MagnetiCode—Physical Mobile Interaction through Time-Encoded Magnetic Identification Tags

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ABSTRACT

We present MagnetiCode, a new tagging mechanism that allows for physical mobile interaction. MagnetiCode tags can be captured and decoded by every compass-equipped mobile phone. They rely on a novel approach of transmitting binary IDs in form of a pulsed magnetic field. MagnetiCode therefore is able to substitute static tagging mechanisms like QR codes or RFID tags, in situations where visual tags are not appropriate or the expected number of users with NFC-enabled devices is poor. We confirm the general feasibility of our approach in a study.

Author Keywords

Tangible interaction, object identification, tags, magnetometer, mobile tangible interfaces

ACM Classification Keywords

H.5.2. Information interfaces and presentation (e.g., HCI): Input devices and strategies.

General Terms

Design, Human Factors, Experimentation.

INTRODUCTION

From EAN/UPC [9] barcodes on groceries, over QR codes [10] on train tickets, to RFID chips [22] for mobile payment—identification tags become more and more pervasive in our world. They allow for a form of tangible interaction [23] referred to as physical mobile interaction [14, 18], where quick response (QR) codes are scanned with mobile phones to explore museum exhibits [3] and NFC-enabled phones allow interactions with displays [2].

We present MagnetiCode (c.f. Figure 1), a novel tagging mechanism repurposing magnetometer sensors in mobile phones. It reads identification tags that are sent in form of a bit-stream, generated by a pulsed electromagnetic field caused by a solenoid (i.e., an *electromagnet)*. This way we offer a new style for physical mobile interaction for situations where visual identifications like QR codes are not suitable or the availability of NFC-enabled devices is sparse. Our approach resembles some aspects of radio-frequency identification (RFID) and near field communication (NFC), as it allows for wireless, contact-free transfer of data through electromagnetic fields without the need for a line of sight. It therefore enables owners of smartphones that are not NFC-enabled to engage in NFC-like interactions. For example the models of the iPhone series—world wide among the most sold mobile devices—up to the current model iPhone 5S are not equipped with a NFC chip. Yet, since the release of the model 3GS in the year 2009, the iPhone provides a magnetometer sensor that serves as a compass—and accordingly works with MagnetiCode. In contrast to passive NFC tags or static visual tags like QR codes, our mechanism allows the adaptation of the transferred information as it offers dynamic altering of the payload.

In the remainder of this paper we give an overview of the background and related work. We further describe the concept and outline applications of MagnetiCode. We give details on the implementation of our native MagnetiCode iPhone app as well as our JavaScript-based solution. We report on a user study of MagnetiCode and discuss the results. Finally, we conclude after discussing current limitations and areas of future work.

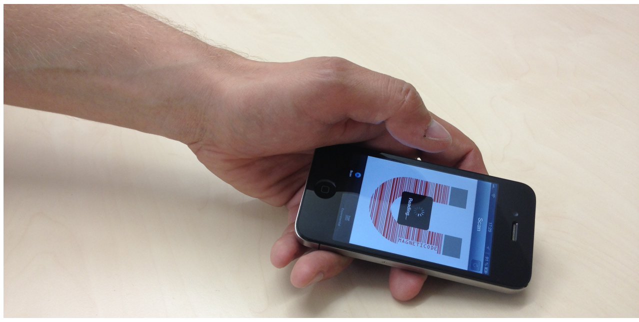

Figure 1. User identifying a MagnetiCode tag with an iPhone.

BACKGROUND AND RELATED WORK

Many different methods for the machine-readable encoding of unique identifiers have been devised, as for example visual tags from 1D-barcodes like EAN and UPC, over matrix barcodes like QR codes, to specialisations like time-multiplexed, 2D colour barcodes [13]. While most of these visual approaches can be decoded with most camera-

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equipped mobile phones, some drawbacks exist, as they need a line of sight, require orientation of the camera and are not aesthetically pleasing. Further RFID and NFC [2, 15, 22, 23] offer wireless, non-contact, non-visual identification through inductive coupling, although they need specialised hardware that has not yet reached considerable market share in many countries. Such different qualities of various tag based identification approaches have already been assessed in studies [14, 15, 18] in great detail. A comparison of advantages of tag-based vs. feature-based object identification is out of the scope of this paper. In our analysis of related work we therefore focus on the two unique aspects of our approach: work that is concerned with novel ways of identification via time-encoded signals and work that explored repurposing magnetometers for new interaction styles in the fields of HCI, and Mobile and Ubiquitous Computing.

