

Publication V

Henry Rimminen, Matti Linnavuo, and Raimo Sepponen. 2010. Human identification and localization using active capacitive RFID tags and an electric field floor sensor. *International Review of Electrical Engineering*, volume 5, number 3, pages 1061-1068.

© 2010 Praise Worthy Prize

Quoted with the permission of the Publisher Praise Worthy Prize S. r. l.

Human Identification and Localization Using Active Capacitive RFID Tags and an Electric Field Floor Sensor

Henry Rimminen, Matti Linnavuo, Raimo Sepponen

Abstract – In this study an active capacitive RFID tag embedded in a shoe was developed. The tags are identified and located with an existing near field imaging (NFI) floor sensor. The NFI system can detect the location of a person in an indoor environment, but does not provide identification. The goal was to identify a person when he or she enters a room. This is used to identify staff in nursing homes that are already equipped with the NFI floor sensor. The tag alters the impedance seen by the floor using ASK modulation. Adapted FMO encoding with a symbol rate of 200 bit/s was used. An SNR of 17 was reached at floor level and the read range was 5 mm. With fixed location the success rate was 100% and the latency was 0.4 s. With random locations the performance was 93%. A two-week test period in a nursing home showed that a 93% success rate can also be achieved in everyday use. The results promote the intended use. **Copyright © 2010 Praise Worthy Prize S.r.l. - All rights reserved.**

Keywords: Capacitive RFID, Electric Field Measurement, Indoor Positioning

I. Introduction

Ambient intelligence and context-aware computing in an indoor environment can be applied to interactive environments, passage control, household automation, and health care informatics. To get the full benefit from these applications, person positioning and identification are needed. The positioning should be accurate and the identity should be continuously tracked. This requires special techniques because e.g. GPS coverage is not available [1].

We present a new way to localize and identify people indoors, which uses the existing infrastructure of a near field imaging (NFI) floor sensor. A matrix of thin planar electrodes under the floor senses the locations of people by measuring electric impedance at a frequency of 90 kHz [2]. The persons being monitored need not wear any tags or similar devices, which makes the system unobtrusive. However, some applications would benefit from person identification. An active capacitive RFID tag embedded in a shoe was developed to add an identification feature to the NFI system. The intended use is to localize and identify staff in a nursing home without special attention on the part of the user. We present the development of the tag, and the protocol, as well as the performance measurements in the lab and in an actual nursing home.

1.1. Related Work

Indoor positioning is typically performed by computer vision. The positioning accuracy lies within 18-30cm [3], [4].

However when identification is required, the person must wear a visual ID tag, such as a 2D barcode. The requirement for successful identification is that the angle between the normal of the tag and the camera's line of sight is no more than 70 degrees [5]. Furthermore, visual tags do not tolerate shading by crowds or furniture.

Biometric identification is possible by observing the person's cadence with pressure-sensitive floors [6]-[8] or with computer vision [9], but these systems must be trained before use. Computer vision also enables facial recognition to be performed at close ranges, but requires near-full-frontal images of the person's face and is disturbed by shading [10].

RFID positioning is an emerging indoor positioning method. The person can wear a reader and tags are placed in the environment [11], [12]. With UHF tags the accuracy is around 2 m [12], depending on the density of the tags. Since this method requires a reader to be worn and an RF uplink, the power consumption is high and a large battery is required. This is avoided by fixing the reader and wearing a passive tag [13], but then the positioning becomes point-oriented and only discrete locations can be obtained.

The use of active transponders is another common way to localize and identify people. The use of visible [14] or infrared light [15] is feasible, but these methods are disturbed by shading. Radio frequency transponders that use sparsely distributed networks such as WLAN [16], Bluetooth [17], ZigBee [18], or mobile phone networks [19] produce accuracies between 1.6 and 8.7m. This may not be enough to determine if a person is inside a certain room, not to speak in a specific location in the room. Active transponders based on Ultrasound [20],

[21], or UWB [22] produce high accuracies (2-45cm), but require specific and relative complex infrastructures to be built into the environment. This increases the threshold to be taken in use.

