Using RFID tags as reference for phone location and orientation in daily life

F. Wahl and O. Amft
ACTLab
Signal Processing Systems, TU Eindhoven
http://actlab.ele.tue.nl
{f.h.wahl, amft}@tue.nl

ABSTRACT
This paper investigates a novel approach to obtain location and orientation annotation for smartphones in real-life recordings. We attached RFID tags to places where phones are located in daily life, such as pockets and backpacks. The RFID reader integrated in modern smartphones was used to continuously scan for registered tags. In a first evaluation across several full-day recordings and using nine locations, our approach achieved an accuracy of 80 % when compared to a manual diary. Only 5.3 % of all tags were missed. We conclude that RFID-based location and orientation tagging is a viable option to obtain ground truth reference for real-life activity recognition algorithm developments.

Keywords
NFC, ground truth, unsupervised annotation

1. INTRODUCTION
Smartphones have become a prospective platform for context recognition due to their integrated sensing and processing features. Different recognition approaches and applications have been developed to estimate context information from the phone's sensors in daily life, including user location and activities, e.g. [1,5,9]. To develop recognition techniques and to evaluate their performance, ground truth about the context information is essential. For supervised recognition algorithms, ground truth is used, e.g. to extract learning data. However, even unsupervised recognition techniques require a ground truth reference to estimate algorithm performance.

In lab-focused studies, it is practical to acquire ground truth on location and activities from an observer's annotations. Due to cost and effort, observer-based annotations are however infeasible for real-life studies. Although often used, participant self-reports of location and activities are known to have limited accuracy. While real-life studies are key to evaluate smartphone-based sensing and recognition, no high-quality context annotation method is readily available. Hence, novel annotation methods are needed that can be seamlessly integrated into the daily life of users. Techniques that could provide annotations automatically, at minimal user effort are preferred.

AH'13, March 07 – 08 2013, Stuttgart, Germany

Recently radio-frequency identification (RFID) readers have become an integrated feature of smartphones through the adoption of Near-field communication (NFC) standards for wireless payment. RFID tags provide unique signatures when scanned with the smartphone-integrated RFID reader close by. Compatible RFID tags that can be powered by the RFID reader are cheap and available in various shapes and sizes, from credit card formats to flexible stick-on patches. Most RFID tags have an adhesive back which allows fast and simple placement on objects and do not require additional batteries. From RFID tags positioned where a smartphone is frequently placed, a smartphone application using the phone's RFID reader could identify locations automatically. Thus, equipping frequently used phone locations with RFID tags could profoundly decrease annotation effort in smartphone evaluation studies and improve detail of ground truth information for recognition algorithm evaluations.

In this paper, we investigate whether RFID tags could be used to obtain fine-grained tagging of smartphone locations. This method could be used as tool to acquire ground truth. The close vicinity of RFID tags and a smartphone when reading tags are ideal properties for tagging the phone's location and avoiding reading multiple tags simultaneously. In turn, detailed location information are retrievable, such as "in a pants pocket" or "on the desk", that will provide reference data for context recognition. We further explore RFID tagging to reveal a phone's orientation, which is relevant for motion-based context analysis. We consider our approach as a useful procedure for context recognition algorithm development and validation. Thus, RFID tags would be used by evaluation study participants only, not during regular deployment.

In particular, this paper makes the following contributions:

1. We detail how RFID tag signatures can be continuously acquired on standard smartphones using the built-in RFID reader. We show how RFID tags could be placed at relevant places to tag phone location, including clothing and environments, such as the desk or car.

2. We evaluate the RFID tag detection performance in a realistic real-life study across several recording days. We investigate two conditions: (1) matching of RFID signatures to manual, self-reported reference, and (2) determining the phone's orientation using a denser distribution of RFID tags.

