of everyday vision of mobile users.
- *Sensor systems* in mobile devices like gyroscopes, GPS, electronic compass, cameras, microphone, as well as indoor location tracking systems.
- *Wireless networking protocols and standards* supporting indoor and outdoor augmentation settings. These also enable multi-user real time interaction in the augmented reality.
- Mobile Phones with computational power to do real time visualization of 3D objects and overlays on a standalone device.
- *Tagging and tracking technologies* with six degrees of freedom, multi-marker tracking, and hybrid tracking systems this is also related to one of the most researched areas in AR, the registration problem (Bimber, 2005). It describes the problem of linking the real world perception of a mobile AR user and the presentation of the augmentation layer. Thus, the registration problem is closely linked to what we have been referring to as synchronization. .
- *Linking of location-based AR information* in storytelling and gaming approaches. There is an urgent need when AR is used for learning support to link AR experiences with instructional designs or at least with task structures and sequencing approaches. Storytelling and gaming approaches are currently the most prominent approaches.
- *Flexible layer-based AR browsers* with integration of social media. Basically, AR systems must also build on existing information channels and can present existing information to users in a new kind of user interface. Therefore, implementations of mobile AR for learning must enable open interfaces to existing content and services.

Educational Models for ubiquitous learning and AR

Specht (2009) describes a generic model for ubiquitous learning for synchronizing real world environments with augmentation media and media channels. In the Ambient Information Channel Enrichment (AICHE) model, five parameters of context are used to synchronize and augment the user's context with information and services. These five high level categories of contextual parameters are location, time, environment, relations, and id. Furthermore, the role of sensors and sensor information is defined as essential to connect media and real world objects for situated learning experiences and the support for reflection in action and about action (Schön, 83). Mobile devices today typical come with a range of basic sensors. Through processing and aggregation of the raw sensor data, higher-level sensor and semantic classification of raw sensor data can be implemented. The AICHE model defines 4 processes by which sensor data can be a) *aggregated*, used for b) *enrichment* of physical artefacts and metadata for media channels, c) the *synchronization* of media channels, artefacts, and users with contextual metadata, and d) the *framing* of synchronized information channels for metacognitive learning processes.

a) *Aggregation*: For achieving contextual learning support with sensors it is important to aggregate sensor information to make it meaningful for the learning objectives or tasks at hand.

As an example, the location of a GPS device carried by a user is only meaningful when it is connected to the user's perceivable environment, and relevant learning tasks. Aggregation can be a quite simple process linking together different sensor information as the time of the day and the location of a GPS sensor. In most cases it is also related to the conversion of raw sensor data into defined categories and scales, but it can also hold quite complex algorithms of sensor input as researched in sensor fusion.

b) *Enrichment:* In this process, artefacts, channels, or users are enriched with aggregated sensor information. Enrichment is mostly based on a specified mapping, which links an attribute of an entity to a raw data stream. Via such a mapping, devices and users also know which sensor information is relevant for them and what should be delivered to them. As a consequence of the enrichment process each artefact, user, and channel is enriched with context metadata.

c) *Synchronisation*: In the synchronisation process, the enriched users, artefacts, and channels are synchronised based on a described logic. As an example, the location of an artefact and the user are used to display a channel via an artefact. Synchronisation is at the core of every contextualised learning support. It is the result of a matching process, i.e. the user location is matched with location metadata of channels and artefacts. It is also evident that synchronisation is based on instructional designs specifying the logic of the matching.

d) *Framing:* Additionally, the display of the synchronised channels can be contrasted with relevant reference information in the instructional design. The framing process is mostly related to feedback and stimulation of metacognitive processes. Especially with augmented reality applications for contextual support, framing gets an important role as most artefacts and real world objects with which we learn need to be framed in the instructional context.

HCI interaction patterns for augmented reality

Lamantia (2009) describes several forms of HCI patterns for mobile AR, which include head-up display, tricorder, holochess, and x-ray vision. These interaction design patterns are the underlying structures that form mobile AR experiences. We will use these also to analyze educational AR applications.

