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Smart Ambient Learning with Physical Artifacts Using Wearable Technologies

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Abstract. Wearable technologies have been developing a momentum recently. However, integrated concepts for teaching and learning with wearable technologies are still not existing in the moment. In this paper, we report about a multi-contextual framework for such an integrated concept. It consists of a number of real-world use-cases coming from a third-party funded project, an entrepreneurial teaching course from a technical university and an open source software development strategy. Conceptual as well as technical issues and first experiences draw an optimistic picture while we outline further needs in research and development.

Keywords. mobile learning, wearables, informal learning

1. Introduction

With the ever-increasing pace of businesses nowadays, also the characteristics of life-long learning underwent a steady change. As an example, the construction sector has to deal with new tools and material on a nearly daily basis, while the budget for training of staff is ever decreasing. Commonly, moving the learning situations to the workplace is considered as solution. Together with the shift to informal workplace learning situations [1], new solutions have to be found for conveying learning material to learners. Our approach presented in this work as technical feasibility study is to allow digital content to be linked to working tools or material. Therefore we discuss three scenarios for wearables usage in informal learning scenarios that are motivated from use cases in a third-party funded project. To evaluate the feasibility of our approach, we implemented a Web-based framework for connecting digital content to physical artifacts in an entrepreneurial teaching course. Our system consists of a backend in the cloud and frontend components for desktop, mobile and wearable devices. As a concrete evaluation scenario, we chose to virtually enrich items in an exhibition. The initial findings and considerations about the technical setup are presented in this paper. To allow for building upon our results, the development work is available under a permissive open source license on our GitHub page[1]. We see a huge potential

[1] https://github.com/learning-layers/CaptusBackend

in extending our prototypes to also address challenges such as personalized and localized digital content to take into account prior knowledge, experience, context of use and performance levels.

The paper is organized as follows. First, we give an overview of our terminology and list underlying technological considerations. Then, the concept of our smart ambient learning system is presented, before the concrete implementation is shown. In the end, we discuss our challenges and give an outlook of possible future work in this area.

2. Background

Before delving into the details of our informal learning scenario, the terminology used in the rest of the paper is laid out. Then, technologies for linking digital devices to physical artifacts are highlighted.

The goal of our system is to attach digital content to physical artifacts. Therefore, digital devices are needed for the users to interact with the digital material provided. To offer a wide variety of interaction possibilities, we chose to support various device types and form factors. Here, we define the device class terminology that we use throughout the paper; in the brackets we list concrete instances of these device types that we used during development and test phases.

- As *stationary devices*, we refer to desktop PCs and laptops (Windows and MacBook).
- As *ambient devices*, we refer to public displays, i.e. fixed large-screen monitors that augment a users mobile screen space (a state-of-the-art 50 inch flat TV connected to a Google Chromecast).
- As *mobile devices*, we refer to smartphones and tablets (Nexus 5 and Nexus 7).
- As *wearable devices*, we refer to smart glasses and smart watches (Google Glass and LG G Watch).

Apart from these concrete instances of devices, we are confident that our findings and prototypes can be transferred easily to other brands and models, since we are using Web technologies as the underlying platform. Besides Web browsers being installed on every device, various cross-platform environments like PhoneGap or Sequoia Touch exist that enable developers to transform their applications from HTML5 into native app packages for Android or iOS. This may be especially important when accessing special hardware capabilities such as NFC readers for discovering present physical artifacts. Other approaches for establishing this link are presented below.

2.1. Technologies for Discovery

Making smartphones and wearables aware of the physical presence of artifacts is a crucial requirement for our system to be able to present additional information about these items to the learners. To identify physical objects, an identifier of at least the object's type has to be available on the digital device that the user

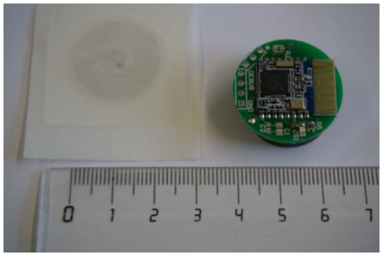

Figure 1. Size Comparison of Near Field Communication (left) and Bluetooth Low Energy Chips (right)

is using; e.g. a *Unique ID (UUID)* that the mobile device can look up to get more details. In the following, we therefore discuss technologies that are useful for establishing a link between a mobile device and a physical information for transferring a limited amount of information.

