Smart Signs are a new type of electronic door and way signs based on small computers which can be seamlessly incorporated in the environment. Smart Signs provide personalized context-aware guidance and messaging designed to support wayfinding activities in large indoor spaces and their surroundings. The system uses the context information such as a user's mobility limitations, the weather, and possible emergency situations to improve guidance and messaging. Smart Signs combine the simplicity of traditional static signs with the flexibility and responsiveness of electronic navigation systems.

Smart Signs

show you the way

Imagine a workshop organized for a large research project or a commercial seminar. Each workshop participant has received a Smart Tag on arrival that identifies her to the Smart Signs system. A Smart Tag is a small Wireless Sensor Node that regularly transmits an identifier to the surrounding devices. After the morning session, the participants head to the restaurant for lunch, which is to be served in another building. When the participants leave the meeting rooms, they consult the Smart Signs attached next to the doors on the building corridor. As each participant approaches a Smart Sign, it displays a dedicated group-message (*Follow the arrows to the restaurant*) and an arrow pointing in the correct direction. Some participants like Peter, who is currently on crutches, and Maya, who uses a wheelchair, receive a personal message and directions that route them through a path that contains no stairs.

Halfway to the restaurant, a sudden fierce rain-shower triggers the Smart Signs system to reroute the participants through a longer but dry path to protect them from getting drenched.

One of the participants, Toni, suffers from epilepsy. He is wearing a context-aware monitoring device that connects him to a healthcare center that warns him of an imminent attack and sends help when necessary. During an evening session, Toni faints and his monitoring device contacts the healthcare center and announces the crisis. This call for help can also be picked up by devices of doctors and paramedics in the vicinity. The Smart Signs system reacts to this emergency by flashing a call for help and showing guidance to Toni. In other emergency situations such as fire, the Smart Signs system guides everybody to the nearest usable fire exit and a mustering station.

Smart Signs provide guidance and messaging functionality. The goal of Smart Signs is to combine the advantages of signage—which subsumes traditional directional signs and messages—with the reactiveness and flexibility of personal services, such as navigation systems and SMS. The Smart Signs system uses context such as user's mobility limitations, the weather, and emergency situations like fire or medical needs to optimize routes and messaging. In addition to personalized guidance and messaging, Smart Signs can also present information for *user groups* and *everyone*. For example the Smart Sign in the Zilverling building shown in Figure 1 (see next page) provides some individual directions and messages for everyone, while the big Smart Sign in the Jaarbeurs in Utrecht shown in Figure 2 gives directions to all visitors of ICTDelta.

Signage is easy to understand—mainly because of our familiarity with it—presents information in situ, is ubiquitous and easy to ignore when not relevant. Another advantage of signage that is generally overlooked is that it is anonymous, because neither the signs, nor the people who install them know who uses the signs. Thus, traditional signs provide absolute privacy from the point of view of the user.

However, traditional signs have important shortcomings. Using signage for navigation requires that a user knows milestones on the route to his destination, because the signs cannot provide directions to every destination. Another shortcoming of signage is that the signs cannot adapt automatically to real time changes—e.g., a lift temporarily out of order—and it is difficult to keep them up-to-date. Signage providing outdated information becomes annoying. Last, but not least, static signs lack the capacity to show information only to the interested parties, and to be displayed only at the right moment. For example a Post-it saying 'Hand in your work to the secretary' at a researcher's door is clearly not meant for everyone passing by, but just for his students.

