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SmartGuide – A Smartphone Museum Guide with Ultrasound Control

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Abstract

While smartphones are well equipped for outdoor localization tasks, they usually do not provide support for identifying an indoor point of interest. This especially prohibits the context aware use of smartphones for guidance tasks inside a building, e. g. a museum. Alternatives like the use of near field communication (NFC) or barcode tagging demands an explicit interaction of the user with the tag, as well as dedicated sensors on the users' phone. WiFi triangulation requires a calibration step for every distinct location. We found that ultrasonic signals, sent by a cheap, stand-alone emitter, can be the basis of a light-weight smartphone based proximity detection system. Using this technique we developed a prototypical context-aware museum guide and tested it successfully in public.

Keywords: Indoor Localization; Ultrasonic; Smartphone; Museum Guide

1. Introduction

Since Smartphones and wireless Internet connection became ubiquitous in the last years, location based interaction, supported via the Global Positioning System (GPS) or WiFi identification became a standard pattern for mobile phone usage. This enabled a variety of context aware applications, which now constitute a considerable part of phone apps, e.g. a dynamic Tourist Guide.

Unfortunately, due to the missing applicability of GPS positioning inside buildings, many scenarios still cannot easily implemented. If a tourist visits a museum, she cannot continue to interact with her smartphone to gain background information about close-by exhibits in a context aware way, as she might have done during the city walk. Instead, she is usually dependent on loaning dedicated hardware to enjoy multimedia content, and is most of the times forced to interact explicitly with the device to select related information - a media discontinuation which seems surprising nowadays. We learned from interviews with museum managers that they look forward to avoid the personnel-intensive and costly renting of dedicated guide devices. But in order to be widely accepted, a smartphone based guide system must run out-of-the-box on a wide range of mobile phones and should be installable at the museum site. System components integrated into the museum building should be cheap in purchase and operation, not invasive, ideally invisible and with low maintenance requirements.

When designing a system for mobile devices that is using an implicit interaction technique (like selecting close by exhibits without explicit user interaction), the sensors required to identify the user context are a limiting factor. WiFi is available on many smartphones nowadays, but is a heavy-weight solution in that maintaining an indoor location system based on WiFi measurements requires an explicit remapping of every museum site after each reordering.

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Additionally, closed operating systems which get more and more popular for smartphones do not always allow to access the WiFi parameters required to determine the device's position from signal processing. On the opposite, audio recording is a standard smartphone system feature, and we found that smartphone microphones are capable to sense sound on ultrasonic frequencies generated with a simple piezo speaker.

Since for the implementation of an exhibit-aware museum guide, the localization task is focused on the identification of close-by points of interests, an exact position of the device in a common coordinate system is not required. Therefore, we developed a smartphone museum guide that identifies surrounding exhibits by receiving a modulated ultrasonic signal. On user side, no special hardware is required, and the sound signal can be emitted using a cheap stand-alone device.

We present our approach in this paper as following: In the next section, we present related works, followed by a presentation of the general system design and the algorithms used for exhibit identification. The system has been evaluated on-site in a small technical museum, the results are summarized in the fourth section. To close, we recapitulate the main contributions of this work, accompanied by a description of the next steps and further improvements with respect to our research findings.

2. Related Works

The *SmartGuide* relates to previous work in two categories: Firstly, the identification of close-by exhibits requires a relative localization technique, so different options to perform indoor localization are presented and compared. Secondly, museum guides as a variant of mobile tour guides have been under research for mobile interaction.

Most modern smartphones are equipped with a GPS receiver, but the signal is well absorbed by buildings. Therefore, GPS is currently no option for indoor localization. [1] proposes a system based on infrared (IR) receivers, distributed inside the building, and a device sending IR signals. Unfortunately, smartphones generally do not integrate an IR emitter, a complex and costly infrastructure has to be built up to fit a museum with the technique, devices must be informed about their position on a secondary communication channel and the centralized position calculation implies privacy concerns. The positioning algorithm can be performed locally on the user's device, if a static field of signals and their origin positions (beacons) are known to the device. This requires the device to access a beacon map, which must be maintained for every site. [2] and others propose the use of WiFi signals to perform such a localization, but absorption and reflection confuse the issue [3] and the required WiFi parameters cannot always be accessed on modern phones operating systems. [4, 5, 6] triangulate the device position using ultrasonic signals, but the used frequencies and algorithms require special hardware on client side. A compromise is the use of ultrasonic frequencies close to the human perceiving threshold (i. e. around 20kHz) to identify the presence of a beacon sender [7]. As we show here, ultrasonic beacon signals can be used on modern smartphones to distinguish the presence of several exhibits per room, supported by cheap dedicated emitters.[1]

