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Indoor Localisation with Beacons for a User-Friendly Mobile Tour Guide

Tobias Kaulich, Thomas Heine, Alexandra Kirsch

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Abstract Bluetooth beacons are a recent technology that promises a simple, low-cost indoor localisation method with mobile devices. One application for such a localisation are museums or other exhibitions to provide visitors with information about nearby exhibits. We tested the localisation capabilities of beacons and explored different localisation techniques. Then we used the localisation in a tour guide app and examined how localisation contributes to the usability of the app.

1 Introduction

Museums and exhibitions have been offering audio guides with a special hardware. With the proliferation of smart phones and other mobile devices, some of these institutions are now offering downloadable apps to guide visitors. The most widespread technique for retrieving information is a user action like typing in a number or scanning a QR code attached to the exhibit. An indoor localisation system could potentially automate this process. This paper examines the question of whether and how indoor tourguide systems can profit from standard beacon technology for localisation.

When new "smart" technology becomes available, technology-focused developers tend to integrate those methods before testing their adequacy or even before understanding the user needs of a specific application. Therefore, we put specific emphasis on how to integrate automatic localisation with beacons into an app in a user-friendly way. As an example, we implemented a tour guide app for the LebensPhasenHaus in Tübingen.

We examine the following research questions: 1) What are the technical possibilities of standard Bluetooth beacons for indoor localisation? To our knowledge, we present the most comprehensive overview of localisation algorithms with Bluetooth beacons with extensive empirical data. 2) How does automatic localisation influence the user experience in a tourguide system? We show that the location does not directly specify the information need of the user, and that the stability of the displayed location is important.

Tobias Kaulich
Department of Informatics, Universität Tübingen
E-mail: tobias.kaulich@student.uni-tuebingen.de

Thomas Heine
Institute of Physical Chemistry, Universität Tübingen
E-mail: thomas.heine@ipc.uni-tuebingen.de

Alexandra Kirsch
Department of Informatics, Universität Tübingen
E-mail: alexandra.kirsch@uni-tuebingen.de

2 Localisation with Beacons

2.1 Beacon Technology

Bluetooth beacons are small devices that constantly emit a specific Bluetooth signal. The technology was first promoted by Apple as iBeacons and is now being adopted by other platform providers.

Each beacon emits three configurable values to allow for a unique identification of the beacon: a universally unique identifier (UUID after RFC 4122[1]) to identify larger areas or otherwise associated beacons, and a major and minor value for further identification of beacons (for example, all beacons in one room could have the same major value and different minor values).

The designated application for beacons is a rough estimate of the distance between a beacon and a receiv-

[1] `http://www.rfc-base.org/rfc-4122.html`

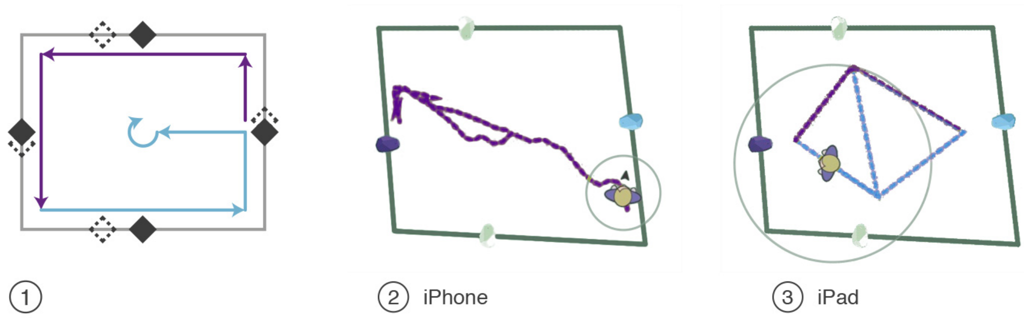


Fig. 1 Localization results with Estimote Indoor SDK. (2) and (3) show the detected trajectory displayed by the Estimote app. The colouring shows two phases of the trajectory; the iPhone only detected the purple part before losing the signal.

ing device. The iBeacon protocol is proprietary, leading to some uncertainty about the received signals:

Received Signal Strength Indication (RSSI) gives the signal strength in decibel.