QR Codes encode certain chunks of information visually, similar to barcodes that are today found on almost every product in supermarkets. QR codes consist of up to hundreds of squares whose arrangement is able to include information as large as around 4000 alphanumerical characters. Over the last years, QR codes have gained huge momentum in street and magazine advertisements where usually the advertised product's website is encoded in a QR code. Mobile apps capable of decoding QR codes are available for free on most mobile operating systems. The main advantage of QR codes is their cheap reproducibility and customizability by simply generating codes on a website and then printing them out on any printer. It is also the most interoperable technology out of the presented ones, as except of a built-in camera, no additional hardware is necessary on mobile devices.

Near Field Communication (NFC) is a contact-free technology for transferring small chunks of information. The principle is known from public transportation ticketing systems and credit cards; the microchip that is usually embedded in the cards has to be held to the reader for a short time so that the data on the NFC chip can be read out. NFC typically works over a range of a few millimeters; it has an active and a passive mode. The active mode allows two NFC devices to actively exchange information over the wireless link; the speed is usually as low as around 100-400 kilobits per second. In the passive mode, the accessing device is sending out wireless waves. Via induction, the field on the sending circuit is activated and the previously saved information is transferred from the NFC chip to the device. These NFC tags are available in different form factors such as the already mentioned credit cards, or simple stickers as in Figure 1 on the left. The NFC technology is available on state-of-the-art Android smartphones and many tablets. Though NFC is recently also available on the iOS platform, Apple limits the hardware's usage to mobile payment.

Bluetooth Low Energy (BLE) is a sub-specification of the recent version of the Bluetooth standard stack for resource-efficient data transfer that is similar to NFC. The circuit for a BLE chip fits on a thumbnail and can be powered by a coin battery for around 1-2 years. To advertise its presence, it periodically broadcasts messages with a configurable signal strength. After calibration, i.e. measuring the

Table 1. Applicability of Physical Object Discovery Techniques with Commodity Hardware

Device	QR Codes	Near Field Communication	Bluetooth Low Energy
PC/Laptop	webcam	–	✓
Public display	–	–	possibly
Smartphone	✓	✓	✓
Tablet	✓	✓	✓
Smart watch	–	–	✓
Smart glass	✓	–	✓

signal strength in 1 m distance, a mobile device may measure its distance to the BLE chip; typically it can reach from a few centimeters to around 70 meters. The iBeacon specification by Apple defines the broadcasted data to be a UUID as well as a major and a minor ID. The UUID is typically the identifier of a specific deployment; the minor and major identifiers mark iBeacons within the UUID. E.g., a retail chain may define a UUID for all its stores, a major ID for a specific store and a minor for a particular iBeacon within the store. While iBeacons are natively accessible through the iOS development framework, libraries with similar functionality are available for Android. Figure 1 (on the right) shows a typical iBeacon.

In this section we discussed different technologies for the discovery of physical artifacts from a mobile device. We defined that artifacts need a unique identifier to be digitally representable. Table 1 shows an overview of the presented approaches and their applicability for the device types presented in Section 2.

3. Scenarios for Learning with Physical Artifacts

In this section, we give examples of real-life scenarios for learning with physical artifacts. They originate from the third-party funded project *Learning Layers*[2] that is dealing with informal learning at the workplace for the construction and healthcare sectors. The scenarios aim to enable different types of digital devices to digitally enhance physical artifacts like tools with additional information. Besides, the objects should be able to be virtually discussed by users.

