RFID-Based Compound Identification in Wet Laboratories With Google Glass

Philipp M. Scholl
Embedded Systems,
Albert-Ludwigs-Universität
Georges-Köhler-Allee 10,
79110 Freiburg
pscholl@ese.uni-freiburg.de

Tobias Schultes
Embedded Sensing Systems,
TU Darmstadt
Hochschulstr. 10, 64283
Darmstadt

Kristof Van Laerhoven
Embedded Systems,
Albert-Ludwigs-Universität
Georges-Köhler-Allee 10,
79110 Freiburg
pscholl@ese.uni-freiburg.de

ABSTRACT

Experimentation in Wet Laboratories requires tracking and identification of small containers like test tubes, flasks, and bottles. The current practise involves colored adhesive markers, waterproof hand-writing, QR- and Barcodes, or RFID-Tags. These markers are often not self-descriptive and require a lookup table on paper or some digitally stored counterpart. Furthermore they are subject to harsh environmental conditions (e.g. samples are kept in a freezer), and can be hard to share with other lab workers for lack of a consistent annotation systems. Increasing their durability, as well as providing a central tracking system for these containers, is therefore of great interest. In this paper we present a system for the **implicit** tracking of RFID-augmented containers with a wrist-worn reader unit, and a voice-interaction scheme based on a head-mounted display.

Author Keywords

RFID; HMD; Google Glass; Wet Laboratory;

ACM Classification Keywords

H.5.m. Information Interfaces and Presentation (e.g. HCI): Miscellaneous

INTRODUCTION

Traditionally taking notes and documenting experiments, as well as keeping tracking of samples and materials has been a pen'n'paper area - mostly for flexibility and legal reasons[14]. Signed paper records are harder to forge, change and delete than a simple electronic entry. However with new legal frameworks[19], and advanced mobile computing interfaces, electronic notebooks are slowly maturing into use in life science laboratories. These provide clear advantages, like capturing of multi-media, indexing and automation of entries and easy sharing of protocols - especially when considering the trend towards distributing work over several laboratories.

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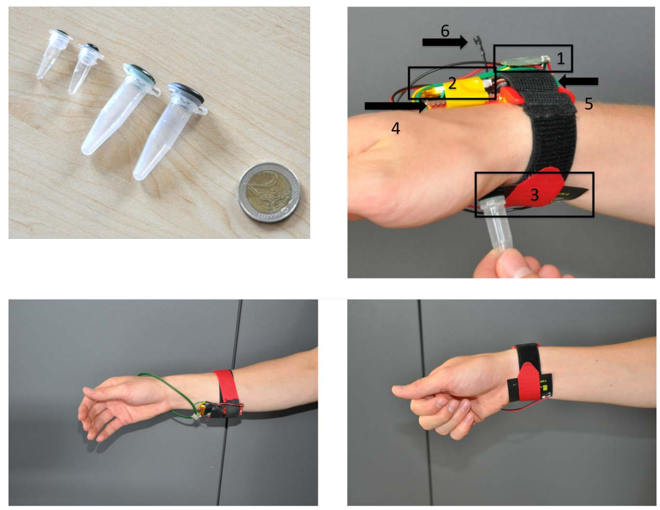

Figure 1. Tracking often miniature components in the Wetlab (top left). The wrist-worn prototype (upper right), along with two different types of antennas explored in this paper. Shown are Skyetec M1 Mini reader (1) battery pack (2) (3) RFID antenna (4) Arduino Fio module (5) Wifi module (6) Wifi antenna.

Despite these features, inventorising of containers is of importance. It allows to keep track of the whereabouts, content and additional information for later use. For example the individual experimenter can review used materials after the experiment has been conducted, which provides additional cues to reconstruct the experiment. But also more serious problems, like mis-labelled patient samples, cross-contaminations and sample destruction by environmental parameters can be remedied by automating labelling procedures[8, 4, 10]

Technically, tracking of containers is split into attaching and rewriting a marker on a containment and reading this marker. The containers of organic samples, and their markers, need to withstand challenging environmental conditions. For example, they are stored at temperatures below $-80°C$ and sharply accelerated in vacuum transportation tubes. Hand-written and colored adhesive markers are used commonly. However, these are not self-describing and require additional tables that can easily get lost and are hard to share. Fiducial markers, like bar- and QR-codes, are used if infrastructure allows, and require material suitable for wetlabs. Miniature RFID-tags can additionally be used to identify containers. In contrast to fiducial markers, with also allow for human-readable markings, RFID-tags can only be machine-read. Combinations of fiducial- and RFID-techniques can also be found, which allow both human- and machine-readable markers. RFID does provide *non-line-of-sight* and *parallel* reading capabilities, *rewriting* of attached tags, and the potential for *continuous environmental monitoring*. These benefits are the reason why the whole identification and labelling infrastructure can be worn on one's wrist[16].