Time-Encoded Identification

IR Ring [17] allows users to identify and authenticate on multi-touch surfaces. A finger-worn ring sends out a continuous bit-sequence in form of infrared pulses that are detected by an infrared camera beneath the multi-touch surface, decoded and thus authenticated. Cricket [16]—an early indoor location system—is based on an ultrasonic pulse in combination with an RF signal sent out by wall- and ceiling-mounted beacons. Passive readers are able to identify the unique IDs of the beacons and to infer the location based on the nearest beacons. Finally, Acoustic Barcodes [6] use patterns of grooves in physical tags made of wood, glass, granite, etc. to store binary IDs. When swiped with e.g. a fingernail, those grooves produce a unique sound that is recorded with a microphone, filtered, and decoded into a unique ID. Accordingly the spatial arranged groves are transformed into a form of time-encoded identification scheme. While Acoustic Barcodes can be identified as the approach that is closest to MagnetiCode, it is fundamentally different in many of its characteristics and application areas.

Magnetic Interaction

Since magnetometers in mobile phones have become more and more pervasive in the last years, several researchers have explored to divert them from their intended use, to allow for new interaction styles. Zhang and Sawchuk [24] explored how changes in the magnetic field sensed by magnetometers can be used to detect the use of household appliance in order to support activity recognition. MagiSign [12] supports magnetic gestural authentication. Based on magnetometer data, MagiSign is able to recognise signatures created in the air with a permanent magnet as input devices. MagPen [8] uses a magnet to augment the input possibilities of a conductive stylus on a mobile phone. Magnetometer readings allow detection of the orientation of a stylus, off-the screen interactions, pressure-sensitive input and more. MagiGuitar [11] and Magnetic Marionette [7] both support more playful forms of interaction with mobile phones through the built-in magnetometer and the use of permanent magnets. The first allows using a magnet to strum guitar strings on a mobile phone in mid-air. The second allows for ludic interaction by recognising different patterns in the magnetic field, when a telephone case that has small arms with magnets attached to it, is tangibly reconfigured to mimic different poses.

Other researchers explored the use of wrist-worn magnetometers combined with magnetic fingerrings. Abracadabra [5] explored the input to a magnetometer-equipped wristwatch worn on one arm by pointing gestures with a magnetic ring worn on the finger of the other arm. Nenya [1] provides an input mechanism that is based on a wrist-worn magnetometer and a magnetic finger ring worn on the same arm. Nenya tracks changes in the magnetic field when the user is sliding or spinning the ring on the finger, and performs appropriate input like menu selections.

While different styles of interactions have been explored with magnetometers, we are not aware of any work that has used magnetometers for identification tasks like MagnetiCode. Magnetism has been commonly used to store information in various forms (e.g., magnetic tapes, floppy and hard disks, or magnetic stripe cards), relying on the same idea of storing spatial patterns of magnetisation in magnetisable materials. MagnetiCode uses a temporal pattern, and also does not rely on hardware that is specifically tailored to data transfer.

THE MAGNETICODE CONCEPT

As laid out in the introduction, the general idea of bridging the physical and digital world by tagging the environment is not novel [23] and partially made the leap from research into our daily lives: QR codes can be found in advertisements on posters and magazines allowing us to obtain more information on the advertised products; NFC tags enable us to buy bus tickets on the go. We propose MagnetiCode as a new tagging scheme and in the following we present its principle and discuss its benefits alongside distinctive application scenarios.

The Principle of MagnetiCode

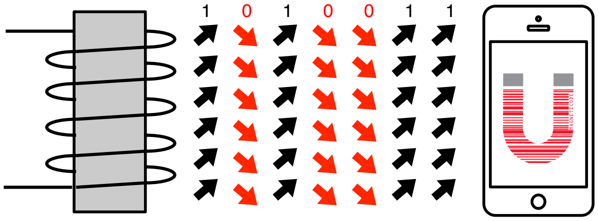

Figure 2. Schematic illustration of the MagnetiCode concept.

The underlying principle of MagnetiCode as illustrated in Figure 2 is based on repurposing magnetometers, which are able to measure intensity and direction of the earth magnetic field and therefore are normally used as a compass e.g. in mobile phones. A MagnetiCode tag cyclically changes the magnetic field by periodically powering an electromagnet. This way the MagnetiCode tag is able to send out a binary signal in form of time-encoded magnetic field changes. When a mobile phone equipped with a magnetometer is brought into the range of the tag's magnetic field, the magnetometer is able to detect these periodical changes between the earth magnetic field and the solenoid's field. The MagnetiCode algorithm uses these changes to decode the binary data.