2. RELATED WORK

RFID tags have been frequently used for object detection, e.g. to infer morning routine using a wrist-mounted RFID reader and tagged household items [6]. In their work, the authors recognised activities from identified tags in the reader's vicinity and their detection sequence. Perkowitz et al. [7] used tagged objects and a wrist-worn RFID reader to recognise activities based on web-mined object use models. These works aimed at recognising activities and objects from observed RFID tags. In contrast, our approach is to use the smartphone-integrated RFID reader to automatically determine the phone location. In our work, RFID tags are placed at fixed positions where the phone is placed in everyday life.

Estimating phone location is of great interest in activity and context recognition. Kunze and Lukowicz [4] considered an approach, where the phone was used to actively probe the environment to determine location. In their work, a loudspeaker and vibration motor was used to generate sounds and the phone's microphone and acceleration sensors were used for recording. Their approach required trained pattern models from predefined phone locations. Current and future smartphones will provide integrated RFID readers since the NFC standard was adopted for new wireless payment methods. Thus, instead of placing readers in each location and using RFID-tagged phones, as suggested in [4], NFC allows us to use the smartphone as a reading device and distribute RFID tags.

3. SENSING APPROACH

RFID tags are very cost efficient and available in many different shapes, sizes, and stick-on versions that can be easily attached to clothing or other objects. These properties make RFID tags ideal candidates for tagging places where a phone can be kept, including pockets, furniture, and other storage compartments.

Since a phone's RF detection range is limited to a few millimetres, RFID tagging can be used to obtain fine-grained location information. Here, we use the short-range detection to determine a phone's orientation in pockets. Depending on the orientation, in which the phone is placed in a pocket, the phone's rear side will face one tag that is subsequently scanned. The RFID tag at the opposite pocket side facing the screen will not be detected.

We implemented a RFID reading application on top of an Android-ported version of the open-source Context Recognition Network Toolbox (CRNT) [2]. When a tag enters the proximity of the reader it is scanned and registered as the new location. The tag-recording framework was configured to create log entries each time a registered RFID tag was read, containing system time and tag identifier.

By default, smartphones will enable the RFID reader only when the screen is active and unlocked. However, for our approach it was necessary to continuously operate the reader independently from the screen's state. Therefore the Android phone was rooted and a patch was applied[1]. Compared to Bluetooth 4, NFC consumes less power during standby[2] and is rated at <15 mA while reading tags.

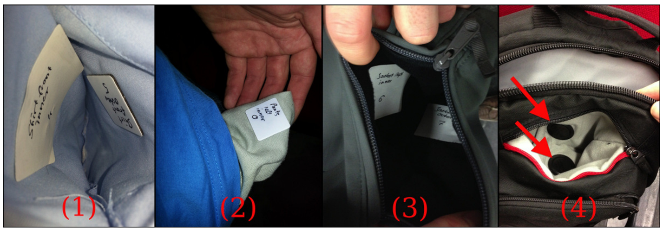

Figure 1: Selected RFID tag attachment options evaluated in this work to automatically tag phone locations: (1) shirt pocket, (2) pants pocket, (3) jacket pocket, (4) backpack cell phone compartment. In total, 9 locations were monitored with 15 tags.

4. EVALUATION STUDY

To evaluate our approach in a realistic setting, a study was set up, including nine locations equipped with 15 RFID tags. Our recordings span over three full days of one user. On each day recordings were started in the morning and continued throughout the day to include any phone location changes. A total of 76 location changes were recognized over a total recording duration of 58.3 hours.

To validate our tagging approach, manual paper-based diaries were used. Upon phone location changes, the user added a diary entry stating time of the change (hours and minutes) and the new phone location. To minimise time differences between diary time stamp and tag recordings, the user was considering the phone's clock for the diary. We consider that for the focused time span of three days, the paper-based diary has been suitable and could serve as accurate reference.

For this evaluation study, a total of nine different places were tagged. Out of these, six locations where the user could place the phone in two orientations, were tagged with RFIDs on each side to face the phone's reader. Hence, using two RFID tags allows us to obtain more detailed information about the phone's orientation rather than the location only. In principle, there is no limitation for the number of tags associated with one location.