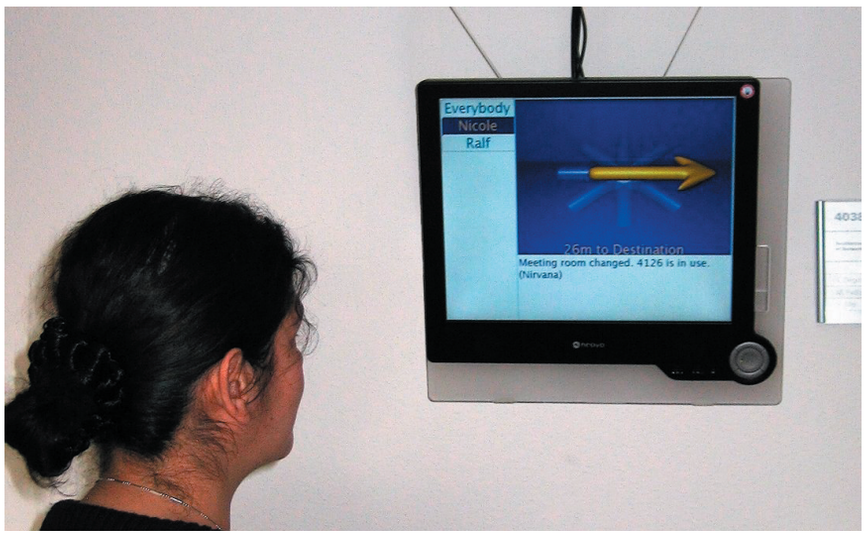

Figure 1: Wall-mounted Smart Sign in Zilverling

Navigation systems use the destination of the users to guide them through the best path and may take into account context, for instance traffic jams. Using a good navigation system, a driver should no longer fear getting lost, because the system can guide him from any location to his destination, even if he decides to take a detour for sightseeing or if he gets distracted and misses some directions.

SYSTEM ARCHITECTURE

An important goal of our architecture is to provide ubiquitous guidance and messaging with affordable hardware (important for the signs) and minimal infrastructure requirements (i.e., cabling).

A second important goal is to protect the privacy of the users. Specifically, we want to prevent or make difficult the direct or indirect tracking of users. In this, we follow Langheinrich's guidelines by considering privacy early in the design, processing the privacy sensitive data as close to its source as possible, and storing it no longer than strictly necessary [1].

We address this goal with a distributed architecture where the central server computes personalized routes, but is unaware of the users' location. The Smart Signs are aware of the users in their proximity by listening to the identifiers that the tags transmit. When hearing a tag, the sign includes the appropriate information into its presentation. The most sensitive user information (location) never leaves the Smart Signs.

Traditional signage is the gold standard regarding privacy, because users are completely anonymous. Because our system is reactive and personalized, users have to sacrifice some privacy by telling the system where they want to go or to whom they want to post messages. Users also need to carry a tag sending an identifier. In the future we will reinforce privacy by letting the tags generate forward-secure unique identifiers so that users cannot be tracked by outside attackers.

Different from conventional signage, the Smart Signs have to solve the problem of presenting individual guidance and messaging for an unknown, potentially large number of people on a limited screen. Three solutions offer themselves: multiplexing in time, space, or both.

Our current generation of signs uses a hybrid approach for presentation. Guidance and messages, which take the major part of the screen, multiplex in time: information is show for one user at a time for five seconds each. The names or aliases of all the users that a sign is showing data for is presented separately (so that users see that there is information for them) and used as an indicator for whom the current guidance or message is meant. We are also experimenting with grouping information per direction, and showing multiple directions simultaneously using extra wide screens.

"Traditional signage is the gold standard regarding privacy"

Figure 2: A big Smart Sign for ICTDelta in de Jaarbeurs in Utrecht

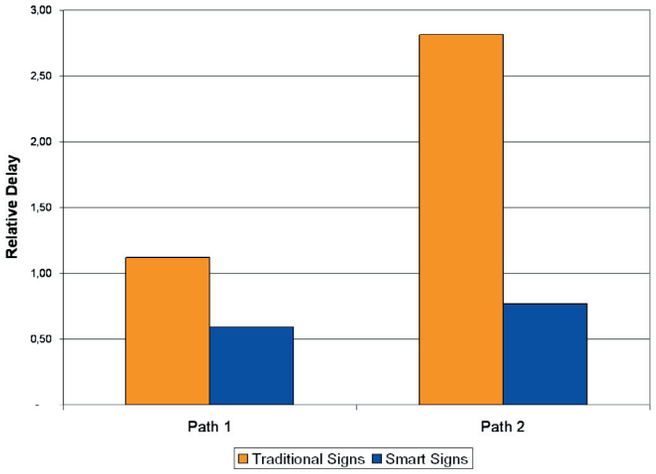

Figure 3: Average normalized time needed to follow the paths

"The working version of the system has been deployed and tested on Zilverling and Waaier"