As MagnetiCode tags constantly send a short binary code in a continuous loop, generally two forms of tags are conceivable: static and dynamic tags. While static tags constantly send the same binary ID, dynamic tags can alter the binary ID depending on different conditions. Information sources for changing dynamic tags are diverse: switches and buttons, different sensors, or remotely via Bluetooth or Wi-Fi by a computer program.

Benefits and Application Examples of MagnetiCode

Current approaches for physical mobile interaction like NFC or visual tags have clear limitations. We designed MagnetiCode to combine advantages of NFC and visual tags, without sharing the same set of drawbacks—to open up new opportunities for interaction based on its unique set of characteristics.

For instance, NFC-equipped phones are not yet pervasive in many parts of the world. In their analysis of the mobile payment market Gartner Inc. 2013 reduce their forecast on NFC transaction due to what they say is a "disappointing adoption of NFC technology in all markets" [20]. Magnetometers now are ubiquitous in mobile phones—at a rate even superseding NFC adoption—making it an opportunity for an adoption of MagnetiCode in some scenarios. Visual tags like QR codes also have certain limitations. They need a line of sight between the tag and the reader, require orientation of the device, and they are not aesthetically pleasing and therefore not adequate for every context. For example Coonan et al. [3] discuss this problem when they report on their experiences with QR code placement in museums and galleries. They found that artists judge such codes to be "visually disruptive" and therefore not ideal to tag art pieces in a museum. Finally, the use of mobile phone cameras—as it would be required for reading visual tags—is problematic in some environments. For example the use of photography is forbidden in many museums, might it be due to preserving the art, copyright rules or to nourishing a certain appeal to a gallery visit and to not irritate other visitors. Camera use might also be problematic in other areas for privacy, security or other reasons, as for example in trade shows, where novel prototypes are shown or R&D departments, where camera lenses in phones are sometimes taped, to prevent industrial espionage.

MagnetiCode is contact-less and can be used in situations where cameras are perceived as problematic or tags need to be hidden for aesthetic reasons. Although not as cheap as mass-produced NFC tags, the MagnetiCode tags with a static information payload can be cheaply custom-built—the electronics for one tag cost around 4 Euros. While more expensive, dynamic tags allow for new interaction possibilities beyond those of visual or NFC tags, by allowing instantly adapting or personalising the payload.

Accordingly we envision MagnetiCode to be applied in scenarios where other options fall short and the unique characteristics of MagnetiCode are advantageous. We devised three application examples in the context of museums, galleries or exhibitions, where visual tags cannot be used and NFC would limit the number of users to those with capable devices. First, MagnetiCode can be used to control a Web-based audio guide on the visitors' mobile phones. Hidden MagnetiCode tags near the exhibits can link to audio files that are directly played back in the browser of the mobile phone. As MagnetiCode can work within a mobile Web-browser, no app installation is required. Second, a museum guide application can use MagnetiCode to allow for easier access to information for individual exhibits. By placing MagnetiCode tags directly below smaller exhibits (e.g., antique plates) invisible for the visitors, such objects can be identified by multiple users at the same time by holding a mobile phone close to the exhibit. And third, interactive museum exhibits—as they are often found in technical and science museums—can incorporate sensors, physical buttons and switches, to change the properties of the exhibit or illustrate a process or phenomena. By using a dynamic tag the exhibit can link the appropriate information for the current state of the exhibit. For example a dynamic tag on an interactive exhibit of a four-stroke engine can send four different IDs—each providing a link to information for a specific cycles of the engine.

THE MAGNETICODE IMPLEMENTATION

To demonstrate the general feasibility of MagnetiCode we implemented two versions: (a) a JavaScript-based version that runs in a mobile Web-browser with a transmission rate of 0.625 bit/s and (b) a Native version with a higher transmission rate of 5.1 bit/s, but requiring an installation. The general method of encoding, sending, and decoding is the same for both versions, but varies in configuration parameters, such as the used clock speed. In this section we describe the implementation starting with encoding and sending data including the used hardware setup. We then describe the process of capturing the signal with the mobile phone's magnetometer and the signal processing for clock and data recovery. Finally, we provide an analysis about transmission speeds of both versions.

