Smart Objects in Accessible Warehouses for the Visually Impaired

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ABSTRACT
The inclusion of persons with handicaps in working life is of increasing importance as equality for both disabled and non-disabled persons is a long-term goal in modern societies. Regardless of physical disabilities, the pursuit of a career suited to personal aptitude is an important concern of every individual. The demand for inclusive design and accessible workplaces is thus great, especially in consideration of the aging European society. In this work-in-progress paper, we investigate the use of smart objects for workplaces of visually handicapped persons. Based on our observations with a commissioning system in production use, we developed a concept for an accessible warehouse by integrating wireless sensor nodes into compartments, boxes and objects. We intend to equip these smart objects with various sensory and actuating technologies, which leverage a time-efficient and easily accessible commissioning process in a warehouse.

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Smart objects, Low-Energy Wireless Communications, Capacitive Sensing

ACM Classification Keywords
H.5.2 User Interfaces: *User-centered design*

General Terms
Human Factors; Design;

INTRODUCTION
With a total of five percent of the German population being visually handicapped or blind [1], we face the challenge of enabling them to be part of the workforce without greater impact on their efficiency in their respective fields of work. While most modern workplaces are equipped with helpful electronic devices, people with low vision are faced with using drawers, file cabinets and paperwork. Nowadays, pervasive technology helps and enables the visually handicapped to use office equipment just as efficiently as people without disabilities. These components have to support different target groups, ranging from kids to elderly people. One has to keep in mind the variety of causes for visual impairment as well - reaching from genetic defects or infection in utero to external influences like injuries. Moreover, in consideration to the age structure of our society, intuitive access and ergonomic design should be key guidelines in designing the workplace of the future. Therefore, the design of such accessible technologies is a crucial and highly demanding task.

In this work, we investigate the use of smart objects in a workplace of a visually impaired person. In particular, we present a concept to equip a warehouse with smart compartments, which provide acoustic feedback for easy and time-efficient localization. In the following, sensing and actuating techniques within the compartments provide naturally accessible functionality for managing object quantities and inserting new items into the warehouse.

BACKGROUND & RELATED WORK
Due to recent advancements in wireless communications, many smart objects and devices pervaded our everyday life. For example, the item finder “Chipolo” uses Bluetooth technology to locate items reliably without requiring a lot of space or high-level hardware [2]. The project employs low-energy Bluetooth receivers to locate items based on their signal strength, using a mobile phone. In consideration to our target group of vision-impaired persons, tangible objects provide an easy and intuitive way of symbolically accessing computer functions [3], [4]. In order to communicate the state of a system, acoustic [5] and haptic [6], [7] feedback techniques are applied. These use two other human senses with both high information density and low reaction time with easy implementation on a technical level.

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Figure 1. In this commissioning system, each compartment is equipped with an RFID tag. A text-to-speech program provides hints on finding the right compartment with the scanner.

CURRENT RFID-BASED IMPLEMENTATION

The idea for a new commissioning system based on smart objects was developed during a brainstorming session with a company developing accessible workplaces for the visually handicapped. The company employs two experts in interaction design, both having a low vision. In this section, we will outline the company's current experiences with a warehouse system based on RFID and a scanner. Figure 1 shows an example of the current commissioning system. Each compartment and object within the compartments is equipped with a small RFID tag. An accessible user interface runs on the PC which connects the Tags to a database, containing information on the current compartment contents, the position of the compartment, and the quantity of items inside one. When the user wants to locate an item within the warehouse, the person is able to search the computer for the desired item. Once the item is found, an iterative finding process is initiated.

The finding process is depicted in Figure 2. After a successful request, a cabled or wireless RFID reader is used to locate the right compartment. The starting point is an arbitrary compartment, which is scanned. Subsequently, the PC outputs voice commands for a refined search (e.g. “move down four compartments”). The search is continued until the desired compartment is located, as depicted in step 4 of Figure 2. The user is able to remove the desired objects from the compartment and feed the PC with the updated object quantity.

ENVISIONED CONCEPT

Requirements

Based on experiences with the RFID system in production use, we aim at achieving a number of enhancements. Specifically, our goal is to make the commissioning process less time-consuming for the user. Moreover, it is desirable to simplify the process, with peripheral devices like an RFID reader no longer required. The sources of error are to be minimized as well.