From the survey conducted in [3] the most common locations of mobile phones were derived. As our user was male, we decided to tag the pants' front pockets, the shirt pocket, and jacket pockets. Besides worn clothes, we also equipped the backpack cell phone compartment, the office desk, the phone's night stand, and the phone compartment in the user's car with RFID tags.

Figure 1 illustrates the RFID tag placement for selected locations. The tag placement was made on the cloth's inside,

[1]http://www.jayceooi.com/2012/07/30/enable-nfc-on-locked-off-screen-for-samsung-galaxy-s3/
[2]http://www.nearfieldcommunication.org/bluetooth.html

thus did not influence external appearance. The tag placement did not impact the use of pockets or the smartphone.

5. DATA ANALYSIS AND RESULTS

In this section we present performance results from our evaluation study for detecting individual locations and detecting individual RFIDs (estimating orientation). To evaluate location detection performance, we combined readings from RFID tags at the same location. Table 1 summarises all tagged locations and how often the phone was placed at each location according to the diary.

Table 1: Phone locations and number of placements at each location in our evaluation study.

ID	Phone location	Recorded instances
1/2	Pants pocket left (inner/outer)	2/4
3/4	Pants pocket right inner (inner/outer)	5/8
5/6	Shirt pocket (inner/outer)	7/5
7/8	Jacket left pocket (inner/outer)	4/1
9/10	Jacket right pocket (inner/outer)	3/1
11/12	Backpack phone pocket (inner/outer)	5/6
13	Office desk	12
14	Night stand	7
15	Vehicle	6
Total		76

For this analysis we consider two error types: (1) location detection errors due to RFID tags missed by the phone's reader, and (2) tagging bounds jitter, e.g. due to delayed reading of RFID tags compared to the time stamp recorded in the user's diary. A tagging boundary jitter in the range of less than one minute occurred in our study data by design, since RFID tags were sampled with a frequency of $f_s = 1\ Hz$, but the user's diary was acquired at a minute-by-minute resolution only. Both, jitter errors and missed tags could occur if tags are placed unfavourably to be read by the phone. We found that with some experience in tag placement, the reading rate could be improved as described in Section 6.

5.1 Results per location

We used confusion matrices to analyse RFID tag identification accuracy. The confusion was determined by a sample-wise comparison of RFID tags that were read to the user's diary. Thus, the main diagonal of the confusion matrix shows both jitter and missed tags error types.

Figure 2 shows the confusion matrix for identifying locations after combining tag readings that represent the same location. In 4 out of 9 locations an instance-normalised accuracy of 90 % or more was achieved, while only for one location less than 74 % was obtained. Tag confusion among locations depends on the order in which the locations were used in the dataset. In particular, the 14 % confusion between the left pocket and the vehicle shows an example of a jitter error. Here the user moved the phone from the vehicle to the left pants pocket while the tag was detected with a delay.

The miss error rates per location are shown in Figure 3. Only 3 out of 9 locations showed misses, where the largest miss error rates occurred for the left pocket (miss rate: 16.67 %).

5.2 Results per orientation

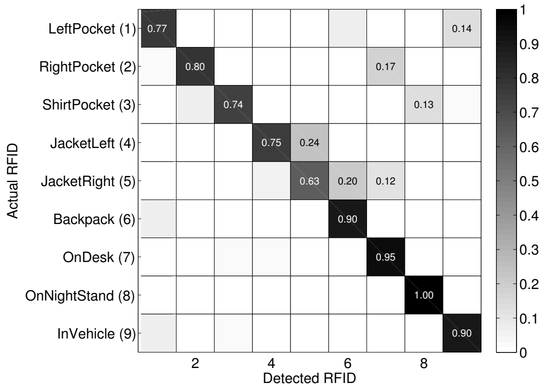

Figure 2: Confusion matrix for the sample-wise *per location* analysis that illustrates the performance of determining the phone's location. The main diagonal shows both jitter and misses errors. Overall, an instance-normalised accuracy of 83 % was achieved.