The Smart Signs system can also be used on a handheld device as *Virtual Smart Signs*. We have implemented such an interface in combination with FLAVOUR [2]. FLAVOUR is a personal application that determines the location of the user using the existing WLAN infrastructure without the need of a centralized system. FLAVOUR does not track people and gives users control over who they share their location information with and under which conditions. The user interface consists of an SVG viewer where the user can view his location, the location of his buddies, and the directions and messages provided by Smart Signs.

The user can run the Smart Signs services locally on his handheld or in a server in the infrastructure that he controls, and thus, keep total privacy. Virtual Smart Signs can be used even when the venue does not provide Smart Signs in the venue. Additionally, the user can simultaneously use FLAVOUR and the venue's Smart Signs.

SYSTEM EVALUATION

The working version of the system has been deployed and tested on the Zilverling and Waaier buildings of the University of Twente. The evaluation of Smart Signs has shown a significant reduction in the time needed to conclude navigational tasks as well as a significant improvement in the perception of learnability, helpfulness, efficiency and satisfaction level in comparison to the traditional way of navigating indoor spaces. The study participants have found the system easy to learn and to understand. They have considered it an efficient solution saving them time searching for other navigational clues. They have also strongly appreciated that the signs were personalized and that the messages displayed by the system were directed only to them.

21 persons (14 male, 7 female) participated in the study; all of whom were entirely unfamiliar with the buildings the evaluation was performed in. The study was a 2x2 factor design: 11 participants used the traditional signs and 10 participants used the Smart Signs to perform two navigational tasks. A navigational task was defined as finding a predefined destination and walking back to the starting point. The first task (Path 1) was to locate Room 4061, which is an office on the fourth floor of the Zilverling building. The second task (Path 2) was to find Room L200, which is a meeting room in the Waaier building. The starting point of both paths was the main entrance to the venue in the Zilverling building.

Each participant has been provided with a study protocol describing in detail the conditions of the test and followed by an observer throughout the entire duration of the study. The observer measured the time needed to perform each navigational task and the number of navigational errors made. The participants were not supplied with directions of how to go back to the starting point. Measuring this time provided information about the user's walking speed and the ability to make a mental map of the venue.

Figure 3 shows the average normalized time needed to conclude the tasks. The normalized time is computed as the time to reach the destination normalized by the time needed to return to the starting point ($T_{dest} - T_{return})/T_{return}$. The time reduction when using Smart Signs shows significant improvement. For Path 1 the improvement is 47% and for Path 2 73%. Figure 4 shows the average number of times the participants declared themselves lost and made a navigational error in each of the paths. In both cases there is a considerable improvement when using Smart Signs for both paths.

After walking each path the participants were asked to fill in a closed questionnaire. After walking path 2 they were requested to fill the closed questionnaire and also an open questionnaire. The closed questionnaire consisted of 29 statements about learnability, helpfulness, efficiency, and satisfaction. The open questionnaire consisted of 10 questions aiming at gathering qualitative data about par-