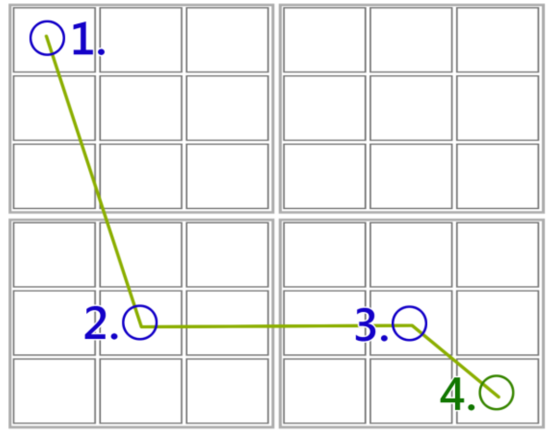

Figure 2. Locating the right compartment is an iterative process. First, the user starts with an arbitrary compartment, then the search is refined by voice commands from the user's PC.

Moreover, the following factors were taken into account when designing the system based on smart objects [8]:

- Natural Mappings: As far as possible, interaction itself shall be initiated by the objects that are naturally involved in the commissioning process. In this case, these objects are the compartments and objects located within.
- Design for Error: Errors are likely to occur, therefore, it is always important to acknowledge the fact that users will make mistakes. Therefore, it might occur that a user selects the wrong compartment or the wrong object. Moreover, he or she might not update the quantity of objects added or removed to the compartment.
- Providing Feedback with Multiple Senses: In order to help users finding the corresponding object, we can rely on other human senses such as touch (for haptic feedback) and hearing. For example, it makes sense for smart objects to send acoustic feedback.

Workflow Design

In order to allow for an efficient commissioning process, we designed a number of different workflows for (1) finding an item and updating its quantity, (2) inserting new items into a compartment, (3) maintenance and changing the batteries.

1. Finding an Item: One of the most obvious use-cases is the search for items within compartments and updating object quantities in the stock database. This begins with a user search for an item within the database. Once the user has found the desired item, the compartment containing the object sends out an acoustic signal which will guide the user towards its location. When the user is within reach of the compartment (approximately 15 cm), it becomes difficult to differentiate the compartment's exact location. Therefore, the compartment will change its acoustic output frequency according to hand distance: With acoustic feedback, selection of the right item is effortless. When an item is removed, it is necessary to update the changed number of items in the database. There are two possible options: (1) When the box is empty, the user may signal this by turning it over or (2) if there are still items left in the box, the user would lightly tap on the box's surface and thus indicate how many items were removed. This workflow uses acoustic feedback extensively during selection, but can also alert the user if a wrong item is selected.

2. Inserting New Items: Here, a user may add new items into arbitrary compartments. In this case, the person first uses the PC and manually enters the name of the item. After, the user selects an arbitrary compartment and taps on it multiple times, depending on the number of items added. Again, acoustic feedback is used to signal how many items are added and if the process was successful.

3. Energy Management: Even though we are not delving into the technical implementation yet, it is obvious that the compartments need a source of energy, e.g. batteries. Depending on how frequently it is used, the power consumption will vary strongly. However, it is also necessary to alert the user when battery power is low. Therefore, the compartments will send heartbeat messages in regular long intervals about their current energy status. When a low battery status is detected, the user will be informed of it. Consequently, the user may locate the corresponding compartment through acoustic clues, similar to the first workflow presented.

Technical Realization

The technical realization depends on a number of key constraints presented in the following. Figure 3 shows an overview of the technical components transforming the compartment into a smart object which can identify usage and is able to communicate with a PC. An essential factor for the successful implementation of the system is the battery runtime of the smart objects. An average battery runtime of one year for normal usage is an important milestone for the project.

A requirement is wireless communication between smart compartments and the PC. Different technologies were evaluated, each with its own advantages and drawbacks. Energy consumption needed for wireless communications represents a substantial amount of the total power consumption. The power consumption also depends on the communication distance to be achieved. In our scenario, this communication distance is between 5-20m within a building. However, this distance depends on the size of the warehouse and if more than one room is involved. We took into account many technologies, such as Bluetooth Low-Energy, ZigBee and proprietary communication methods in the Sub-GHz-domain.