Proximity is a rough estimate of the distance between the mobile device and the beacon in four distance classes: immediate, near, far, and unknown. For Estimote Beacons those classes are defined as immediate from 0 m to 0.5 m, near to 3 m and far up to 70 m. The theoretically possible maximum range of a beacon for Bluetooth LE is about 100 meters.

Accuracy estimates the accuracy of the measurement by the strength of the signal. As the signal strength in Bluetooth technology depends both on the distance between sender and receiver as well as on any obstructions like walls or human bodies, the meaning of this value is not completely clear and has been discussed a lot in internet forums [1] and blogs [8]. In an idealized situation (like outdoors) the accuracy value can be equivalent to the distance between beacon and receiving device.

As the *proximity* measure is too coarse for exact localisation and too inaccurate to rely on for a per-room identification, we only used *RSSI* and *accuracy*.

2.2 Default Localisation Method

The manufacturer Estimote provides an Indoor SDK[2] for position detection. The website contains no information about the used method. We tried this as a simple approach to estimate the position of a mobile device.

After calibration and positioning of beacons using a specific app provided by Estimote, we tested the SDK by moving the same trajectory as for calibration, but in the opposite direction (Figure 1(1)) and turning on the spot in the middle of the room to account for occlusions of signals by a person.

[2] http://estimote.com/indoor/

Using an iPhone 5 (2012) as a receiving device, the computed positions are very far from the actually moved trajectory (Figure 1(2)). The only useful information was that the iPhone was inside the beacon-equipped room, but after about one minute, the iPhone was detected to be outside the room. We reproduced this effect in several runs with different calibration areas. We assume that the antenna of the iPhone is too weak to detect the signal appropriately.

The detection with an iPad Pro 9.7" (2016) (Figure 1(3)) worked better when the detecting device was near the beacon, but the positions are not detected as a smooth trajectory, but rather as jumps between the positions. We considered this localisation as too coarse and unreliable for our tour guide app.

2.3 Sensor Models

We made several experiments for obtaining a reliable sensor model for the beacons using three iBKS beacons by Accent Systems[3] and six beacons by Estimote[4].

Before the experiments, all beacons were calibrated according to the manufacturers' instructions. For the measures we used an iPad Pro 9.7" (2016). All beacons were set to the same UUID, transmission power of 0 dB and a 100 ms advertising interval.

Bluetooth signals are damped and reflected by walls. To obtain generalisable sensor models, we performed our experiments outdoors.

2.3.1 Experiment 1: Static distances

Figure 2(1) shows the setup of all beacons in a circle of 2 m radius around the measuring iPad. Figure 3 shows the range of RSSI (in decibel) and accuracy (in meters)

[3] iBKS105, http://accent-systems.com/ble-beacons/

[4] Estimote Development Kit with Proximity Beacons, hardware version: D3.4, firmware version: A3.2.0, http://estimote.com

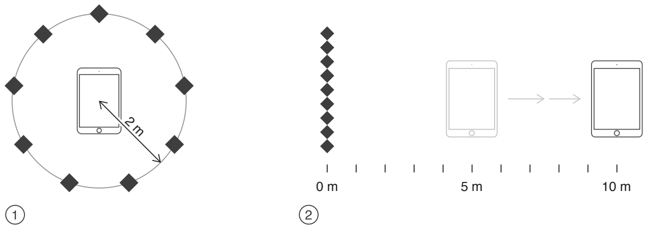


Fig. 2 Setup for measuring (1) static distances, (2) variable distances.

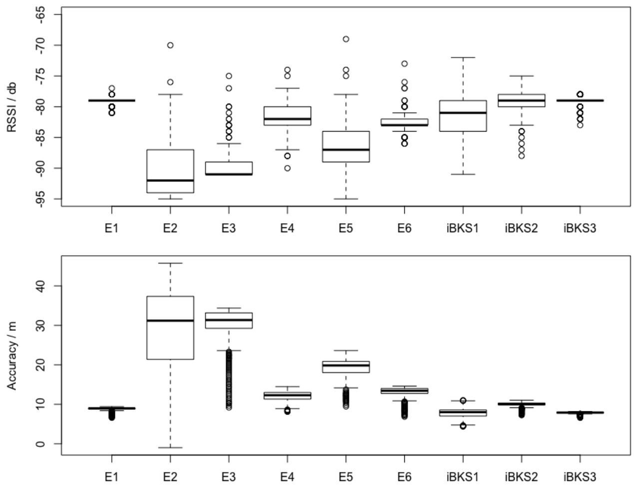


Fig. 3 RSSI (above) and accuracy (below) readings from all beacons during our static distance measurement.

values over a period of six minutes with a sampling rate of 1 Hz. We discard the first 20 samples to account for the instability of the values at start-up.