Other options to recognize the presence of close-by objects (i. e. performing a relative localization of the device) include image processing [8], radio frequency (RFID) tag identification, Bluetooth beacon search and barcode scanning [9]. Placing barcodes (e. g. *QR-tags* [10]) next to an object is a cheap technology, and the tag can carry enough information to point the visitor to related web page. Unfortunately, we learned from interviews that many museums are unwilling to place a barcode next to their exhibits, since they seem not to match with the artistic concepts of the exposition room design and provoke a perceived visual disturbance. Additionally, taking a photo of the barcode with the mobile device can interfere with the museum's prohibition of taking pictures. This is even more problematical for the approach of image processing, since the museum staff cannot distinguish between a photo taken for image recognition and the snapshot for storage. In every case, both approaches require an explicit interaction of the visitor to trigger the identification process. RFID technology or Near Field Communication (NFC) [11] can be used to trigger context switches implicitly by approaching them, but requires dedicated sensors available today only on a small number of devices. In addition, NFC sensing range is typical limited to a couple of centimeters, which limits the possibilities of implicit interaction. Bluetooth receivers are integrated in many smartphones, but the access to it is often limited by the operating system.

[1]The commercial system Shopkick (`http://www.shopkick.com/`), published after our main research has been conducted, seems to place only one rather complex emitter per shop, so signal interference seems not to be an issue there.

The research on smart museum guides focuses on different aspects: Context aware content selection, content navigation and research concerning how the conception of a multimedia guide can be improved. Content selection via image recognition has been performed e. g. by [12, 13, 14], barcode scanning within others by [15, 16]. These approaches suffer from the limitations of photo-taking in a museum mentioned before. IR-based and RFID based approaches [17, 18] require a specially equipped smartphone or a rented device. Exploring new standard sensors on smartphones, [19] allows a content navigation using device tilt, for exposition selection, RFID is used. Adaptive and proactive technologies for contextualized presentations is one of the research areas that is treated by the PEACH project[2]. Inside this group research about the adaptation of the displayed content has been done. In [20] a system is presented that provides the visitors of an museum with personalized information about the exhibits, [21] refines this system by letting the visitor influence his user model.

3. System Design

To allow our *SmartGuide* to run on a wide range of smartphone models, we've chosen ultrasound based signaling to identify proximate exhibits. Since modern smartphones allow to record sound with 48,000 samples/s, according to the Nyquist-Shannon theorem [22] sounds with a maximum frequency of 24kHz can be technically detected. To our surprise, modern smartphone microphones were well able to record sounds up to this frequency (see Table 1), leaving a spectrum of about 4 kHz above the human reception level for proximity signaling.

Receiv. Device	IDs Sent	True Pos.	False Pos.	Detection Rate
HTC ADP 1	235	201	2	85.5%
Sony x10 mp	320	304	1	95.0%
HTC Desire	1023	928	10	90.7%

Table 1: ID transmissions in a quiet office setting (2m distance).

Next to the exhibits of the museum we placed small sound emitters. This hardware component, designed around a 8-bit 3.2 MHz Freescale microcontroller and a simple piezo speaker is as prototype already priced at less than 15$, and can be power supplied in parallel with the museum lightening. For encoding the transmission data, we are using a Frequency Shift Keying (FSK) technique, signaling bits at 20kHz and 22kHz respectively.