Head-up Display (HUD)

Head-Up displays (HUD) project information into the visual field of the user and were, so far, mainly used for navigation or additional information necessary in the course of action. A HUD is the oldest AR interaction pattern and was introduced in the 1950s. Using a Head-Up Display in the cockpit of a fighter-jet, pilots can read information without having to move their eyes to a special instrument panel.

The main characteristics of this interaction pattern are:

- A user does not take his eyes from the environment to an instrument panel to move.
- Information is integrated with the visual field of the user and is synchronized with the movement of the head.

- A HUD is typically an integrated system. Whereas many AR tools rely on handheld monitors, a HUD is typically integrated into another existing device (e.g. a helmet, a plane or car).

HUD applications can project information on senses other than vision. An audio HUD AR system can inform the user of the environment using a headset. The LISTEN project (Eckel, 2001) immersed the user in 3D audio scenes synchronized with the movements of the user. One of the most challenging problems hereby is the synchronization of the audio rendering with the physical movement of the user. With newer smartphone devices first apps also enable mobile phone users outdoors to experience audio augmented reality. By using headphones, the user is not limited in his interaction possibilities and can freely move both head and hands.

Tricorder

The tricorder was introduced in the Star Trek science-fiction television series (1966-1969; http://en.wikipedia.org/wiki/Tricorder). It is a mobile device that can scan an environment and provides information about that environment. For example, after landing on a new planet, the tricorder was pointed in a certain direction and would then present a detailed examination of living things in that direction.

The tricoder-style interaction pattern provides the user with information about his surroundings and the objects in that environment with the help of a screen. A key characteristic of this pattern is that the tricorder is a handheld device. With this device (e.g. a smartphone) the user waves in the direction of interest. This pattern builds on an experience in the real world and allows the user via augmented reality get additional information about his/her environment.

The main characteristics of this interaction pattern are:

- It provides information about an existing environment.
- It is realized through a handhelddevice such as a smartphone. This distinguishes it from a HUD which is integrated. A tricorder introduces interaction constraints, which makes it different from a HUD. A user needs at least one hand to utilize the tricorder and thus it constrains a user’s movement. The tricorder pattern is very important for mobile devices. Most of today’s mobile AR applications are built on this pattern to display points of interest.

By contrast, the decoupling of the AR display from the user’s viewpoint also enables different perspectives on presented content and explicit selection of perspective by the user. Nevertheless, this type of use is also closely related to the holochess pattern.

Holochess

Holochess is the name of the chess game in Star Wars. The holochess interaction pattern places virtual objects in the real world. These virtual artifacts that are positioned in the real world can often interact with one another or can interact with objects in the real world. Although mobile AR applications have properties of both holochess and tricorder, the most important difference is that in holochess the virtual object is the object of interest, while with the tricorder the object serves as an enrichment of what the user is looking at. The holochess patterns can be realized with stationary and mobile devices. Recent research also mixes real world object manipulation and approaches based on automatic scanning of tagged objects. This enables especially also integration of tangible interfaces and simulations and recent research has shown the efficiency of these approaches in vocational training (Do-Lenh et AL, 2009).

X-ray vision

In the X-ray vision interaction pattern basically surfaces can be looked trough or underlying structures can be visualized. On the one hand, this can be realized in combination with different patterns as tricorder or head-up display, on the other hand, it extends these patterns as the augmentation is in most cases based on high precision registration. Most application nowadays can be found in the medical domain.

Educational patterns and practices in mobile AR

(Mobile) Augmented reality can be applied in various educational domains. It can help learners to gain a deeper understanding, experience embedded learning content in real world overlays, or explore content driven by their current situation or environmental context. Most prominent examples support exploration of the physical environment with different topics of interest, e.g. history, arts, technology, biology, astronomy and others, or by enriching artifacts in the physical environment with AR techniques. In general, AR technically is divided in marker-less and marker-based AR to register digital content for real world orientation and placement. In this section we describe a number of educational patterns that are related to the interaction patterns discussed earlier. The patterns described below connect an educational objective to the usage of certain dimensions of context (Specht, 2009) in synchronizing the augmented reality layer with real world learning situations. They are therefore positioned via these connection points in a matrix (fig.1 below). We will elaborate on the patterns with several empirical examples and findings that are associated with each.

