AmI-VR: An Accessible Building Information System as Case Study Towards the Applicability of Ambient Intelligence in Virtual Reality

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ABSTRACT

Ambient intelligence represents a paradigm in which the user does not react to the environment, but vice versa. Accordingly, smart environments can react to the presence and activities of users and support them unobtrusively from the background. Especially in the context of accessibility, this offers great potential that has so far only been demonstrated for individual user groups. To overcome this limitation, we propose the automated, user- and context-related adaptation of the modality as well as locality of the representation of building information in the form of both an adjustable table as well as two displays on the basis of a prototype for a library information center. For being independent from material and regulatory restrictions and for better planability (especially with the ongoing COVID-19 pandemic) we used in addition to the hardware components also a Virtual Reality simulation, which proved to be very useful. Further optimization and evaluation will be needed for a more in depth understanding and dissemination in the long run, yet our prototype aims to help fostering further activities in the field of ambient intelligence, accessibility and virtual reality as a planning tool.

CCS CONCEPTS

• **Human-centered computing** → **Ambient intelligence**; **Virtual reality**; **Accessibility**.

KEYWORDS

Ambient intelligence, impairment, accessibility

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1 INTRODUCTION AND RELATED WORK

The term ambient intelligence (AmI) means that smart environments react to the presence and activities of people and objects and offer them corresponding services. The technology fades into the background and is ideally not obvious. Exemplary applications in the context of a smart city are smart parking, i.e., monitoring the availability of parking spaces, traffic jam monitoring using smartphones, and smart lighting to turn on street lamps individually when a person approaches.

Initial research on smart cities was essentially limited to technological feasibilities - however, research in this area has evolved to a socio-technical perspective. A major criticism of previous implementations is the lack of participation and inclusion of all citizens [7].

However, the requirements for smart environments are not the same for all people, it is important to address the individual needs of citizens and especially to let disadvantaged people benefit from it. According to the World Health Organization (WHO), the proportion of people with disabilities is about 15%, i.e. more than one billion people [8]. Also with regard to the aging population, inclusive smart cities are a future model with potential.

The Smart City Charta defines guidelines [4] for future smart cities - these should sometimes be "participatory and inclusive". The digital transformation should include people with impairments of all kinds. As in urban areas (and buildings), there are already numerous approaches for intelligent environments at home. Numerous sensors are used for this purpose. There are also camera-based approaches, for example to log activities of seniors (e.g., [5]) or to monitor their health parameters (e.g. [1, 2]). However, these approaches only address one group of people and provide a specific solution for them (apart from rare and outdated work, e.g., [3]). However to be able to support people with special needs, it is helpful to be able to differentiate between groups of people. Therefore, we demonstrate a prototype for a camera-based system that allows automated differentiation between groups of people.

Figure 1: Photo montage of the environment modeled in VR using BIM data and the real prototypes: The left table, adjustable in height and inclinable, is designed for wheelchair users and general sighted users and holds an audiovisual display. The right table is fixed in height and inclination and holds a tactile tablet designed for blind people.

2 APPROACH

Based on a new building of the Nuremberg Institute of Technology, we outline a prototype for an information center that recognizes different user groups at the entrance of the library and offers individual support (see Fig. 1). After entering the library, a camera detects the person and recognizes which group of people the visitor belongs to using pre-trained machine learning components. For our initial prototype, we consider three exemplary groups of people for simplification purposes: Visitors who are pedestrians, who use white canes or who use wheelchairs. The classification artifact is then sent via *Bluetooth* to a microcontroller. This controller then triggers the movement of a table with a tablet containing audiovisual information (see Fig. 3) so that wheelchair users, for example, can operate this tablet at the appropriate height and inclination. If the person is a sighted pedestrian (i.e., no white cane was detected), the table is moved up and levelled, if necessary. In both cases, the table also draws attention to itself acoustically. If, on the other hand, a person with a white cane gets identified, the audiotactile tablet on the second (fixed) table is activated (see Fig. 3) and auditively draws attention to itself. Once there (via the floor indicators for white cane usage), the blind user receives explanations on how to use the tablet with a text document written in Braille.