Electric field floor sensing has been used for person tracking since the mid-nineties [23]. The positioning accuracy is high and it varies from 21 cm (our work [24]) to 41 cm [25]. Digital communication between the floor or furniture and a person has been studied by placing a transmitter in a belt or a shoe or by carrying it by hand [26]-[28]. A method for positioning and identifying a person with multiple electrodes on the floor, which relies solely on digital information, has also been suggested [28]. Thus people in the same room who have no transponders are not detected or positioned. Furthermore, the transponder used was a bulky PDA and the accuracy was limited to one meter.

The proposed method using NFI floor and capacitive tags avoids the above-mentioned disadvantages of related work. Such as the other high-accuracy techniques (Ultrasound or UWB), the proposed method also requires a very specific infrastructure. However, when the NFI floor has already been installed, the threshold to use the shoe tag is non-existent.

The NFI infrastructure is in actual use in several locations in Finland. The identification system was tested in a large nursing home in Helsinki, Finland, where the NFI system has been installed in the rooms of 60 residents [29]. The NFI infrastructure has obvious benefits in care for the elderly: detection of getting out of bed, exiting the room, and of falls [30]. The system is commercially available at a cost of approximately \$30 per square meter.

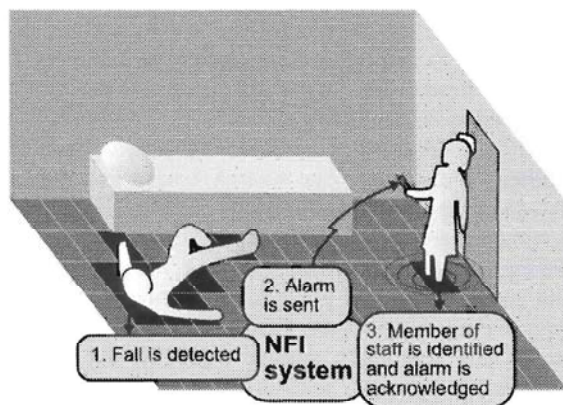


Fig. 1. One application scenario of the NFI floor using the shoe tag

1.2. Application of the Method

The intended application of the identification feature is to detect when a staff member wearing a tag enters a room equipped with an NFI floor. This is useful, for example, when a fall has been detected in that room and an alarm has been sent to the cell phone of a nurse. When the nurse enters the room to help the resident, the

alarm is acknowledged and further alarms are temporarily turned off; see Fig. 1. Other staff members can concentrate on their own current tasks as they see that the alarm has been acknowledged.

Other applications could include identifying and positioning the residents or ward equipment, providing context-related information to the staff, and recording the work routines of the staff. In this paper, we concentrate solely on measuring the performance of the room entry detection to illustrate the cooperation of the tag and the floor. The other possible applications, including the identification of people, would merely require changes to the software. Identifying equipment would require a new design for the antennas and casing of the tag.

II. Materials and Methods

II.1. Tag Coupling

The NFI floor sensor system operates at a frequency of 90 kHz and measures the impedance of a single sensor element with reference to all other sensor elements. Each sensor element in a matrix is scanned sequentially while the others are grounded. The body of a person is sensed by observing changes in the impedance [2]; see Fig. 2, part (a). The sensor under measurement is referred to as the hot sensor, and the grounded ones are referred to as the cold sensors. As the goal was to provide identification with no additional infrastructure, the tag must couple to the floor sensors and modulate the existing electric field. The following two modes of coupling were studied here.

Mode A: the most obvious way is to modulate the impedance between two parallel conductive surfaces [31], which are coupled with two neighboring sensors (hot & cold) in the floor; see Fig. 2, part (b). This mode requires one conductive plate under the heel and one under the toes.

Mode B: as the person's body acts as a transmitter while standing on the hot sensor [23], the impedance seen by the floor can be changed by modulating the impedance between the sensor and the body; see Fig. 2, part (c). This mode requires one conductive plate under the sole of the shoe and one on the insole to form a galvanic coupling to the person.

II.2. Tag Implementation

The tag should function as long as possible without recharging. To preserve energy and allow a small battery, the tag should be motion-activated.