Surprisingly, different beacons send on different RSSI levels. The variance is sometimes enormous. Figure 3 indicates that the variance depends on the specific beacon, but repeated measurements show that the same beacon can produce rather stable measures in one run and extremely fluctuating values in another. Similar values are reported by Golestanian and Poellabauer [7].

The accuracy measurements show fewer fluctuations (at least for most beacons), but the values are very high: the best values are around 10 m for a measuring distance of 2 m.

2.3.2 Experiment 2: Variable distances

In the second experiment, all Beacons were positioned in a vertical line at the same horizontal distance to the measuring iPad (Figure 2(2)). We measured in intervals of 1 m between 0 m and 10 m. The measurement period was two minutes with a sampling rate of 1 Hz.

In this setup we found that the specific order of the beacons and whether their measurements were taken in a group setup or as a single beacon, make no difference, showing that there are no interferences between the beacon signals.

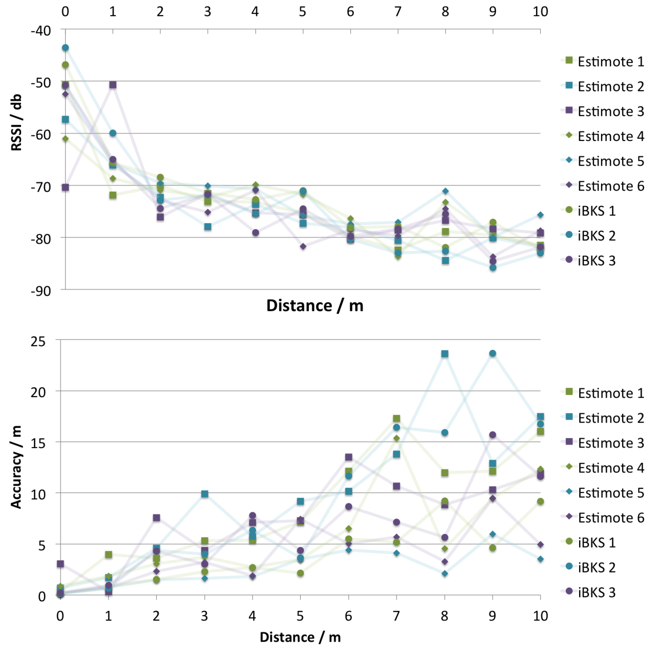


Fig. 4 Average RSSI (above) and accuracy (below) readings from all beacons in a given distance to the measuring device

Initialisation Create random population of N samples, each representing a point $\mathbf{x}_0^i = (x_0^i, y_0^i)$, $i = 1 \dots N$
Update cycle (repeat for each time step)

1. **Propagate each sample forward** by sampling the next state value $\mathbf{x}_{t+1}$ given the current value $\mathbf{x}_t$ for the sample and using the transition model $P(\mathbf{X}_{t+1}|\mathbf{x}_t)$
2. **Weigh each sample** by the likelihood it assigns to the new evidence $P(\mathbf{b}_{t+1}|\mathbf{x}_{t+1})$
   b: data from beacons
3. **Resample population** to generate new population of N samples. Select each new sample from the current population with probability proportional to its weight. The new samples are unweighted.

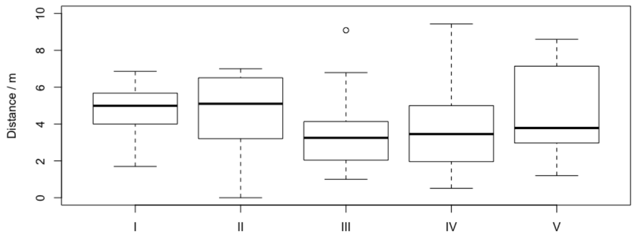
Fig. 5 Algorithm for particle filtering.

We measured similarly large variances and inaccuracies as in Experiment 1 (Figure 4). The accuracy values are even more unreliable than the RSSI values. This is why we are using only RSSI values in the particle filter localisation.