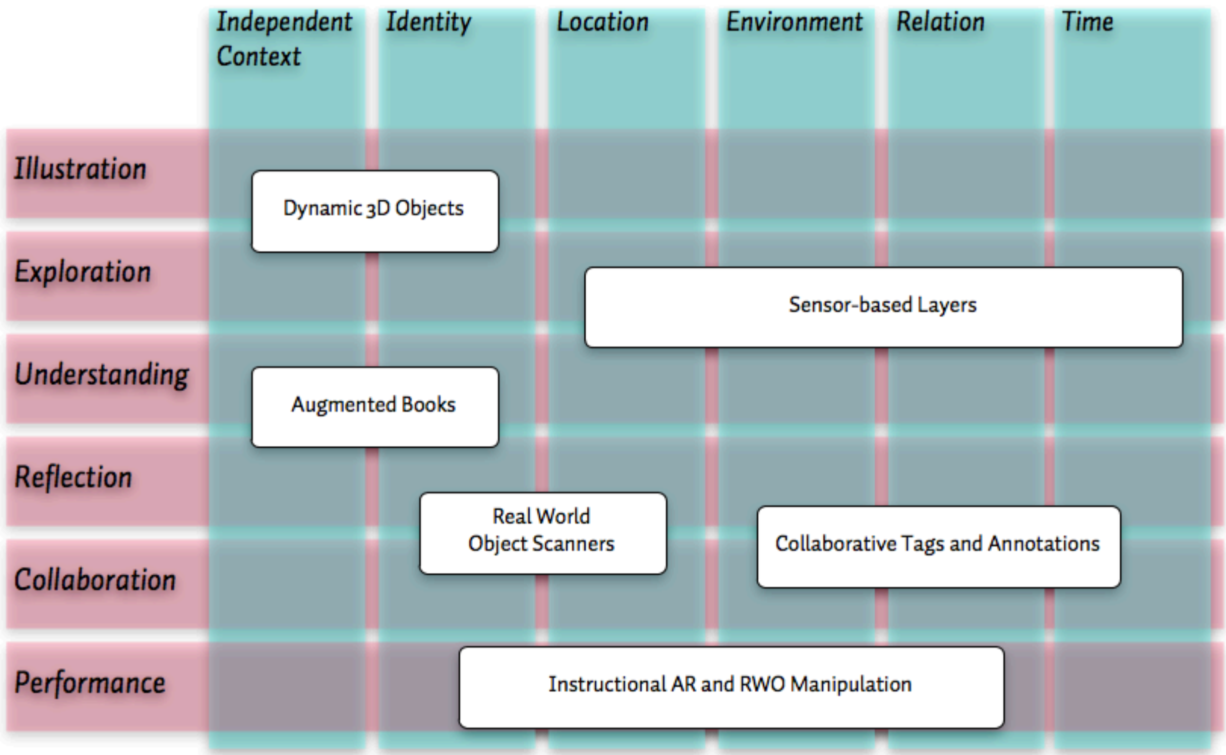

Figure 1: A matrix classifying educational patterns for mobile AR based on educational objectives and context information taken into account.

Dynamic 3D Objects

Education objective: Illustration and interactive 3D visualization of learning content, which is explorable from different perspectives.
Implementation and context: In most cases, the pattern is implemented by using markers that identity the content to be displayed.
Examples and evaluations: Several examples in the literature use the power of dynamic displays embedded in mobile devices or with stationary screens to visualize 3D objects to illustrate the relation between 2D objects and 3D objects or relevant 3D concepts (Hagbi et al., 2009). Martin-Gutierrez et al. (2010) used augmented reality visualization for training of engineering students on spatial engineering tasks and measured a positive impact on spatial abilities. According to Dede (2009) AR approaches generally enable multiple perspectives on 3D objects as a more immersive and situated perception of complex spatial shapes. Schmalstieg et al. (2007) found that an AR system for maths and geometry education encouraged experimentation of students and improved spatial skills. While the simple examples mostly do not need an exact mapping on real world objects, like visualizing an object on a table, the more complex examples also need extensive registration and linking of the augmentation and the real world objects. Dynamic 3D objects are also used in collaborative scenarios for stimulating discussion and collaborative construction.