The tag that was implemented uses a low-power microcontroller (ATtiny13-20SU, Atmel Corp.), which is motion-activated using a commercial vibration switch (CM1800-1, Assemtech Europe Ltd.).

Three rechargeable 1.2V Ni-MH button cells in series are used to power the tag (Varta V 20 HR, Microbatterie GmbH).

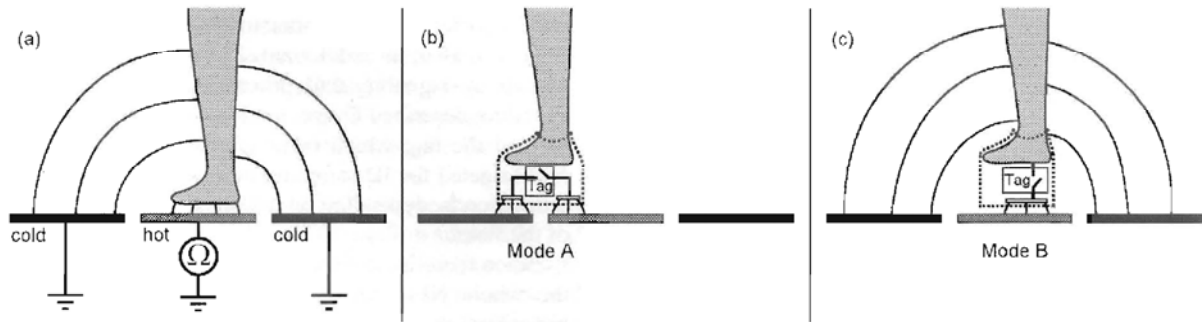


Fig. 2. Coupling modes of the proposed method: (a) A person wearing no tag; (b) Mode A: the tag modulates the impedance between two neighboring sensors (hot & cold). (c) Mode B: the tag modulates the impedance between the hot sensor and the person

The current consumption of the tag was found to be 37 μA in active mode (I_{act}) and 30 nA in sleep mode (I_{idle}). The theoretical battery life t_{batt} can be calculated as in (1):

$$t_{batt} = \frac{C_{batt}}{\frac{I_{act}}{24 h} I_{act} + \frac{24 h - I_{act}}{24 h} I_{idle} + I_{self-discharge}} \quad (1)$$

where the battery capacity C_{batt} is 22 mAh, the self-discharge current $I_{self-discharge}$ is 6 μA , and the active time duration per day t_{act} is eight hours. According to (1), the device should work for 50 days without recharging.

The physical implementation of the tag is shown in Fig. 3. The diameter is 50 mm and the thickness is 5 mm. Epoxy casting is used to protect the components. The connector is used for programming and charging the tag. The antenna plates in the shoes are connected to the modulation output with durable steel wires, since copper wiring was found to break in use.

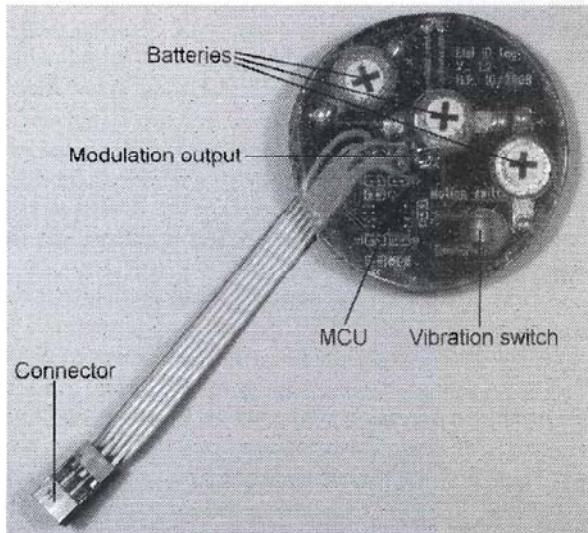


Fig. 3. The implementation of the tag

Fig. 4, part (a) shows the tag being embedded into a shoe. It is placed in a cavity in the heel and is later covered with a rubber outsole. The connector is

accessible on the side of the shoe. The ground plane of the tag's circuit board acts as the heel plate and couples to the hot sensor. Coupling mode A needs a separate plate under the toes, which is made of a dense steel mesh. Coupling mode B needs a galvanic contact to the person. Two types of conductors on the insole were tried out: strips of conductive fabric glued onto the insole, and a stainless steel plate embedded in the insole; see Fig. 4, part (b). The conductive fabric was found to be more comfortable and worked well.