Encoding and Sending

MagnetiCode uses the change in the magnetic field to transmit data. We change the magnetic field by switching a solenoid—that is a coil of tightly enamelled wire wound around a long straight metallic core producing a uniform magnetic field when electric voltage is applied to it. In our prototype we use a SOLEN 121E14140 (12 V, 5 N traction, and 20 N retention). We found this solenoid to be strong enough, that a mobile phone is able to sense changes in the magnetic field in an area of roughly 30 cm^2 around the electromagnet. Figure 3 depicts our complete testing setup including an Arduino UNO R3 (A) connected to a computer via USB for programming and serial communication; a breadboard (B) with the circuit and a connection to a 12 V power supply; the 12 V solenoid (C); and a mobile phone (D). Figure 4 shows the wiring for this setup. We have two circuits: a 5 V circuit for signal pre-processing, and a 12 V circuit for powering and switching the solenoid. The two circuits are connected using a NPN transistor (2N2222A, `Q1`).

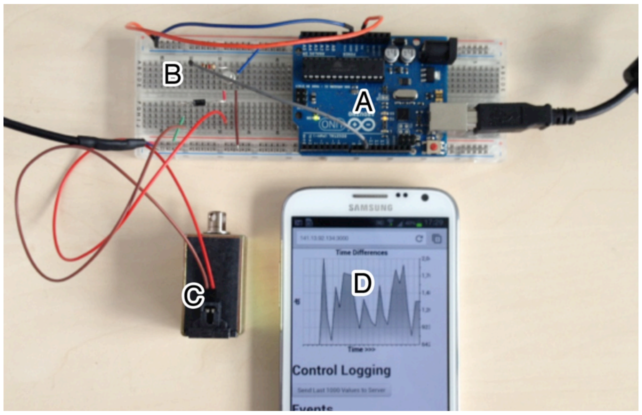

Figure 3. Testing setup, including the Arduino (A), our circuit (B), the solenoid (C), and the mobile client (D), here with a JavaScript version running in logging-mode for development.

In the 5 V circuit, the Arduino changes the current on its digital pin `D10` from `LOW (0 V)` to `HIGH (+5 V)` or vice versa. The transistor `Q1` recognises these changes on its base and switches its collector accordingly in the same direction.

In the 12 V circuit, a diode (1N4001; `D1`) limits the current from leaking towards the resistor. In the case that the transistor `Q1` switches to `HIGH` the solenoid will switch to its relaxed position applying no change to the magnetic field. In the other case, when the transistor `Q1` switches to `LOW` the solenoid will switch to its holding position and change the magnetic field.

For encoding data, we have two states `LOW` and `HIGH`. Data composes of sequences of `0`s (i.e., `LOW`) and `1`s (i.e., `HIGH`) and each state can follow successively (e.g., `0011`). We use frequency modulation (i.e., the presence or absence of transitions to declare a logical value) with a Biphase Mark Code (BMC) for encoding. BMC is a special form of Differential Manchester encoding where a period always starts with a change of the signal (i.e., zeros last a full period in one state, ones last half a period in one state followed by a switch of state and a second half in the new one). We explored a shortest possible transition for the Native version (c.f. next subsection on the sensor's capabilities) to be 98 ms. This means a sending frequency of 10.2 Hz.

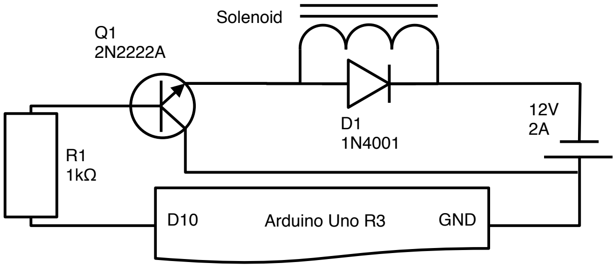

Figure 4. Circuit diagram for the MagnetiCode prototype.

The Arduino modulates the binary data as signal of state changes. In order to guarantee constant sending times, the Arduino samples sending timestamps in milliseconds and delays its operation accordingly. So we are able to provide half-clock speed precise pauses between transitions from `LOW` to `HIGH` or vice versa. It means, that the transmit rate is half the clock speed of the transmission, but a receiver detects changes of signal at least at every end of a full period and thus can distinguish successive logical states.

To allow applications that handle human readable data, we decided to transmit an 8-bit ASCII character embedded into a start and stop bit (i.e., one full transmission cycle consists of 10 bits). Figure 5 shows a complete transmission cycle for en- and decoding the ASCII character 'A'. After each transmission cycle a pause of 6 times the clock speed guarantees a receiver to distinguish between different transmissions.