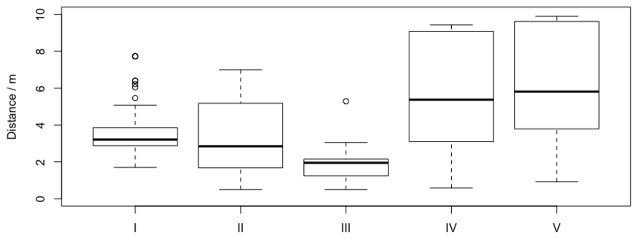
2.3.3 Localisation with Particle Filtering

We used a particle filter for localisation as a well-established method from robotics [6]. The algorithm is shown in Figure 5. We chose the following parameters:

Initialisation: The samples were randomly drawn from a uniform distribution, $N = 200$.



(a) Sensor Model 1: Interpolation of raw data values



(b) Sensor Model 2: approximation with Gaussian distribution

Fig. 6 Localisation errors as a distance between device and estimated location for five positions (see setup in Figure 7). The box plots show the median (bold line), upper and lower quartile (box) and minimum/maximum. Values outside 1.5 inter-quartile range are depicted as outliers.

Transition model: In our tour guide application we assume that users are either standing still or walking. For the tests we report here, we assumed that the user was standing still.

Sensor model: For the sensor model, we transformed the position estimate in the particle into the euclidean distance $d_i, i \in \{1, \dots 9\}$ to each beacon. b_i denote the RSSI values. We experimented with two probability models: (1) Using the data from Experiment 2, we calculated the relative frequency $P(b_i|d_i)$ for each beacon using a linear interpolation between the measurement points. (2) We idealised the measurement error of the beacons into a Gaussian distribution using the average and standard deviations measured in Experiment 2 (see [15] for a similar approach). For each beacon we calculated a measurement error Δ_i between the particle estimate and the average distance measured at b_i. $P(b_i|d_i)$ was then determined by the value of the Gaussian error distribution at Δ_i. The probabilities $P(b_i|d_i)$ are conditionally independent if we assume that there are no interferences between the beacon signals. Thus $P(\mathbf{b}|\mathbf{d}) = \prod P(b_i|d_i)$

Our setup uses 7 beacons (two iBKS beacons were broken) where one beacon was at each corner and on each line on a 6 m by 6 m square. The particle filter was applied to an area of 10 m by 10 m.

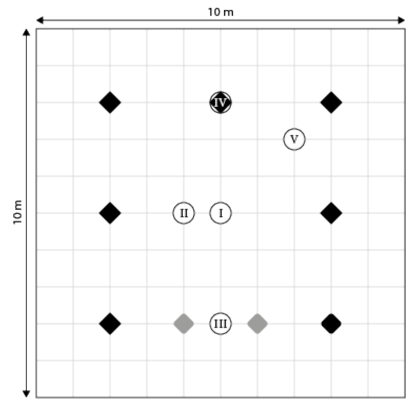


Fig. 7 Test setup. Diamonds are beacons (Estimotes are represented with sharp corners and iBKS with rounded corners). Measurement locations displayed in a circle. Two iBKS Beacons suddenly stopped working and are therefore displayed in light grey.

Figure 6 shows the distance of the location of the device and the estimate by the highest ranked particle. The medians of the errors are for all five positions several meters. The figure shows that there are also some good estimates, but those are more the exception than the rule. The particle filter is not able to compensate for the huge measurement inaccuracies of the beacons. A higher number of beacons might lead to better estimates, but the advantages of the small, low-cost devices dwindle if high numbers of them are necessary for an exact localisation. Also the maintenance would become problematic.

2.3.4 Localisation with Fingerprinting

Stepping back from a space independent solution, we used measured finger prints to enhance accuracy. Measuring each corner of a 4 m square inside our beacon region. Between those points we used linear interpolation to generate a grid of reference points with a resolution of 1 m (Figure 8).

For the localisation we used the closest measured or generated fingerprint by calculating the Euclidean distance between our current measurement vector of 7 beacon RSSI values and each fingerprint. Using this method we saw a significant improvement, dropping the average localization error distance from previously 4.2 m to 1.4 m, see Figure 9.