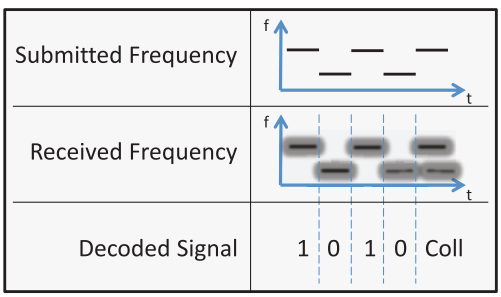


Figure 1: Example of signal decoding.

With a transmission duration of 26ms per bit, an 8 bit identification number could be transmitted in 208ms. Several exhibits had to be supported within sound distance (i. e. in the same room), but on the other hand, due to the goal of a simple sender design no sender coordination was possible. This requires every sender to decide individually upon the point, when to emit its signal. By pausing a random time between signaling (20ms-5.25s in our experimental setting for up to five senders in the same room), other emitters can transmit their ID in parallel (cp. [23]). Collisions are easily detectable with FSK by receiving a signal on both frequencies at the same instance. Error correction was done using

[2]http://peach.fbk.eu

the Hamming Code schema [24]. On client side, a Wiener Filter [25] improved the sensing results, so a comparison of the signal noise ratios against a threshold allowed the signal detection (see Figure 1). By juxtaposing the signal strengths of different received ID transmissions, an ordering of the exhibits by approximate distance[3] is possible. The localization software system is developed as an independent Android module, so that it can be incorporated as context source into a broad variety of applications, of which we picked the use case of an intelligent museum guide.

As the smartphone application should be easily available for the museum guidance, we designed a generic, framework-alike system that can be updated incrementally with specific museum data (see Figure 2). By this, the user installs the application once on her device and is able to access the content of all museum sites from there. The content itself can be hosted on the museum's web server and is visualized using the phones browser component, so the full range of supported media and styles can be included. Images, videos and sound sequences are handled specifically to meet with the user's interaction expectations, i. e. media controls and image sliding are supported. The data can be transmitted to the device during the visit, but if the user plans his museum tour beforehand, she can decide to cache all the museum's media data already at home, so no data connection is required during the visit. A pre-caching can also happen at a hotspot in the museum's entrance area.

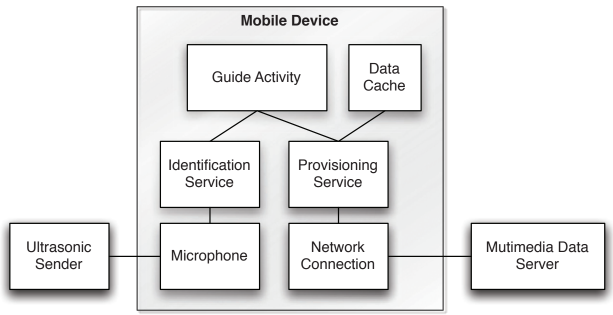


Figure 2: The general architecture of the *SmartGuide* system.

Once the *SmartGuide* application is running, a discrete sound and vibration notifies her of newly detected exhibits in her proximity. She can tap the information bar at the bottom to reveal a list of close-by exhibits (see Figure 3), whose media data is pre-cached in the background to allow an immediate display after selection. Although easily implementable, we set aside the option for auto-navigating to the closest exhibit's data in the evaluated version of *SmartGuide*, since some visitors tend to amble through the room while consuming background media information, and its unintended interruption would cause dissatisfaction with the system.

4. On-Site Evaluation

To test the approach in practice, we ran a public on-site evaluation for five days in a small technical museum. The museum itself is designed as one big irregular room, connecting two floors with a central atrium (see Figure 4). We placed six signal emitters in the museum, of which five were placed above the vitrines of the corresponding exhibits and one was our prototypical experimental board acting also as a technical exhibit. Three of the senders were placed on one level at a close distance of around four meters, the others were on the other level around 25 meters apart from each other.

Interested visitors of the museum were provided one of the available Android[4] smartphones (HTC Desire, HTC Wildfire, HTC ADP 1, Sony Ericsson x10 mini pro, Vodafone 845) and headphones at their wish[5]. At the end of their visit, the users were asked to fill out a survey. In total, 36 visitors provided feedback (around 15% of the individual museum visitors), 35% female, 65% male. 45% were aged below 30 years, 37% below 50 years and 18% above. 55%

[3]Due to varying microphone characteristics, differences in sending volumes and multipath signal propagation, the ordering might be inaccurate.
[4]http://www.android.com
[5]We experienced that some cheaper smartphones ignore the forced selection of the internal microphone and switch to a presumed headset mic, even if only headphones were connected. In that case, the user must be informed of the misconfiguration.