In this paper we analyze a system which combines a wrist-worn RFID-unit with a head-mounted display for tracking miniature sample containers in wetlab environments. Through voice interaction a user can rewrite and read RFID-tags in the vicinity of his wrist. Thus gaining the ability to focus on the task at hand instead of labelling a container. The acceptability in everyday routines depends on the interaction scheme - two possibilities were compared. For this, seven users were asked to mark containers in a set-up scenario with (1) an *implicit* interaction, which prompts the user whenever a tag is detected near the wrist and (2) an *explicit* interaction which guides its user through the whole labelling and identification process but needs to be initiated by the user itself. Scores for each interaction scheme were elicited with a post-experiment questionnaire on the System Usability Scale (SUS). Furthermore two antennas, one small, flexible and less performant and one large, rigid providing far better performance were compared to find which is more acceptable.

RELATED WORK

The facility in which biological samples are stored are often called Biobanks or Bio-repositories - these are charged with the preservation of patient (and other) samples, their documentation, storage and retrieval. Best practises for Bio-repositories workflows[2] include the barcoding of samples with a unique identifier, together with human-readable information. Electronic records can be connected via this identifier, and location tracking can be implemented in a less cumbersome way via Barcode scanning. A centralized database even allows for keeping track of shipment logs and cross-institutional information sharing. RFID technology is believed to be superior for this task by providing *non-line-of-sight reading*, *read-write* support, *fast parallel reading* capability, and the potential for location, temperature and motion sensing[13]. The latter three are important since they allow to mitigate common errors[8], like tracking of transportation failures, avoidance of unnecessary heating during identification, and to a certain extent the mis-labelling of samples. Location tracking is of special interest since a discrepancy to the electronic record can be automatically detected if samples are stored next to a reading unit. Smart tubes[12], RFID labels in repositories[20], and freezable tags[9] have been reported. All of these reports have looked at fixed "stations" to interact with the inventory system.

The development of wrist-worn RFID reading units is mainly driven by applications in Activity Recognition. Based on the ability of RFID for remote, non-contact identification of objects, specific tasks, e.g. using a hammer, and their accompanying activities can be derived in a reliable fashion[16]. Antenna design is a major challenge: a trade-off between size, flexibility, robustness and wearability has to be found. The placement on the human hand mainly dictates the possible choices. In first iterations the reader was placed on the back of the hand[11, 15, 16] which allowed for reading distances of $1-2cms$. Antennas looped around the wrist[3, 11, 7, 16] have replaced this design. However loop antennas need to be rigidified to keep their performance controllable, a $10-15cms$ reading range with a common $5cm$-patch RFID-tag has been reported. A flexible antenna placed between thumb and index finger[17] was challenged by sweat and by changing (antenna) parameters due to movement. While placing the antenna on the thumb achieves the best reading performance, especially for miniature tags, its attachment point also hinders the movement of the wearer's hand. We therefore decided to compare a flexible antenna worn in the palm, and a rigid loop antenna worn around the wrist.

Simplifying and integrating the identification and labelling of samples has been argued for in other research as well. Boriello et. al. [5, 6, 1] do not only argue for tracking samples, but also the tools used in a micro-biology wet laboratory. This information can be used post-experiment for reconstruction purposes, or during conduction for error checking. In the eLabBench[18] project fiducial markers were registered with a camera below a tabletop. This allowed for rack-based identification of samples. For tube-level identification RFID tags were added to all containers, a reader integrated into the rack communicated with the system via an LED-based active fiducial marker. Both setups allowed for labelling and identification of multiple tubes in parallel.