With both tablets, users can select a destination (e.g., a specific book or area of the library) and are shown visually or tactilely how to get there. The route is not only presented to the user in a variable way via the modality of output, but also adapts to the needs: Blind people, for example, often prefer the stairs to the elevator and therefore receive a corresponding route. For other people with limited mobility, such as wheelchair users or users of walkers, the use of the elevator is intentionally included in the route to the desired destination.

Since on-site implementation (and later evaluation) is not foreseeable with the current ongoing CoVid-19 pandemic, and furthermore to experiment regardless of regulatory and material constraints, BIM (i.e., Building Information Modeling) data from this environment was used for a VR simulation. In the following, the individual elements are discussed in more detail.

2.1 Image processing: Pipeline and Preliminary Results

To implement the detection of different groups of people (and thus their needs) in our ambient intelligence environment, we propose to use a *Raspberry Pi 4* computer in combination with the official *camera module V2* (i.e., a *Sony IMX219* 8-megapixel sensor and 1080p video). To improve the performance of the model, we suggest to use an external Edge TPU (Tensor Processing Unit) *CoralAI* USB Accelerator. We also suggest to use Transfer Learning, i.e., using pre-trained object detection models and refining to our specific use case with additional training. The model must be quantized with 8 bit Integers, in order to make best use of the hardware acceleration, and for additional training a high-entropy image dataset for each class must be created. To this end, a more generalized model can be created by extending already available datasets (e.g, [6] for wheelchairs and pedestrians) with newly taken and labeled images. For our specific use case, we can assume a fixed angle and position for the camera. Thus one has a fixed background, which can make the person identification easier, but less robust with other backgrounds.

A preliminary test with *Tensorflow 1.15* and the pre-trained *SDD MobileNet V2* using a small data-set consisting of the 3 previously mentioned classes and multiple images of 7 different people showed promising results. So, images from one person, which was previously not shown to the model, were correctly classified in most cases (average precision: 95% pedestrian, 64% users of white canes and 98% users of wheelchairs) [9].The mean average precision is accordingly 86%. By comparing it to the equivalent metrics during the training (average precision: 99% pedestrian, 93% users of white canes and 96% users of wheelchairs) it can be seen that the model is overfitted in terms of blind cane detection, the training to detect wheelchairs was successful and is just suitable for persons. Although these results are promising, they have only a very limited validity with regard to generalizability due to the small amount of training data. The general functionality of such a detection is not in question, but its precision and robustness must be optimized with more effort on a larger scale.

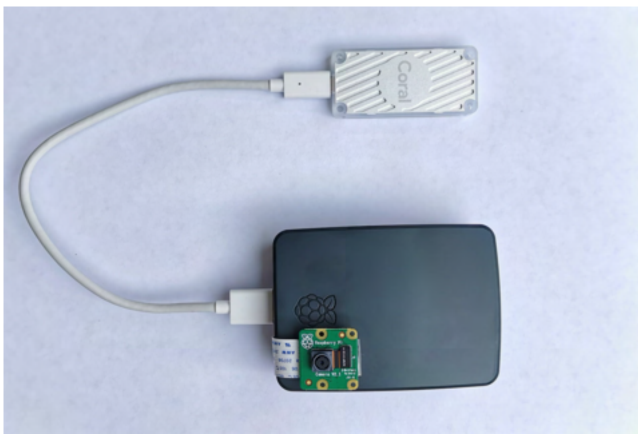

Figure 2: Detection module consisting of Raspberry Pi, camera and *CoralAI* processing unit.