At **construction sites**, workers have to deal not only with a large variety of building materials, but also with a huge quantity of different tools. As an additional burden for fast adaption of construction techniques, these materials and tools are rapidly changing. Thus in this scenario, workers carry around a mobile device in their worker belt and wear smart watches on their wrists and possibly even a smart helmet[3]. At the start of the day, the workers open a digital toolbox app for getting a list of the day's tasks. The app presents a list of tools like drills and screws to collect. For every tool, annotated videos are available as manuals that can be played in the smart helmet. Additionally, new videos may be recorded and uploaded to a repository for co-workers to be discussed. Finally,

[2] see http://learning-layers.eu
[3] E.g. the one available at http://hardware.daqri.com/smarthelmet/

Figure 2. The Exhibition Scenario

the wearable apps may track the current context to nudge construction workers in case there are subtle optimizations in their work progress.

In the **healthcare** scenario, staff in a hospital carry around tablets and wear smart glasses. When entering a patient's room, healthcare data is automatically loaded on the tablet. Important health data may be displayed on the smart glass during operations as an augmented reality overlay. Finally, alerts on a patient's status may be automatically received on the smart glass at any time, just like pagers notify doctors about certain events (although the authors are aware of ongoing discussions, we neglect ethical and privacy issues here).

The **exhibition concept** can be seen in Figure 2. In the scenario, visitors enter a museum space and then use their mobile and wearable devices for interacting with the exhibition items. Besides the exhibition items on display, more digital material is available in a Web-based backend. Notifications on the wearables guide the visitors to material that can be accessed with the help of mobile devices. Such digital information include a textual description, PDF documents, and multimedia such as audio tracks and videos. Users may discuss the exhibits by adding comments to the digital version of the items and even commenting remarks by previous visitors for enabling a discussion. Besides simply viewing the items, visitors are able to bookmark physical artifacts in a personal library within the system. To take home the impressions and collections after visiting the museum, users may email their library to an email address after the visit, with links to the existing discussion threads for further comments. A public display may temporarily be used to see the content at a larger screen; the material may also be printed out by a stationary printer in the museum. Both versions include Web links to the system so that the discussion may be even continued later on.

3.1. User Concept

User engagement in terms of discussions, sharing and later retrieval of the collected information is an essential part of our system as discussed in the previous section. To keep track of exhibition visitors in the discussions and to maintain the library of bookmarked exhibits, a user management is necessary which includes unique identifiers for users. For lowering the entry barrier, exhibition visitors should be able to use their own accustomed devices and accounts for interacting with the exhibits. The user authentication mechanism in our system is therefore based on the *OpenID Connect (OIDC)* single sign-on standard that is widely supported by big players such as Google and Microsoft. With OIDC, visitors use their third-party accounts to access the exhibition.

3.2. Digital Exhibition

For linking physical artifacts to their digital counterpart, we employ the notion of a digital exhibition repository. This repository contains all the learning material to the exhibits including longer texts, graphics and multimedia elements like audio tracks and videos. While the physical items in the exhibition are possibly fixed in their position, with their arrangement intrinsically suggesting a certain learning path, the digital version may be traversed via links. This may even imply a custom route between the exhibits based on previous knowledge, personal preference or qualification.

3.3. Connection to Physical Artifacts

While moving through the exhibition, users need to be able to get to the digital counterpart of the exhibits through their mobile devices. This step from the physical to the digital world needs to be as easy as possible. Since visitors are able to virtually jump from one item to the other, we also want to support the other way round, from the digital page of an item to the exhibition space. We support this via an interactive room map that displays the position of the items at their approximate real location.

3.4. Reflection After the Visit

To enable reflection, sharing, discussion and extension of the learning materials after the visit, the visited content can be bookmarked during moving around the exhibition both physically and virtually. During the exhibition, this list can be accessed at any time. Additionally, the system compiles the list of bookmarks and allows it to be shared via email. Besides, the material may be compiled as a PDF to be printed on a stationary printer in the exhibition space.

This section presented a number of real-life scenarios for engaging with physical artifacts for learning. In particular, the exhibition scenario was presented in detail as it is the underlying concept for the prototypical implementation of the system that follows in the following.