SYSTEM DESIGN

The presented system is thought to ease the identification and labelling of sample tubes in wet laboratories by using a wrist-worn RFID-unit and tagging single sample tubes. Two tasks are of importance for the experimenter using this system: (1) identifying a sample tube (reading a tag) and (2) labelling a sample tube (writing a tag). Both tasks should be supported in a hands-free manner, during normal laboratory routines, to relieve an experimenter from manual labelling tasks. Currently this task is limited to hand-written or colored stickers with a separate lookup table, or supported by hand interacted label printers. In turn requiring the experimenter to put down all tools and concentrate solely on the labelling or identification task. The design of our hands-free system for identifying sample tubes with RFID is based on these practises and on the principle of reducing the amount of interaction to a safe minimum. Not only single tubes, but multiple correlated ones are typically labelled. This correlation is often a variation of one parameter, for example the amount of concentration of one compound or the heating time of the sample. Labelling a series of tubes is therefore also included in our design.

RFID tags. Throughout this paper, we assume that RFID tags are already attached to sample tubes. Sample tubes count as consumables in a wetlab, and are usually thrown away after usage if not kept for long-term storage. Integrating RFID tags directly into the tube is thinkable, however it is more likely that tags are integrated into some kind of removable attachment - for now. For example, they could be integrated into re-usable protective caps which are routinely used during