2.4 Tagged Localisation

Another option is to turn the fact that Bluetooth signals are shielded by walls and other objects into an advantage for localisation: distributing the beacons in a way that their signals can only be detected from specific

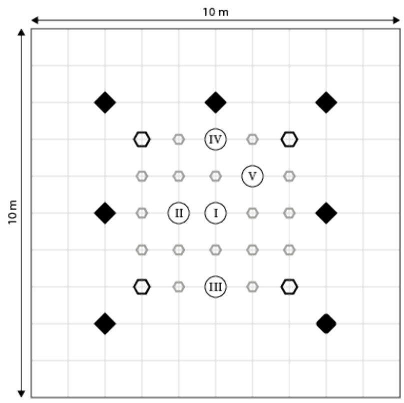


Fig. 8 Fingerprinting Setup. Diamonds are beacons (Estimotes are represented with sharp corners and iBKS with rounded corners). Measurement locations are displayed in a circle. Measured fingerprinting locations displayed in a black pentagon and linear interpolated values in grey pentagons in between.

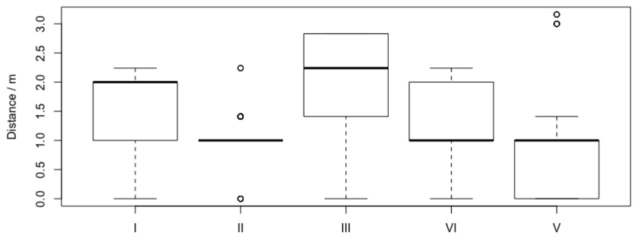


Fig. 9 Localisation errors as a distance between device and closest fingerprint for five positions (see setup in Figure 8). The box plots show the median (bold line), upper and lower quartile (box) and minimum/maximum.

locations, thus the signal acts as an invisible tag for an individual place. Recently the home automation company LinkDesk released the 'Room locator'[5], a Bluetooth LE powered iBeacon to detect in which room a user is, using this room-based strategy.

In our case, we put one beacon in a corner of each room of the LebensPhasenHaus. The signal is only strong enough to be detected by receiving devices in the same room as the beacon, because it is shielded by the walls. To further reduce a beacon's visibility we turn down the transmission power of all beacons to -20 db.

For a more fine-grained resolution the beacons can be hidden in furniture or behind objects with the same effect of only being detectable from a close distance. A per-room-resolution is enough for our application case and we use this tagged localisation in the following case study.

[5] `https://www.linkdesk.com/locator/`

3 Case Study

3.1 Background

The LebensPhasenHaus is a project funded by the Ministry of Social Affairs and Integration Baden-Württemberg (Germany) and is coordinated by the University of Tübingen. With the LebensPhasenHaus the respective consortium is tackling the challenges of the demographic evolution and the ageing European society. Following the European Commission's quadruple helix approach, all relevant stakeholders like academia, businesses, government authorities and the civil society are involved.

With the attention on the elder population the LebensPhasenHaus raises awareness for solutions to stay independent, live healthy and age well, preferably in the surrounding one is used to by adapting/extending one's own home.

Potential users and stakeholders have the possibility to explore, touch and experience existing solutions, but in addition to that the idea is to start a dialogue to discuss, evaluate and design new solutions (products and services). The LebensPhasenHaus is a space to innovate and become creative on the technical fields (e.g. home automation, entertainment, communication, comfort, safety and security) in combination with the sectors of health and care.

Introducing the instrument of the senior technology companions, the LebensPhasenHaus-team is supported by interested elder experts to interact intergenerationally on a voluntary basis. It has been shown that the dialogue within neighbouring generations leads to much more openness, trustworthiness and confidence, a key of acceptance [13].

3.2 Requirements

The app is supposed to support two different user groups: tour guides and visitors. The tour guides are the aforementioned technology companions — senior citizens with interest in technical developments volunteering to guide visitors through the house. Visitors cover a wide range of people such as senior citizens, their children or even grand-children, care professionals and people with different kinds of disabilities. The visitors can explore the house on their own or with a tour guide.

For the tour guides, the app is supposed to provide access to additional information when visitors have specific questions. The visitors have two options: either to get a general overview of the house in a guided tour (guided by the app) or to gain deeper information on specific devices or rooms in the house.

3.3 Design

Figure 10 shows the three modes of the app, all are designed to fit the intended usage scenario best, but using the same localisation technique and following the same design principles. In the following, we restrict our description to the guide mode, as this is the mode we tested on users.