Capturing Magnetometer Sensor Data

For capturing the signal we rely on the magnetometer sensors embedded into standard smartphones. For the JavaScript version we use the compass data a Web-browser delivers using `DeviceOrientation Events` as drafted by W3C [21]. Each event includes an alpha value denoting the direction. For the Native version we rely on the `CMMagnetometerData Events` as provided by the `CoreMotion` framework[1] in iOS 6.1.3. Each event consists of a timestamp and a `CMMagneticField` struct containing the magnetic field values in x, y, and z direction.

We measured strong differences regarding sampling frequencies and rawness of the signal between both versions. While the JavaScript version provides already smoothed samples and at irregular times (intervals vary from 23 to 328 ms on a Samsung GT-N7100), the Native version delivers raw values regularly (approximately every 0.023 ms on a Apple iPhone 5). However, we found that these differences in timing and regularity are software-based: both devices employ the same magneto-resistive permalloy AK8963 as 3-axis electronic compass. In 'Continuous measurement mode 2', the AK8963 magnetometer sensor[2] measures periodically at 100Hz—we receive data at 3 and 21.7 Hz.

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[1] http://developer.apple.com/library/ios/

[2] http://www.akm.com/akm/en/file/datasheet/AK8963.pdf

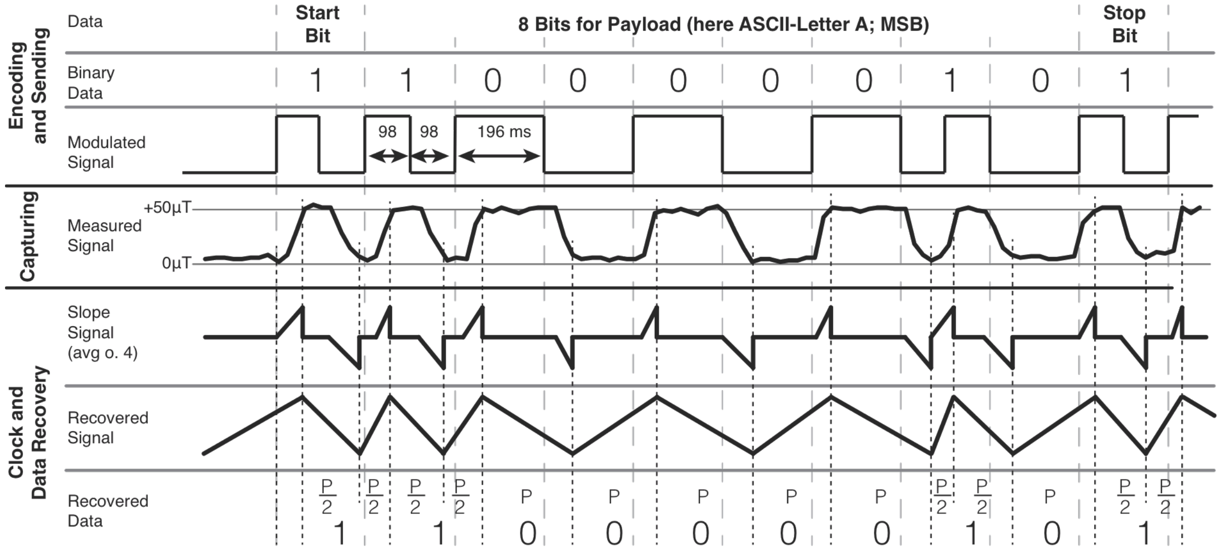

Figure 5. En- and decoding of data.

According to the Nyquist–Shannon sampling theorem [19] the theoretical achievable data rate is limited to at least half of the receiver's sampling frequency for a full signal reconstruction. We use the measured maximal sampling interval (c.f. time values in the previous paragraph) as boundaries for the sampling frequency of both versions: a sampling rate of 2.5 Hz for the JavaScript and 20.4 Hz for the Native version. This results in a data sending frequency of 1.25 Hz for the first, and 10.2 Hz for the latter version.

Clock and Data Recovery

As indicated in Figure 5 (i.e., differences between black-dashed and grey-dashed vertical lines), the rise of the signal is different from the fall of the signal. Deviations in the step-responses of the solenoid, lead to jitter (i.e., deviations from the true periodic signal). To recover the logical signal we apply filters as subsequently described. For recovering clock information and data we do the same three processing steps in both versions.