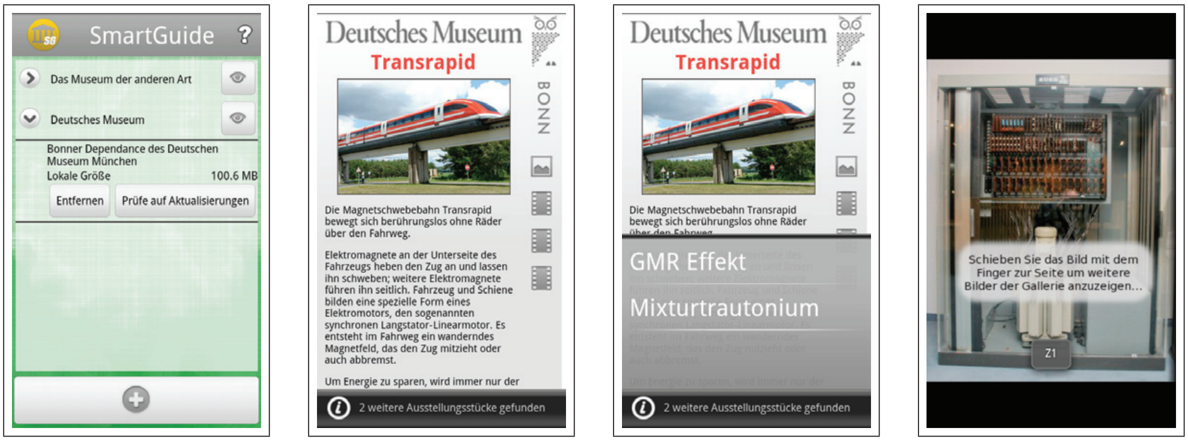
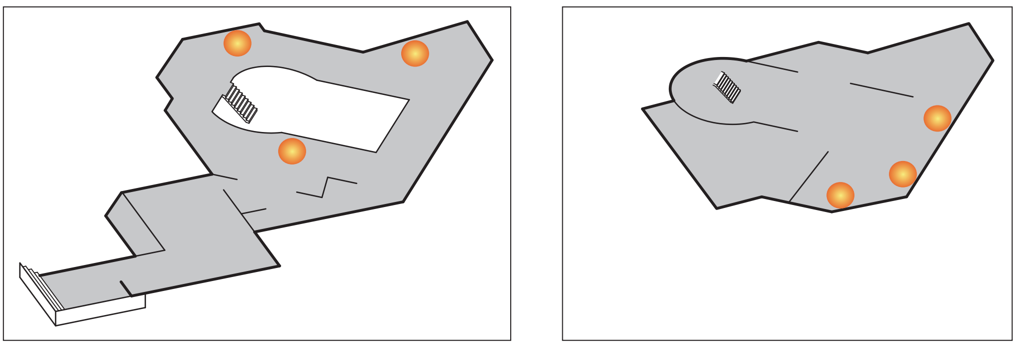


Figure 3: The selection of close-by exhibits as presented to the user.

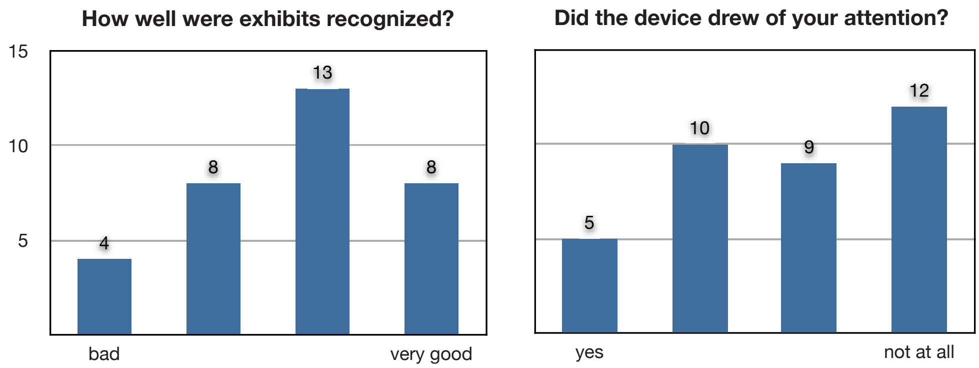


(a) Ground Floor (b) Basement

Figure 4: The museums groundplan. Senders marked as dots.