We tried to keep the interface as simple as possible, with an elegant, but unobtrusive style and using standard tablet gestures. In the guide mode, the rooms of the LebensPhasenHaus are displayed in the left column, each with a photograph, the name of the room and a symbol for the room. For each room several information items are provided, containing information for specific devices (such as the oven) or concepts (such as the lighting concept of the house). The information items are displayed in four categories that are also used on the website and other promotional material.

In the visitor modes, the localisation information is shown on a map. But for the tour guide mode, we wanted to show it on the same screen as the information, so that tour guides would not be distracted by switching screens. The localisation with beacons was intended to make the choice of the current room more efficient without imposing any decisions on the user.

3.4 Implementation

The app is written in Apple's own Swift programming language (Swift 3.0) and is available for iPhone and iPad running iOS 9.0 or later. It uses Apple's CoreLocation Framework to scan and communicate with iBeacons. Our main test devices were an iPad Pro 9.7" (2016) and an iPhone 5 (2012) running iOS 10, for the usability test we used only the iPad Pro 9.7".

3.5 Usability Test

We performed a test to evaluate the usability of the app, compare two strategies of integrating the localisation with beacons and to gain overall a better understanding of the usage situation.

Materials and methods. The test focused on the guide mode, being tested by experienced guides in a realistic tour guide setup.

For testing the best use of localisation with beacons, we prepared two versions of the app: in condition M the localisation was used to mark the detected room in the list of rooms in the left column of the app (Figure 10(c)), in condition S the rooms in the list were sorted so that the detected room is on top of the list and adjacent rooms to the detected one come next. The order, in which the two modes were presented, was randomized.

The participants were given a short introduction about the app and its purpose to support them in their work. They were also told that a special feature of the app was to localise itself. We gave this information, because we did not expect users to recognise this feature on their own. The participants were asked to give the experimenter an abbreviated tour through the house, thereby carrying the tablet and using the app whenever the visitor (experimenter) had additional questions. They were informed that there were two versions of the app, so they had to perform two rounds. The participant gave informed consent and started with the first tour. After both tours, the experimenter asked the participant what she/he thinks the difference in the two version was and which version she/he would prefer to use. Finally, the participants were given a short questionnaire asking for personal data (age, sex, familiarity with computational devices), the System Usability Scale [4], and a field for open suggestions.

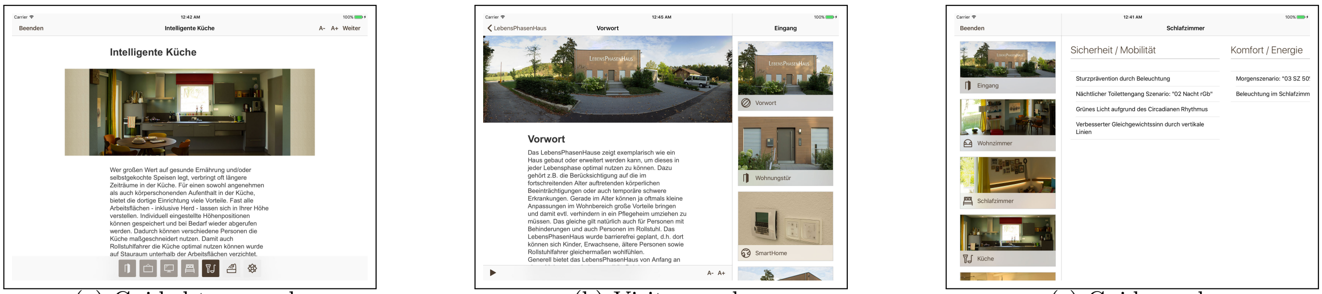
For a general assessment of the usability of the app we used the System Usability Scale (SUS) [4], a standardized questionnaire to quickly assess usability. The SUS contains 10 items on a 5-level Likert scale. We use the German translation of Lohmann [12].

During the two tours the experimenter observed the participant and took notes. The tests were run at public visiting hours of the LebensPhasenHaus, which meant that at the same time other guided tours were taking place.