Augmented books and real world object scanners

Educational objectives: Illustration, reflection and dynamic materials addition, deeper understanding through additional perspectives, extending user senses or perceivable perception range.

Implementation and context: Augmented books and objects are the simplest form of relating real world objects and digital augmentations. In principle, these can be done by manual identification of objects via number codes, with camera based phones using visual codes. There are two possibilities for displaying the augmentation: a) with a mobile device identifying the augmented object, the mobile device can be used to show the augmentation to the user, b) with stationary devices, the users can carry and manipulate real world objects while ubiquitous camera systems follow the objects and their orientation, rendering the augmentation on screen. Mostly, these augmentations use the identity context to link augmentation and printed material. Newer approaches also enable the object recognition via the built-in camera and filter the relevant information like for example Google Goggles[1].

Examples and evaluations: Via the integration of markers in books, different augmentations can be achieved and applications for more immersive book experiences or illustration of 2D static media with dynamic 3D media can be implemented. Dias (2009) identified several effects when using augmented book approaches, such as enhanced perceived values of learning material, educational illustration and better understanding of text material. Furthermore, the linking with real world objects can also be used for collaboration and object annotation as for example in urban design (Wang et al., 2007).

Sensor-based Layers

Educational objectives: exploration support, immersion support.

Implementation and context: Sensor-based layers extend the perceivable information of users based on sensor information. Either the sensor information is embedded in the viewpoint of the user, or it is used to filter available information such as underlying geo-tagged information databases. In location-based information layers, the current user location and direction is taken to filter information objects and present maps or camera overlays with selected information. Most popular approaches are based on augmented reality browsers like Layar. From the educational perspective this is strongly related to the inquiry-based approaches to learning support.

Examples and evaluations: Alessandro (2010) compared different user interfaces combining AR and classical map search interfaces for real world search tasks. Most efficient solutions for well-defined searches on location-based information have been the "zoom interfaces" combined with direction highlighting based on compass.

Collaborative Tagging and Annotation

Educational objectives: Knowledge sharing and awareness.

Implementation and context: First approaches on collaborative augmented reality can be found using location-based environments where users can collaboratively annotate and tag real world objects and share this information with others. Furthermore, first approaches also embed shared artifacts in AR games that support the collaborative manipulation of 3D objects.

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[1] http://www.google.com/mobile/goggles/#text

Examples and evaluations: Nilsson et al. (2009) used this in the cooperation between different stakeholders in a crisis management scenario like rescue services, the police and military personnel. They found positive effects on efficiency of cooperation and users perceived added value.

Instructional AR for real world object manipulation

Educational objective: real time feedback, linking movements and AR feedback systems.
Implementation and context: Quite fine granular registration of real world overlays is needed for complete instructional environments in AR.
Examples and evaluation: As far as the manipulation of real world objects is the objective, good examples are maintenance support systems like the BMW augmented reality system (Interone Worldwide, 2010). Kotranza et al. (2009) used direct visual feedback to enhance task performance on joint psychomotor-cognitive tasks.

Conclusion

Mobile Augmented Reality if a fast growing field in the commercial application market as also educational practices are becoming adopted in a fast pace. As with most new technologies the central question is what the educational added values of theses technologies is and what added value and practices will survive the technology hype.

This whitepaper tries to identify possible educational patterns of mobile augmented reality both to classify existing practices but also to stimulate the discussion about the educational effects and the core innovation of the technology from an educational perspective.

When educators use new technologies as augmented reality they should always ask questions about what learning outcomes do I want to achieve and will the technology enhance the learning experience. Nevertheless in this context learning can and probably has to be seen in a broader perspective of including engagement, cognition, and new media facilities. Applied to augmented reality these questions could be:

- What virtual media will help learning considering my specific learning outcome?
- Are the virtual media shared between learners or linked to real world objects?
- What aspects of the real world do I want to augment?
- What linking between real world objects and digital media can bring a new quality for learning?
- What collaborative manipulation of augmentation can be helpful for stimulating learning and collaboration?

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