of the participants already own a smartphone, and 64% claimed to have a general interest in computer technology. While the user group is too small to provide statements of general validity, the feedback still can give hints for further research directions.

Figure 5(a) shows that the recognition of exhibits worked in general quite well, comments suggest that it improved when people learned how to hold their device without obstructing the microphone. 45% of the participants reported situations in which an exhibit was identified, which seemed not to be close-by, but this number decreased as soon as we attached information icons to the exhibits. This suggest that it was not always easy for the user to correlate the information on the device with the correspondent exhibit. Nevertheless, all users indicated that the system was useful or very useful for them, so they generally accept this kind of adaptive museum guide. Nearly all (91%) of the participants reported a good to very good usability of the system, and 86% would like to use their own devices for it. While distraction seems to be a slight problem (see Figure 5(b)), 77% of the visitors said, that they learned about new aspects of the exhibits from the system, especially through video (34.9%) and audio (19.7%). The concept of offering context-awarly selected multimedia data to the visitor seems to be reasonable, but it is a challenge for content authors to balance between a distraction due to intense use of the smartphone screen and the use of classical media like audio. On the technical side, improvements can be made on the accuracy of the identification, e. g. by using only error detection in spite of an eager forward correction, leading to false positive hits.



(a) (b)

Figure 5: Selected results from user feedback.

5. Summary and Further Works

In this paper, we demonstrated how a smartphone based multimedia museum guide can be implicitly controlled using ultrasound signals. We developed and evaluated a prototypical system, designed in an application oriented way:

- Installable on a wide range of smartphones without special hardware requirements.
- Unattended exhibit identification using a cheap, stand-alone hardware emitter.
- Discrete user interface to signal context changes without intercepting the users current task.
- Server based media management with proactive caching supporting museums without uniform network coverage.

Our experiments with various Android based smartphones proved the applicability of the approach and our field test attested a high satisfaction of museum visitors.

Nevertheless, further improvements are on schedule: Currently, the frequencies used to transmit the exhibit ID are fixed, but we found that in contradiction to the statement in [7, 2.1] steady noise also occurs in the 20kHz region, presumably originating from electrical ballast. Therefore, an adaptation of the used frequencies to the museum site situation is inevitable. As a small flaw, our current senders emit a quiet click when switched on, but it was almost unnoticed by our evaluation users, and can be avoided by modulating the amplitude of the senders. If the senders' hardware is extended with a microphone, further the emittance amplitude could be adapted to the rooms' noise level and a carrier sense technique could be used to avoid transmission collision between several senders in the same room. Finally, we envision further applications of the identification technique in the areas of fair management, logistics and mobile games.

References

[1] R. Want, A. Hopper, V. Falcao, J. Gibbons, The active badge location system, ACM Trans. Inf. Syst. 10 (1) (1992) 91–102. `doi:http://doi.acm.org/10.1145/128756.128759`.

[2] P. Bahl, V. N. Padmanabhan, RADAR: An in-building RF-based user location and tracking system, in: INFOCOM, 2000, pp. 775–784. URL `http://www.ieee-infocom.org/2000/papers/589.pdf`

[3] K. Kaemarungsi, P. Krishnamurthy, Properties of indoor received signal strength for WLAN location fingerprinting, in: Proc. MobiQuitous'04, 2004, pp. 14–23. URL `http://csdl.computer.org/comp/proceedings/mobiquitous/2004/2208/00/22080014abs.htm`

[4] A. Ward, A. Jones, A. Hopper, A new location technique for the active office, IEEE Pers. Comm. 4 (5) (1997) 42–47.