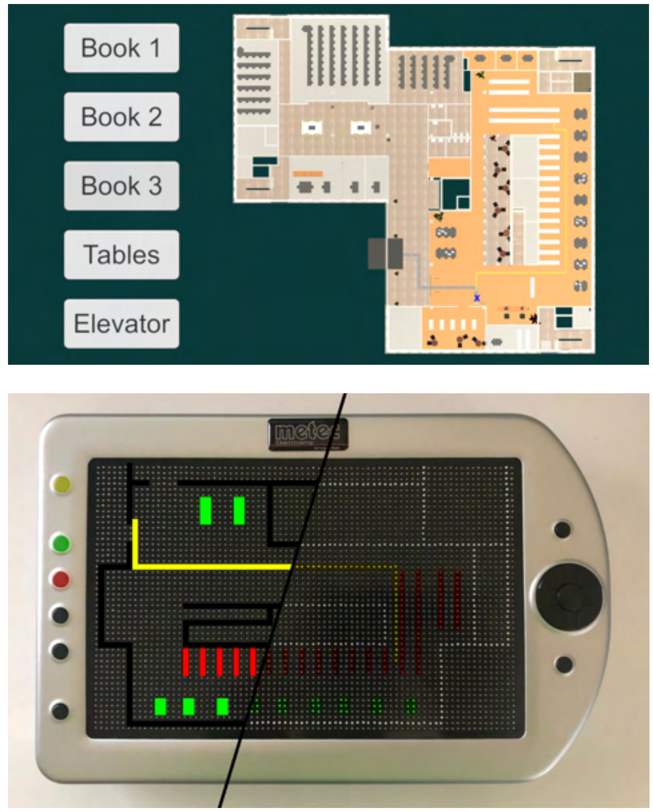

Figure 3: Display on the two tablets: For sighted users, a floor plan is shown on the *Samsung Galaxy Tab S7+* on the left and routes to sample books can be displayed when touching the respective button. The *Metec Hyperflat* tablet also displays a floor plan for blind users, but in a tactile manner. The latter is also interactive and displays corresponding elements and/or routes of the environment at the touch of a button (see color coding).

2.2 Hardware and Software

Audiovisual Tablet

For rendering audiovisual information to sighted users, we used an Samsung Galaxy S7+ tablet. The app (as shown in Fig. 3) allows the user to select exemplary items (e.g., several Books, a reading area or the elevator) via touch input and the route to get there is displayed. This app was implemented with *Unity 2019.4*.

Audiotactile Tablet

For rendering audiotactile information to blind users, we used an *Metec Hyperflat* graphical tactile display (see Fig. 3). Having read the braille instructions on the Braille printed document next to this device, the users can select exemplary items (such as seating possibilities) by pressing one of the buttons. Thus, the users can explore the layout of the building and are also shown important landmarks and the path to go to their target.

Motorized Table

The table supporting the audiovisual tablet can be adjusted in height and inclination by means of a *Justech* linear motor. The mount suitable for the *Galaxy S7+* and likewise motorized tilting of this was made with 3D printed components and acrylic glass cut by laser cutter, (i.e., a *Ultimaker S3* and an *Epilog Zing 16*). The motorized tilting was implemented by a *Savöx SC-0254MG* standard servo and both actor devices were powered by a *L289N* motor driver.

2.3 Virtual Reality Simulation

Due to the CoVid-19 pandemic, it was hardly possible to access the room described above, which meant that the individual hardware components could only be functionally tested in a laboratory environment. Nevertheless, in order to be able to walk through the room together with the additional components described above and to (roughly) test the functional sequence, a 1:1 scale model was created using existing BIM (Building Information Modeling) data. This virtual room was physical walkable in a *OptiTrack* environment with a wireless *HTC Vive* head mounted display (see our video attached). With true-to-scale dimensions by matching virtual and real dimensions, the spatial impression and general functions as well as the positioning of the individual components can thus be tested in advance without having access to the real room. If not available as a real object which is positioned congruently with the VR proxy, the haptic perception of individual components is missing and the functionality (individual components or in the entire system) can only be simulated realistically to a limited extent. However, the virtual room proved to be very useful for jointly developing the Ambient Intelligence prototype presented here.

3 CONCLUSION AND FUTURE WORK

Using the prototype example of a user-adaptive and multimodal information center, we outline in this paper how different components from the fields of image processing, mechanical engineering and designing user interfaces can be combined in the sense of ambient intelligence to create an intelligent and accessible environment for more than one user group. For this purpose, we propose the automated, user- and context-related adaptation of the modality as well as locality of the representation of building information in the form of an adjustable table and two displays. For better planability and independence from material and regulatory restrictions (for example the ongoing COVID-19 pandemic) we use a VR simulation, which proved to be very useful. Further optimization, development (also in the individual research fields of the modules) as well as an evaluation involving a comprehensive user study will be needed towards a deeper understanding and possible dissemination of such an Ambient Intelligence approach, but our contribution shows a first step to get there and seeks to stimulate further activities with the presented prototype.

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