In a first step, we average incoming samples (i.e., using two on both versions) for smoothing the signal. We then analyse the slope between samples (i.e., here also using two on both versions) as a fraction of differences in timestamps and values. In a second step we apply thresholds as a low-pass filter to the slope values. We use a threshold range of [-0.25,0.25] for the JavaScript version and a threshold range of [-2,2] for the Native version (c.f. the 'Slope Signal' in Figure 5). In a third step we recover the frequency-modulated signal by filtering out all samples between each rise and fall (c.f. the 'Recovered Signal' in Figure 5). We then compute the time differences between each change. If we detect two successive small changes, we write a logical 1 into a result buffer. If we detect a twice as long period, we write a logical 0. If we detect no change for a long period, we clear the result buffer, as a new sequences start. Table 1 shows the time ranges for decoding a logical 1 and logical 0.

	JavaScript	Native
Logical 1	[600 , 1200] ms	[50 , 150] ms
Logical 0	(1200 , 2900] ms	(150 , 240] ms
Pause	Above Range of logical 0	

Table 1. Accepted time boundaries for one, zero, and pause

Finally, in order to save users time while capturing MagnetiCode tags, we already process the input buffer each time we have recovered 10 bit—we deliberately do not wait until we detect the end of a pause. We evaluate the start- and stop bits of the result buffer and decode the payload into the ASCII character representation.

Transmission Speed Analysis

We have tested the JavaScript version on an Apple iPhone 4 (Mobile Safari) and a Samsung GT-N7100 (Chrome). We achieved better results with the GT-N7100, as the iPhone required a strict placement beside the solenoid (i.e., in direct vicinity to the volume button). The GT-N7100 allowed a very still handheld operation within a range of 5–10 cm. Having a sending frequency of 1.25 Hz and using BMC encoding—where each logical bit requires the time of two state changes—the transmission rate is 0.625 bit/s.

$$800\,\frac{\text{ms}}{\text{change}} \xrightarrow{yields} \frac{1.25\left[\frac{\text{cycle}}{\text{s}}\right]}{2\left[\frac{\text{bit}}{\text{cycle}}\right]} = 0.625\left[\frac{\text{bit}}{\text{s}}\right]$$

We tested the Native version on different Apple iPhones (i.e., 3GS, 4, 4S, and 5) with comparable results: all devices allowed an operation within a range of 5–10 cm. We also use BMC encoding, but the regular and faster effective sampling frequency allows an increased sending frequency of 10.2 Hz resulting in a transmission rate of 5.1 bit/s

$$0.98\,\frac{\text{ms}}{\text{change}} \xrightarrow{yields} \frac{10.2\left[\frac{\text{cycle}}{\text{s}}\right]}{2\left[\frac{\text{bit}}{\text{cycle}}\right]} = 5.1\left[\frac{\text{bit}}{\text{s}}\right]$$

In both versions we continuously sample magnetometer events. The calculated synchronised best case and worst-case recognition times for both versions are 16 s and 36 s for the JavaScript-Based and 1.96 s, and 4.41s for the Native version. The best-case scenario denotes to the synchronised start between sender and receiver. The worst-case scenario means a client receiver starts sensing after the sender has sent the first half of the first bit—the receiver captures the rest of the first transmission, the pause and one full transmission.

EVALUATION

We conducted a user study to receive insights on how the Native MagnetiCode client would perform with end users; comparable to the study done by Harrison et al. [6] where they assess the feasibility of Acoustic Barcodes. The focus of this study was to get a first impression of the achievable accuracy and robustness of the recognition system with real users. We analysed how different poses of placing the mobile phone over a tag influences the recognition performance resulting from increased shaking motions and distance to the tag. We also asked some questions regarding the experience with other tagging approaches (NFC and visual tags) and the users' thoughts on MagnetiCode.

Figure 6. Study setup with two MagnetiCode tags on the table.

Study Setup and Procedure

We recruited 8 participants (4 female) between the age of 26 and 63 (*M* = 40.1) among members of our university administration and faculty. The study had four parts: (1) a brief introduction, (2) a period of 3 minutes where the participants tried MagnetiCode, (3) a user test with three randomised conditions, and (4) a short semi-structured interview with an overall duration of approximately 15 minutes per participant. Figure 6 shows the setup of the study, which took place in our Noldus usability lab. We mounted two different MagnetiCode tags (one for the ASCII character 'A', the other for 'B') underneath a table. On the table's surface, we placed markers for each tag as indicator where to place the mobile phone (i.e., iPhone 4).