[5] N. Priyantha, A. Chakraborty, H. Balakrishnan, The cricket location support system, in: Proc. Mobicom'00, 2000.

[6] M. Hazas, A. Ward, A novel broadband ultrasonic location system, in: Proc. Ubicomp'02, 2002, pp. 264–280.

[7] A. Madhavapeddy, D. Scott, R. Sharp, Context- aware computing with sound, in: Proc. Ubicomp, 2003. URL http://springerlink.metapress.com/openurl.asp?genre=article&issn=0302-9743&volume=2864&spage=315
[8] D. G. Lowe, Object recognition from local scale-inva- riant features, in: Proc. ICCV'99, 1999, pp. 1150–1157. URL http://dx.doi.org/10.1109/ICCV.1999.790410
[9] E. Rukzio, S. Wetzstein, A. Schmidt, A frame- work for mobile interactions with the physical world, in: Proc. WPMC'05, 2005.
[10] Int. Org. for Standardization, QR code 2005 bar code symbology specification, ISO/IEC 18004:2006 (2006).
[11] Int. Org. for Standardization, Near field communication wired interface (nfc-wi), ISO/IEC 28361:2007 (2007).
[12] P. Foeckler, T. Zeidler, B. Brombach, E. Bruns, O. Bimber, Phoneguide: museum guidance supported by on-device object recognition on mobile phones, in: Proc. MUM'05, 2005.
[13] H. Bay, B. Fasel, L. V. Gool, Interactive museum guide: Fast and robust recognition of museum objects, in: Proc. IMV'06, 2006.
[14] B. Ruf, E. Kokiopoulou, M. Detyniecki, Mobile museum guide based on fast SIFT recognition, in: Proc. AMR'08, 2008. URL http://www-poleia.lip6.fr/~marcin/papers/Ruf_AMR_08.pdf
[15] S. Ghiron, C. Medaglia, A. Perrone, Art-sonomy: Social bookmarking of real artworks via mobile applications with visual tags, in: Pr. UAHCI'09, 2009.
[16] S. Chan, QR codes in the museum – problems and opportunities with extended objects, http://www.powerhousemuseum.com/dmsblog/?p=666 (March 2009).
[17] R. Oppermann, M. Specht, A context-sensitive nomadic exhibition guide, in: Proc. HUC'00, 2000. URL http://link.springer.de/link/service/series/0558/bibs/1927/19270127.htm
[18] E. Rukzio, G. Broll, S. Wetzstein, The physical mobile interaction framework (pmif), Tech. Rep. LMU-MI-2008-2, University of Munich, DE (2008).
[19] J. Mäntyjärvi, F. Paternò, Z. Salvador, C. Santoro, Scan and tilt – towards natural interaction for mobile museum guides, in: Proc. MobileHCI'06, 2006. URL http://doi.acm.org/10.1145/1152215.1152256
[20] C. Rocchi, O. Stock, M. Zancanaro, M. Kruppa, A. Krüger, The museum visit: generating seamless personalized presentations on multiple devices, in: Proceedings of the 9th international conference on Intelligent user interfaces, ACM, 2004, pp. 316–318.
[21] D. Goren-Bar, I. Graziola, T. Kuflik, F. Pianesi, C. Rocchi, O. Stock, M. Zancanaro, I like itan affective interface for a multimodal museum guide, in: Workshop on Affective Interactions at the 9th International Conference on Intelligent User Interfaces (IUI-05). San Diego, CA, January, Citeseer, 2005, pp. 10–13.
[22] C. E. Shannon, Communication in the presence of noise, Proc. IRE'49 37 (1949) 10–21.
[23] N. Abramson, The aloha system: another alternative for computer communications, in: Proc. AFIPS'70 (Fall), 1970, pp. 281–285. doi:http://doi.acm.org/10.1145/1478462.1478502.
[24] R. W. Hamming, Error detecting and error correcting codes, Bell System Technical J. 29 (1950) 147.
[25] N. Wiener, The Extrapolation, Interpolation and Smoothing of Stationary Time Series, Wiley, 1949.