4. Prototype Implementation

The previous section presented the concept of the ambient learning prototype. In the following, the prototypical implementation is discussed. First, the Web-based backend solution including its WordPress application and the established XMPP network is described. Then, the mobile app as information hub and finally the wearable prototypes for enhancing the experience are shown.

WordPress is an open source blogging software and is one of the most used content management systems on the Web. With its extendable plugin system, WordPress allows to install a wide variety of extensions. For the feature of creating a new information page for an exhibit, we employ standard WordPress pages. The comment functionality allows discussions to take place on every page. This allows to reflect on the material and discuss it with other people accessing the page. To help content creators, we created the WordPress plugin called *Captus* that introduces the notion of exhibition items to the system and displays recent activity on these contents on the front page.

The **Messaging and Presence Protocol (XMPP)** and its several extensions are widely used in instant messaging scenarios to send structured messages between any two or more entities [2]. For connecting exhibition visitors to the physical artifacts and bookmarking items, we leverage concepts of XMPP known from the *Internet of Things (IoT)* [3]. The protocol and its several extensions are widely used in instant messaging scenarios to send structured messages between any two or more entities. In particular, the bookmarking system is implemented as an XMPP contact list; i.e. every time a user connects with a physical object to display its digital information on his mobile device, a virtual friendship is created between the user the and object. The main reason for this architecture is the wide availability of client libraries and servers with the needed functionalities, without having to develop dedicated clients and backend services.

The **mobile app** is the main part of our system that connects to physical objects and all other devices including wearables and public displays. It is operating as an information hub for accessing physical artifacts, the app includes functionality for reading QR codes, touching NFC tags and accessing BLE beacons. Due to missing hardware access in HTML5 for NFC and BLE, we implemented a hybrid solution for Android smartphones based on Android WebViews as a window to the actual WordPress Web content. Another role of the mobile app is the interconnection to wearable devices. The power of this concept is visible if an exhibition visitor approaches an iBeacon. The smart glass then shows a notification about the availability of further learning material.

In our scenario, **wearable apps** are mainly responsible for the smartness of the exhibition by notifying about nearby items. For both wearable types, smart watches and smart glasses, visitors get notified about learning material that is available for nearby exhibition items. We therefore employ Bluetooth Low Energy beacons that are broadcasting a unique identifier every second with limited signal strength. The mobile Android app listens to these requests and then notifies attached wearable devices. In the case of our Google Glass prototype, the wearer may also scan QR codes on exhibition items for opening the digital content on the connected mobile device.

In this chapter, we presented our implementation of the exhibition scenario. In the following, the evaluation of our approach is discussed.

5. Evaluation

The main focus of our research was a technical and developer evaluation of the underlying technologies for creating ambient learning spaces for wearable technologies. We therefore developed parts of the framework in an entrepreneurial teaching course using open source technologies. On the users' end, we only performed an informal user evaluation by showing the prototype at a project meeting with 40 researchers and collecting oral feedback. Though we got positive results for the innovativeness of our solutions, we noticed a lack of awareness for how technologies like localization via Bluetooth Low Energy works. Technically, for connecting physical artifacts we made the best experiences with QR codes and NFC due to their technical maturity. The iBeacons we employed lacked a stable signal strength, we solved this by increasing the broadcast frequency to every 500 ms. A practical issue in our evaluation was the limited battery life of mobile and wearable devices.

6. Conclusion and Future Work

In this paper we presented a system for interacting with physical artifacts using mobile and wearable technologies. As our underlying scenario, we used a museum setting where visitors are equipped with mobile devices such as smartphones and wearable technologies like smart glasses and watches. The concept emphasizes the need of unique identifiers for both users as well as physical objects. During the visit, digital material may be collected and bookmarked in the system. Our main achievement is an integrated framework for developing this new kind of learning applications in an open source software development strategy that was boosted in a project-based learning course at a technical university.

The concept is extendable with gamification elements, e.g. points for collecting items and starting discussions. On the scenario part, sensors for temperature, light or other environmental parameters may be integrated in future for an even more immersive experience. Due to the open source character of our framework, they are easily embeddable into the presented architecture.

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