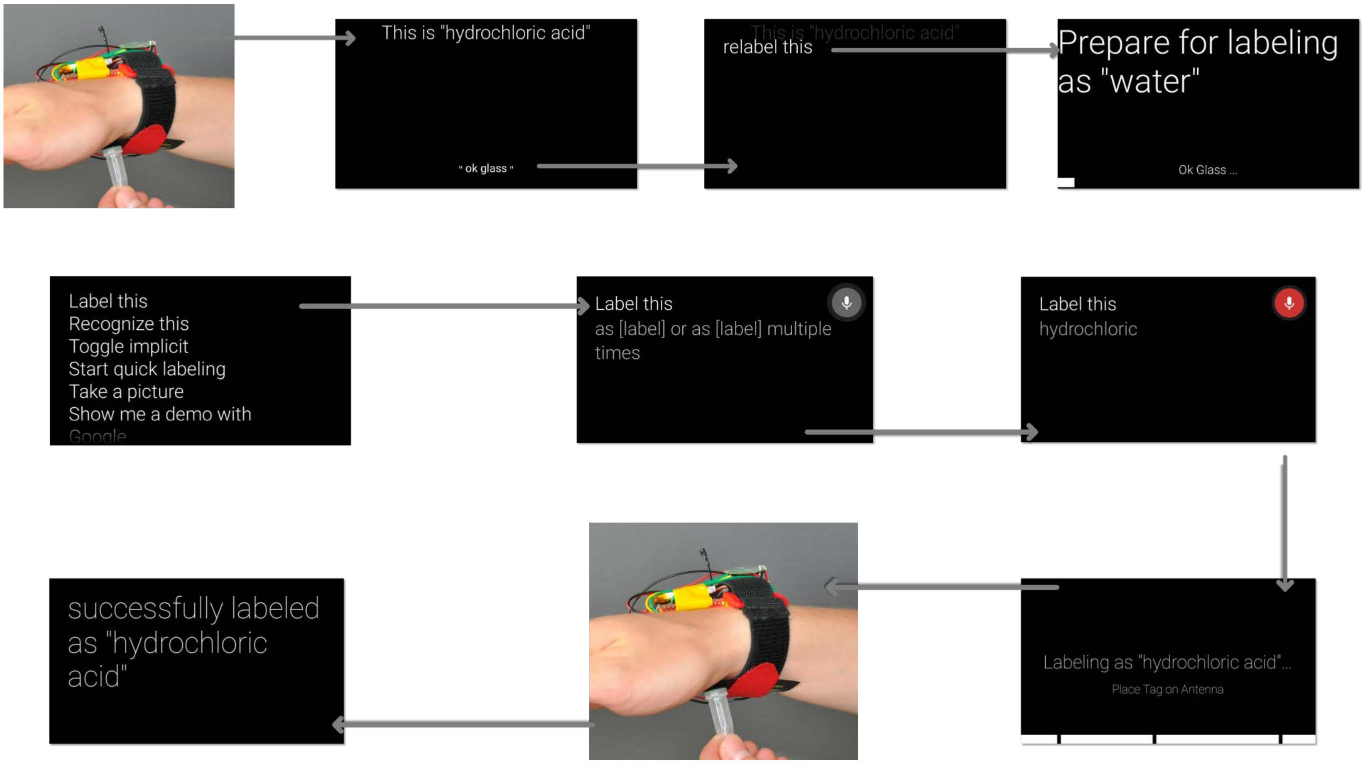

Figure 2. Top figure shows the implicit interaction for retrieving and labelling a sample tube. After a tag has been registered by the RFID reader Google Glass will activate. Visible are the screens as displayed on the screen of Glass. The lower figure part shows the explicit interaction. The major difference is the number of steps that need to be taken and the activation of the RFID reader.

storage and transportation. Since smallest sample tubes have a diameter of only $10mm$, we decided to test tags of according size. Miniature tags[1] (cf. Figure 1) with a diameter of 15 to $5.5mm$ are glued to the top of sample tubes for our prototype. The associated information for each tag is stored in a central database to avoid local RFID storage limitations.

Reader. To test different antennas and attachment points, an off-the-shelf RFID reader module[2] was used and hooked up to a micro-controller. The reader could be operated in *continuous* and *on-demand* mode. In continuous mode, the reader actively scans at $20Hz$, which draws $86mA$ of power. On-demand mode draws the same power, albeit only when the user explicitly interacts with the system. Implicit interaction requires the reader to operate in continuous mode, since a detected tag is an interaction cue. A slower rate of $.5 - 1Hz$ can be used however, since a delay of $4 - 2secs$ can be assumed to be tolerable.

Connection. The wrist-worn reader does not include any user interface. Google Glass, specifically a voice activated interface, allows for interaction. The connection between Glass and the reader is established via a WiFi interface. In principle this should allow the system to be used in different scenarios as well (e.g. statically placed reader), and is easier to integrate into existing applications. The wrist unit provides a TCP server, that only operates the RFID reader while a client is connected. In continuous mode a tag's identifier is directly transported to the client, while in on-demand mode, a read needs to be requested first. With this design energy-saving modes can be readily implemented.

Table 1. Reading times and maximum distance ($0mm$ for those that need direct contact to the antenna) for each used RFID tag.

	large antenna		small antenna	
tag	distance	time	distance	time
d14-special	5mm	.7s	12mm	.7s
d14-tag	20mm	.8s	15mm	.6s
d7-tag	0mm	.6s	0mm	.6s
d6.7-tag	0mm	.6s	0mm	.6s
sticker	30mm	.8s	100mm	.7s

Interaction. Two interactions mechanism are provided. Both support the same two earlier mentioned tasks, however the *implicit* one requires a less interaction albeit requiring more energy. Constant operation of the reader unit is required for this scheme. We hypothesize that the advantages of an implicit interaction outweighs a shorter system run-time.

implicit interaction. This interaction mechanism refers to an interaction that is initiated by placing a tag next to the RFID reader. Google Glass is activated during tag detection, and the current label is read and displayed. An optional voice activated menu allows to re-label the current sample tube afterwards (cf. Figure 2 top).

[1] manufactured by MicroSensys GmbH `http://www.microsensys.de/`

[2] Skyetec M1 Mini

explicit interaction. An identification or labelling task has to be manually started. A voice menu on Google Glass supports this by providing key phrases, after Glass has been activated by head movements. Afterwards the user is guided through the whole process of tag detection, i.e. placing the tag on the reader, and displaying the results (cf. Figure 2 bottom). After a tag has been detected, the interaction is the same as for the implicit interaction scheme.

Both techniques differ in the time spent for tag detection. In the implicit case the time spent for reading a tag is ”hidden” from the user, by activating interaction possibilities only after successful detection. The explicit interaction provides more feedback to the user, giving its user a hint of what to do next if tag detection fails. However, we assume that this advantage will disappear with user training.

USER STUDY

A user study to shed light on which antenna is acceptable, and which interaction mechanism is more usable was conducted.

Participants We recruited seven students at the TU Darmstadt. They were aged between 25 and 35 years, one female and eight male. For all of them a technical affinity could be assumed, and they were partly experienced with Google Glass.