Participants. At the LebensPhasenHaus, guided tours are performed by non-paid senior citizens. We recruited four experienced guides aged 60–74 years (median 67.5, three male). The participation was unpaid. All four participants own a mobile phone, a computer and have internet access, which they also use frequently. One participant had never used a tablet before, one had used tablets, but was uncomfortable using them ("they never work for me"), the other two were comfortable using tablets. One participant requested to abort the test after the first round, but filled in the questionnaire. We include the data from this test in the evaluation.

Results. We organise the results according to our initial questions for the user test: usability, strategies to use the beacon localisation and general observations about the task.

Usability: The scores of the System Usability Scale were 65, 72.5, 75, 90, resulting in a median of 73.75. This



(a) Guided tour mode (b) Visitor mode (c) Guide mode

Fig. 10 Effective information display for different user groups and purposes.

falls between the median and 75th percentile of SUS scores of a large range of studies [17, p.149]. Considering the age group and partially low affinity to tablets our score suggests a satisfactory to good usability.

Most of the usability problems we observed came from the general usage of tablet computers, like making the content turn into the correct orientation or the system not accepting touch gestures. Specifically for our app, the participants had problems in recognizing which room was currently selected. This information is displayed on top of the screen, but it seems not to draw enough attention. A related problem was that the marking to indicate the room recognized by the beacon localisation was mistaken for an indication of the selected room. All four participants were very curious about the information stored in the app and after a while started to skip through this information even without explicit questions or prompting by the experimenter. We interpret this as a positive indication for the overall usability, because the participants could freely concentrate on the content without worrying about the usage. Also the feedback of the participants mostly concerned the content.

Use of localisation: From the three participants who completed both tours one saw no difference and had no preference, but thought to have found a difference in the information stored in the two versions (which was, however, identical). Two participants recognised the difference in the ordering of the rooms as being fixed in one version and adapting to the place in the other. One of them preferred the fixed ordering, but suggested that this order should follow the order in which the rooms are presented in the tour. The other participant who saw the difference preferred the adaptive version — adding "if it works properly".

Two participants had conscious or unconscious problems when the order of the rooms in the left column changed: one voiced a clear complaint ("something is strange here"), the other did not complain, but sometimes hit the wrong room, when the ordering had shifted between the identification of the button and the pressing of it. Additionally, this participant clicked on the rooms more often than the other participants, because he did not use the button for going back and thus had to click his way through the room choice when changing the information item.

At least two of the participants misinterpreted the marking of the rooms in the marking condition for a highlighting of the selected room. This problem is related to the overlooked feedback about which room is selected, but it is a problem in itself, because any kind of highlighting of a room can be interpreted as being the active choice rather than the detected room.

Observations of the task: Running the test in the real environment at public opening hours provided us with interesting observations about the usage scenario. All four participants considered the app as a helpful tool.

The four guides had different preferences about the order in which they presented the rooms and items in the rooms. One participant would not like to carry a tablet around during the guided tour, but would appreciate the presence of the tablet at some fixed point and answer the more specific questions afterwards.

The Guide mode of the app was intended to provide additional information for deeper questions (which was appreciated by all participants). In addition, we observed that the participants used the app as a kind of check list of whether they have given the visitor all the information. One of the participants also suggested that the app could be used as a tool to train new tour guides.

The information in the app was often not accessed in the corresponding rooms, for the following reasons: 1) when a room is small, visitors and guides sometimes stay outside the room or in the doorway, 2) when a room or place of interest is occupied by another group, the guides change the intended order of their tour or explain the occupied place from a distance, 3) the guides sometimes forget to mention some detail and add it later in the tour (the same can happen if visitors ask their questions at some other point in the tour), 4) some association from one room prompts the guide to give more information about a similar object in another room (e.g. while discussing the lights in the living room, the guides would start to explain the lighting concept of the whole house or the continuous light strap going from the bedroom to the bathroom). Aoki and Woodruff [3] list other reasons why a user may want to access information other than that for the current location.

Discussion. Our observations confirm that the localisation mechanism should not take away control from the user, on the one hand because the localisation is not reliable, and on the other hand because users often want to access information from other places.

A good fixed order of places to choose from would be the best solution. However, the guides prefer a different order of visiting the places and sometimes they have to change it when a place is occupied. The guides would probably get used to any fixed order over time, but for the visitor modes we cannot expect such a habituation. Therefore, an automatic sorting according to the place could be useful if the localisation is reliable and especially does not change too often (even a wrong localisation seems to be better than one jumping around). Highlighting the current location is difficult, because any highlighting can easily be interpreted as a selection.