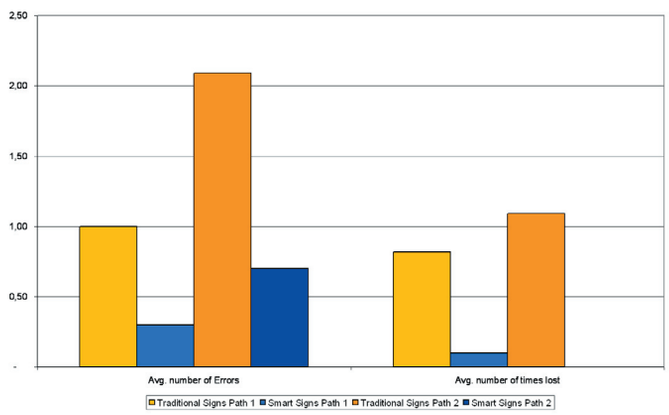

Figure 4: Average number of times the participants made a navigational error or got lost

ticipants' perceptions regarding the system that they had used. In each case the perception of the learnability, helpfulness, efficiency and satisfaction was significantly higher for participants navigating with Smart Signs (see Figure 5).

PRESENT AND FUTURE OF SMART SIGNS

The first evaluation of the Smart Signs system has been based upon a scenario, in which a visitor arrives at an unfamiliar indoor space. It has shown that when using Smart Signs people tended to find their destination in an unfamiliar environment faster and with fewer errors. Furthermore, the participants expressed a high degree of satisfaction when using Smart Signs applauding the personalization of the signs as well as their efficiency in an effective expression of easily understood navigational aids.

In commission of ICT-Regie we have carried out a two day pilot during the ICTDelta congress in May 2007, which was held in the Beatrixgebouw at the Jaarbeurs in Utrecht. The signs were used to guide visitors to the multiple parallel sessions and events, and to the stands on the exposition floor.

As the following step, we want to analyze how Smart Signs can be used on a daily basis by the permanent occupants of an office environment. We think that that user group will be best to assess and evaluate the privacy advantages and limitations commenced by the Smart Signs system. We also aim at verifying in what way the changes in the system behavior reflecting different user preferences and changes in context are appreciated by the users. ■

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"we have carried out a two day pilot during the ICTDelta congress in May 2007"

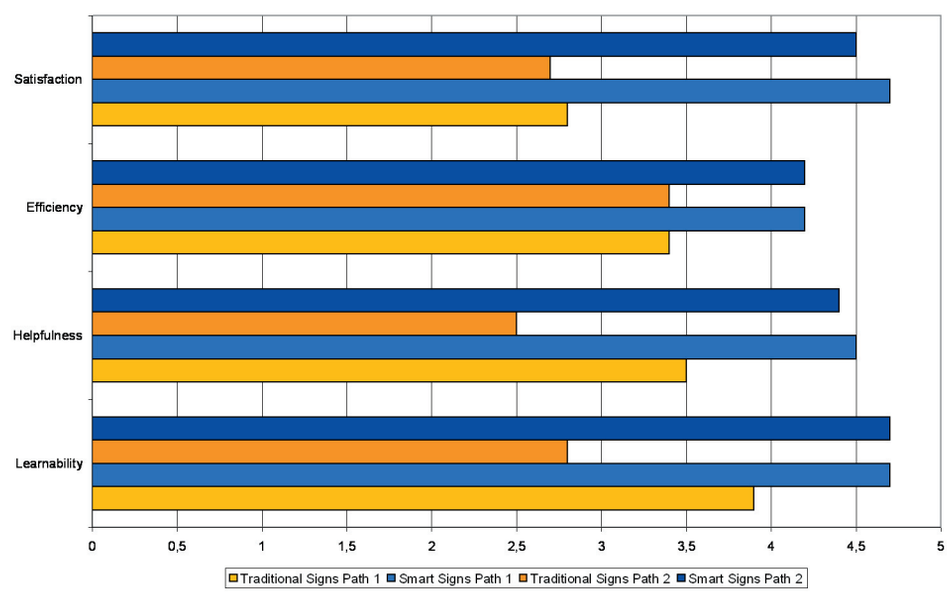

Figure 5: Differences in the perception of learnability, helpfulness, efficiency and satisfaction dependent on the system and the path followed