Material Two small sample tubes (diameter $8mm$) and two large tubes (diameter $13mm$) were provided. Small tubes were tagged with a d6 and d6.7 tag, while the large ones were tagged with d14 tags. Tag numbers refer to their diameter, and Table 1 highlights that small tags do not allow for non-contact reading. A water bottle tagged with a $25x25mm$ standard tag was also provided to emulate a large container in a wetlab. For transferring liquids a pipette was provided. Google Glass and our wrist-worn RFID-reader prototype was worn by each participant.

Procedure Each participant was outfitted with Glass and our wrist-worn RFID-reader. A small introduction to the interaction scheme was given. Afterwards the participant was asked to identify and re-label the D14-tagged tube. The next task was to label a series of all containers (including the water bottle), in order to test the series labelling process. The final task was to transfer water into a D14-tube and label it accordingly.

These task sets were repeated for each interaction scheme and each antenna, four times in total. Starting with either explicit or implicit was counter-balanced over all participants, selected at random by the examiner. The rigid antenna was always tested first. After each test, the participants were asked to complete a System Usability Scale (SUS) and were asked for general remarks.

Results Implicit interaction (81.1) scored only slightly higher than explicit interaction (79.1). When looking at Figure 3 implicit interaction is scored higher when introduced after explicit interaction. We assume that this is due a familiarization with the system. While implicit interaction is not self-explanatory, it becomes much more obvious when introduced after the more verbose explicit interaction. This confirms our earlier assumption that user training can replace more explicit

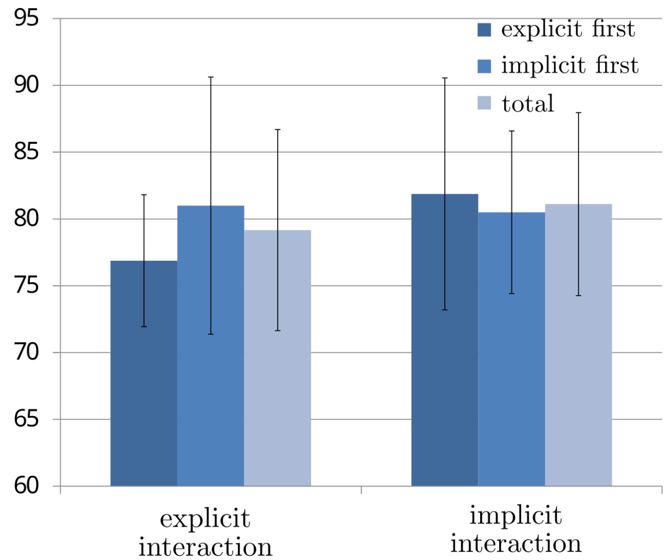

Figure 3. Mean and standard deviation of SUS scores. Total score, and score when explicit or implicit interaction was done first are shown. Implicit interaction generally scores higher, especially when introduced last.

feedback. Participants identified a major speed-up for identification tasks as one of the strengths of implicit interaction. However, the missing feedback when tags were not read, even though they were next to the reader, was mentioned as a shortcoming, mainly by those participant that have started with implicit interaction. A reliable reading process, when using RFID readers for initiating interaction is therefore of major concern.

Only one participant scored the large, rigid antenna higher than the small flexible one, even though it provides a better reading performance. Beside the concerns of comfort, it was unclear for most participants how tags should be brought into contact with the looped antenna. The small antenna made this clearer, since it was attached to a flat surface, rather then spun around the wrist. This is only an issue for small tags, that have to be used on small containers, larger tags also provide better reading performance and do not require direct contact. A combination of both antennas, for example one integrated in the wrist-band and one on the wrist, could be of benefit.

CONCLUSION

Tracking sample tubes, and materials in wet laboratories is of major concern. To allow for tracking of these samples, an RFID based solution with a wrist-worn reader and a head-mounted display is introduced here. Two antennas, as well as two interaction schemes have been compared during an in-lab study with seven participants. Antenna comfort was scored more important than performance, and a higher system usability score was achieved for an interaction-minimal operation scheme. The proposed system does not only allow to track samples after they have been exposed to harsh environmental conditions, but also allows for a limited activity recognition by identifying used tools while conducting experiments.

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