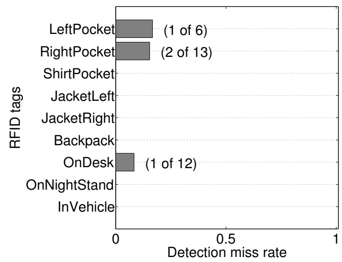

Figure 3: Miss error rate for the per location analysis. Only 3 out of 9 locations showed misses.

Our results per orientation (per RFID tag) illustrate the performance of determining the phone's orientation in pockets in addition to the location. Figure 4 shows a confusion matrix with actual and detected RFIDs.

The results for the per orientation analysis showed an overall instance-normalised accuracy of 80 %. In 6 out of 15 tags an accuracy of 95 % or higher and in 13 out of 15 classes an accuracy of 70 % or more was achieved.

Figure 5 shows the miss error rate per orientation and thus per RFID tag. Miss errors occurred only in 3 out of 12 tags, while the remaining tags were detected at every phone placement. Miss rates of 25 % were found for the outer tags of the pant pockets that may be explained by an unfavourable tag placement.

6. CONCLUSION AND FUTURE WORK

We introduced a new approach to tag location and orientation of smartphones in real-life studies. We used the built-in RFID reader in standard phones and tags placed at locations where the phone is kept. We consider our approach as essential tool for developing and evaluating context recognition algorithms in realistic conditions since there is currently no viable reference available.

Our evaluation showed an overall RFID tag miss error rate of

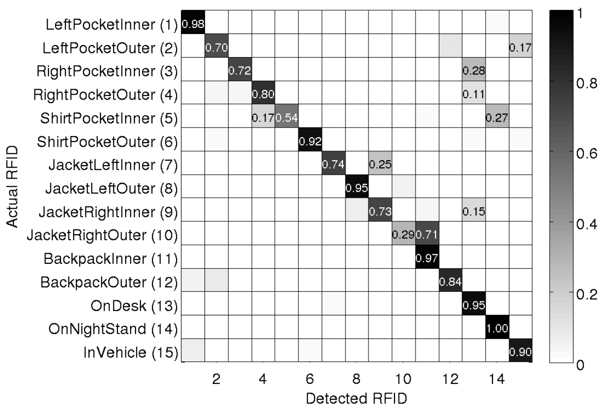

Figure 4: Confusion matrix of the sample-wise *per orientation* analysis that illustrates the performance of identifying each RFID in pockets. The main diagonal shows both jitter and misses errors. Overall, an instance-normalised accuracy of 80 % was achieved.

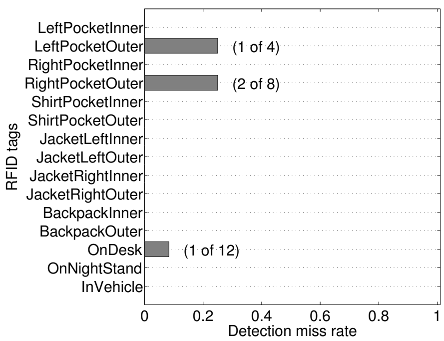

Figure 5: Miss error rate for the per orientation (per RFID) analysis. 3 out of 12 tags showed misses.

5.3 %. Only 3 out of 9 locations had missed instances. Overall, accuracy was above 80 % for both per location and per orientation analyses and considering miss and jitter errors. This result confirms the general feasibility of our approach. In future investigations, tag placement in clothing could be further tuned to maximise accuracy. E.g., in pants pockets tags could be glued at the pocket's inner textile to avoid ripping tags off while carrying items. Alternatively, washable tags could be sewn into the pockets.

Even at current accuracy results, our approach already outperforms simple activity self-reports, reported at tremendous error rates when used for longer than a few days, e.g. in [8]. While the present evaluation focused on obtaining an accurate manual diary as reference, further studies should target multiple participants and longer-term evaluations.

We consider that our *per location* analysis will be widely applicable for studies that require reference data on the user's phone location. Phone locations can be freely customised by users, since RFID tags can be placed according to personal phone usage behaviour. The number of phone locations could be easily expanded by adding RFID tags for purses, kitchen table, etc. The overall accuracy of our approach will not be affected by additional locations.

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