The participants were asked to use the MagnetiCode app in three different poses (c.f. Figure 7) as our test conditions. The three poses are: Laid (L), where the participants placed the mobile phone on the marker and removed their hands while identifying; Pointed (P), where they hold the mobile phone while touching the surface with its top-edge pointing to the marker; Held (H), where they held the mobile phone in one hand slightly above the marker, and were not allowed to touch the surface. We randomised poses and marker sequence over all participants using Latin Square.

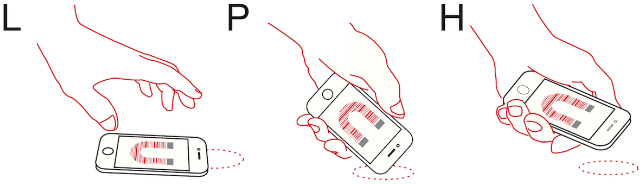

Figure 7. Three poses analysed as conditions in the study.

The participants were instructed to do five trails per pose by alternating between the two MagnetiCode tags ('A' and 'B'), resulting in 15 identifications per participant. To initiate identification, they pressed a button in the app. We deliberately added the button just for the study in order to exactly measure the interaction times. After a successful identification, the app displayed the recognised character. In case identifying a tag failed (i.e., not able to recognise a tag during a identification time of 10 s), the participants proceeded with identifying the next tag and an identification error was recorded. Each participant was recorded on video from three perspectives and the MagnetiCode app measured the time between initialising the identification and receiving the complete ID. Finally, we interviewed the participants on their experience with NFC, visual tags, and opinion on MagnetiCode, as well as four usability items on a 5-point Likert scale.

Results and Discussion

From the videos and log files we derived the times for all identification as well as the number of identification errors. The identification times varied between 0.3 s and 9.4 s over all poses. As Figure 8 shows we defined three intervals. In the first interval (up to 2.0 seconds), the identification times were faster than the synchronised best case—as described earlier we do continuous background sampling; so the app already recognises the tag before the user explicitly initiated the reading process. The second interval (2–4.5 s) contains 72% of all identifications over all poses. Accordingly 100% of identifications in the laid pose and 95% of identifications in the pointed pose were completed before the synchronised worst case has been reached. In the third interval, above the synchronised worst case, there are only 11 of 120 successful identifications.

Considering the poses as conditions we found the following: The laid pose allowed for the fastest recognition times (*M = 2.2 s; SD = 3.7 s*). As the participants first placed the device on the marker, the continuous background sampling already started recognising the tag and is immediately available at the moment users pressed the button. The laid pose is followed by the pointed pose (*M = 2.6 s; SD = 1 s*); although the participants often simultaneously placed the device and pressed the button. The mean difference between these two poses is about one quarter of the total synchronised time. In the held pose (*M = 3 s; SD = 1.8 s*), the participants required more internal sampling cycles.

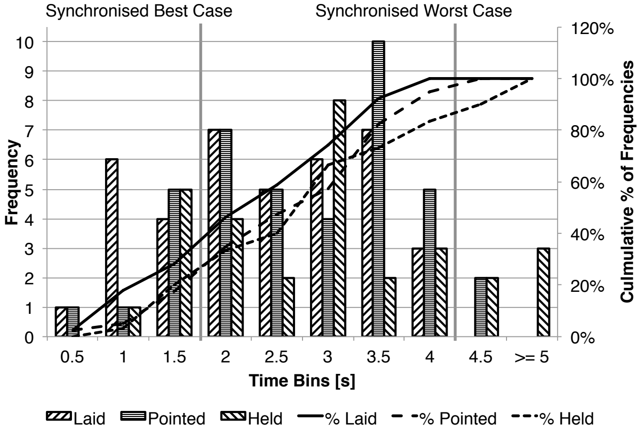

Figure 8. Frequencies of identification times per condition.

Overall 89.09% of the identifications succeeded and we only observed identification errors in the laid and held pose. In the laid condition (*M = 0.4 s; SD = 0.5 s*) we found from the video observation that participants were unsure were to place the device above the tag. In the held condition (*M = 1.8 s; SD = 1.7 s*), we observed—as expected—smaller movements of the hand. Albeit that one participant had especially difficulties with this pose in all trails, we generally think this higher error rate and the longer identification times are due to the unsteady handling in this pose. No identification error was measured for the pointed condition. However, some participants state that this pose is not very comfortable. As this issue is strongly related with the ability to reach the button in the study, this will not be as problematic in real world use cases where constant background capturing can be used.