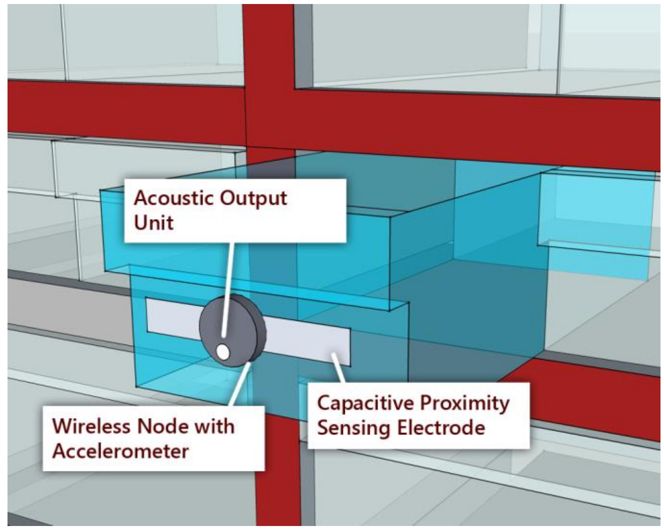

Figure 3. The smart compartment will be equipped with a wireless node which is connected to an accelerometer and a capacitive proximity sensing electrode. It may also use an acoustic output unit to generate polyphone sounds.

We came to the conclusion that a single-chip solution, combining microcontroller and RF-functionality is most feasible for our use-case. For this, we selected an ultra-low power micro-controller with RF functionality by Texas Instruments[1] (CC430F5137). The RF functionality also supports sophisticated Wake-on-Request handling which will be an important feature for energy saving. Therefore, when a compartment communicates with the PC, it is woken up by a request message from it. The compartment itself will only be listening to the incoming message for a few milliseconds and then go back to hibernation. These stand-by times will be adjusted to the frequency of usage of the system and can range from 5 seconds to a few minutes. However, this feature will decrease the reaction time, and a suitable trade-off must be found in the upcoming user studies.

In order to detect object manipulations, such as taps on the compartment's surface and the proximity to a user's hand, two different sensors will be integrated. An acceleration sensor (ADXL345)[2] will measure the compartment's accelerations in three axes. Moreover, it can automatically detect taps and double taps. The micro-controller can also be woken up by the accelerometer when activity is detected.

Furthermore, we integrated a capacitive proximity sensor from the OpenCapSense project [9]. The proximity sensor conducts a self-capacitance measurement by loading and unloading the capacitance between the environment and the

[1] http://www.ti.com/product/cc430f5137 (date accessed: 13-Dec-2013)

[2] http://www.analog.com/static/imported-files/data_sheets/ADXL345.pdf (date accessed: 13-Dec-2013)

sensing electrode. Depending on the sensing electrode's size, the sensor may recognize the proximity to a human hand for distances up to 35 cm. Currently, we are aiming at recognition distances of approximately 15-20 cm, which will be a more reasonable goal to achieve.

We have not yet made a decision on the acoustic output unit, aiming at maximum energy-efficiency and easy controls. Therefore, different frequencies have to be supported – e.g. by providing a pulse-width-modulated output signal on the microcontroller.

Current Work-in-Progress

As described in the sections above, the workflows have been specified working closely with future system users. Moreover, suitable components were already selected, which are required for realization of the smart compartments.

In the technical development process we use CC430 evaluation boards to develop a communication and broadcasting mechanism. Simultaneously, we implemented bindings for the capacitive sensor and the accelerometer. We plan on conducting the first experiments on energy savings once the wireless communication concept has been successfully implemented. Hereafter, we will move to the final PCB design. The size of the final node and the housing will also greatly depend on the battery required for the desired runtime of one year.

The next steps will include creating interfaces for the warehouse's database with an accessible front-end. Due to this, we plan to integrate an additional component into the current RFID-based commissioning system.

CONCLUSION

In this paper, we presented an approach for the realization of an accessible warehouse for vision-impaired persons using smart objects. Specifically, we presented the concept of smart compartments, aware of physical manipulation and with wireless communication abilities. We introduced a concept which applies various means of natural interaction to make the commissioning process easier and more time-efficient.

Currently, we are at a vital stage of the process. It is not yet resolved if the implementation of the desired features with the specified requirements will comply with our goals, among them are low energy consumption and low maintenance effort. Therefore, it might be necessary to change certain components or revise the concept. Moreover, it is also necessary to find a suitable trade-off between the system's reaction time whilst locating a compartment. Thus, we plan on developing a predictive algorithm which schedules the microcontroller's sleep times intelligently.

After completion of the system, extensive user studies will reveal if our ambitious goals on simplifying the commissioning process can be met. However, our solution may also be transferred onto other use-cases with which smart objects can support handicapped persons in their personal or work life.

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