4 Related Work

Several authors have described first steps in using Bluetooth beacons for localisation [15, 5]. Dahlgren and Mahmood [5] compare different localisation approaches with beacons. A particle filter was their best solution with an error of about 3 m in an area of 8 m×11 m.

Others have combined beacons with other sensors, for example with ultrasonic sensors [11]. Krevl and Ciglarič [10] introduce a framework for integrating several indoor localisation methods such as WiFi and GSM networks, and beacons.

Aoki and Woodruff [3] describe a design methodology for electronic guidebooks using a three-step model of user interaction: Location, Intimation and Selection. They argue that usability problems arise from mixing some or all of the steps, in particular location and intimation. As discussed above, our study confirmed that from the detection of a location a system cannot infer the user's interest in a specific exhibit.

Kramer et al. [9] conducted a field study on how to incorporate personal user preferences into tour guides. Their approach is somehow complementary to our location-based approach. It needs users to explicitly state their interests, which may be too high a burden for a small exhibition such as the LebensPhasenHaus, but one could specify fixed profiles, for example depending on a visitor's type of handicap.

Other lines of research use virtual agents [14] or robots [16] to guide tourists. These system may include a location-based adaptation of their tours and thus should consider similar design criteria. For our application, we deliberately implemented a non-agent-like user interface to emphasise its purpose as an additional resource, in particular in the tour guide mode. In fact, one of the first questions asked by one of our study participants was whether we intended to replace the human tour guides. In the LebensPhasenHaus the direct contact between tour guide volunteers and visitors is part of the basic concept. The app is only intended to support tour guides or to step in when there are more visitors than the available tour guides can handle.

5 Conclusion

To conclude, we summarise the findings regarding our original research questions, and then provide an outlook on improvements of our tour guide system and possible future extensions.

5.1 Lessons Learned

Our first research question was: What are the technical possibilities of standard Bluetooth beacons for indoor localisation? We showed that the use of beacon technology is limited by the very noisy signals. Workable solutions require some engineering in the environment (like specific calibration of the fingerprinting method or the clever distribution of beacons for the tagging solution).

The second research question was: How does automatic localisation influence the user experience in a tourguide system? Our user test has shown that localisation can improve the user experience if it works reliably. Sudden changes in the estimation are particularly problematic. Apart from the technical difficulties, we have found that automatic localisation is not necessarily an improvement to user interfaces. The degree to which localisation information is imposed on the user should always match the degree to which location-based information can be assumed to be useful. In our specific domain of a tour guide app, the location of interest can differ from the location of the user.

5.2 Outlook

The most annoying effect of imperfect location estimation was the sudden change in the display of locations. A user may thus decide for an item to click on, but the display changes before the finger has touched the display and thus the intended user action fails. In our next version we are going to implement a location-based re-ordering of the rooms, but with higher hysteresis to avoid jumps in the information display. Currently the room is determined by the mode of the last three measurements, thus displaying the location that was sensed the most often in the last two seconds. Usually there are only two locations that are chosen alternately, considering only three points in time can still lead to frequent changes in the display. A possible solution is to allow changes in the display only if the new location has been detected for more than a certain number n of time steps. The choice of n influences the responsiveness of the app and may delay updates when the user moves. Therefore, we will include data from the motion sensor to determine n: a detection of motion decreases n, time spent without motion increases n. This should stabilise the order of the shown locations.

Many visitors of the LebensPhasenHaus have some kind of disability. Beacon technology has been used for guidance systems for the blind [2,18]. Or if users are restricted in their use of the hands, a more automatic mode of using the localisation could be useful. By switching automatically to the information relevant to the location of the user, the app would not have to be controlled explicitly. With an additional voice output, the system could be extended to a fully automated guide that may be too obtrusive for able-bodied users, but could provide a useful tool for users with restrictions.

Beacon technology is an active field of development. For example, Estimote recently announced Beacons with built-in Ultra Wide Band radio, coming with a software package to map the environment and locate users[6]. Such technologies may lead to better indoor localisation, but it will still be important to critically evaluate the claims of vendors and to consider the user context.

[6] `http://blog.estimote.com/post/154460651570/estimote-beacons-with-uwb-can-now-automatically`

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