Half of the participants already used a form of visual tags like QR codes in situations that ranged from obtaining product information or prices, accessing additional content in newspapers, magazines or advertisements to transferring configuration files to a mobile phone. Only 2 of the participants already used NFC on their mobile phones, and both participants stated they did it just once in order to explore the functionality. 7 participants stated they could imagine using MagnetiCode in various situations from museum information systems and audio guides to mobile payment at a parking meter. Over using NFC, the participants see the compatibility with a large variety of mobile phones beneficial. 3 participants said that it is often hard to photograph visual tags because they are too small or the camera is too bad. Besides that, two participants mindfully stated that they would use MagnetiCode over photographing visual tags, because using camera phones is sometimes not allowed (i.e., in research & development) and photographing visual tags in dark areas or at night is hardly possible.

Finally, for the usability items: the participants stated that MagnetiCode was easy to use (*M* = 4.5; *SD* = 0.5), easy to learn (*M* = 4.5; *SD* = 0.5), intuitive (*M* = 4.5; *SD* = 0.5), and was not found to be cumbersome (*M* = 1.8; *SD* = 0.5).

CURRENT LIMITATIONS AND FUTURE WORK

In its current experimental form, MagnetiCode still has some limitations, which can be addressed in future work.

While the native application currently outperforms the JavaScript version in terms of stability and data rate, a JavaScript version without installation requirements is preferable from a user perspective. While parameter tuning alongside better noise and error removal can help to improve the JavaScript version, future changes to the devices' SDKs to reveal raw magnetometer readings in the mobile browser would directly boost the performance of the JavaScript version to that of the Native version. The speed and accuracy of MagnetiCode is influenced by the device's motion during recognition and the proximity of the device's sensor to the solenoid. If the device is handheld during the detection process, the speed and accuracy is strongly correlated to the steadiness with which the device is held. Besides improving the signal quality by filtering out frequencies and peaks lying outside the expected signal curve, taking data from more of the device's sensors (e.g., accelerometer and gyroscope) into account could increase the robustness to motions from handheld operation (e.g., allow to filter out inference from static magnetic fields like the earth magnetic field). Error correction codes [4] also can have a positive effect on the identification results, yet they decrease the number of payload bits. Furthermore, a client can use the convention of 10 bits per transmission in order to compose two partial transmissions into a full one. This will lower the times in the worst-case scenario to ~21 s for the JavaScript version decoding, and to ~2.6 s for the Native version. Depending on the application, the encoding can be optimised, by choosing an adequate payload size for the intended purpose. For instance, in a scenario where only 32 different tags need to be distinguished the use of a 5-bit code results in a transmission time of 0.98 s for the Native version.

On the hardware side, incorporating step-response times of the solenoid into the modulation can produce a signal with less jitter. We plan to explore, if Pulse Width Modulation (PWM) of the solenoid can lead to more than two transmission states for a higher data rate. We used an Arduino for exploring and testing MagnetiCode. In setups that deploy multiple static tags, the design and production of custom PCBs to replace the Arduino with simpler and cheaper circuits is recommended. We estimate the costs with small batch quantities of custom-built electronics components for one tag around 4 Euro. For dynamic tags the flexibility of the Arduino in combination with other customised components like Wi-Fi or Bluetooth shields is beneficial. Our current prototype is powered by a 12VDC/1.6A power supply— however an estimation of the operating costs (i.e. power consumption) should be done on basis of a custom-built tag and an embedded design. In our exploration phase, we also chose a relatively strong solenoid for the ease of prototyping. For deployment, the exploration of different electromagnets can have several beneficial effects, as the strength of the magnet relates to the area in which the tag can be read. While weaker magnets can be placed closer together without interfering each other and thus allow to identify smaller objects in close proximity, stronger magnets extend the range in which a tag can be identified. Based on a final version of the tags, accuracy and robustness as well as the usability needs to be assessed in a broader user study.

CONCLUSION

We described our work on MagnetiCode, a novel tagging and identification mechanism based on time-encoded patterns of changes in the magnetic field, which can be read and decoded by magnetometer-equipped mobile phones. We have shown that MagnetiCode achieves fast and accurate results for pointed and laid poses and provided improvements for the held pose. The unique characteristics of our approach allow the substitution of other tag-based approaches (e.g. QR codes or NFC) where these fall short.

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