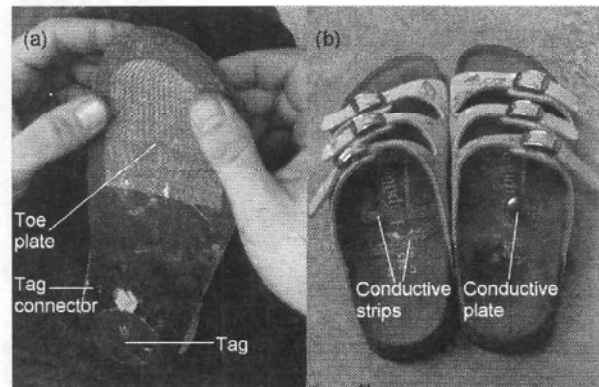


Fig. 4. Implementation of the shoes. (a) The tag is placed in a cavity in the heel. The toe plate is made out of a steel mesh. (b) The galvanic coupling to the person can be made with conductive fabric strips or with a conductive plate

11.3. Signals and Encoding

The tag can transmit data by using coupling modes A or B or both. It creates ASK modulation by shorting the heel plate and the selected antenna plate and then leaving it floating. One I/O pin of the microcontroller performs the switching, as it is capable of changing its state between a high and a low impedance to the tag's circuit ground. Typical signals recorded with the NFI floor sensor are presented in Fig. 5. The test subject stepped on the center of a sensor and stood still for a couple of seconds and then moved away. A normal step can be seen as a 19-Ohm drop in the signal. A step with the tagged shoe can be seen as a 25-Ohm drop containing a data burst. As soon as the person lifts his foot the ASK amplitude weakens rapidly.

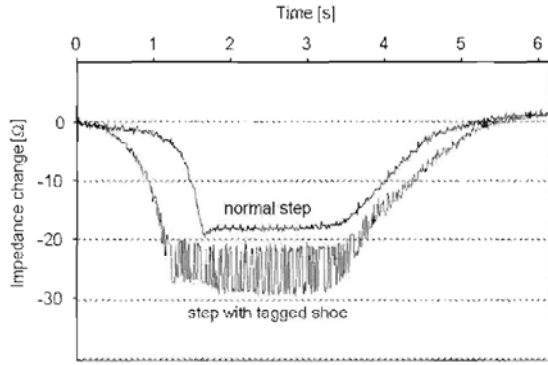


Fig. 5. Typical signals. The upper signal is without a tag. The lower signal is with a shoe tag

A close-up of a successfully-detected data burst can be seen in Fig. 6. An adapted FM0 encoding with a symbol rate of 200 symbols per second was used. The symbol rate is currently limited by the sampling rate of the NFI floor sensor, which is 1.2 kilo-samples per second.

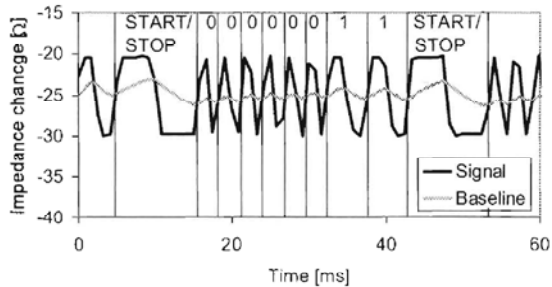


Fig. 6. Successfully detected tag signal. The ID number '3' (0000 0011) is transmitted using adapted FM0 encoding

The ID of the tag is stored as an 8-bit number in the EEPROM of the microcontroller. The ID is transmitted continuously and the cycles are separated by *start/stop* marks. Normally, the symbols in FM0 are of equal length [32], but because of the low sample rate, we needed to increase selectivity by increasing the differences between the symbol durations. A ratio of 1:2:4 was used for the symbols *zero*, *one*, and *start/stop*; see Fig. 6. Symbols are detected by timing the rising crossings of the signal and the signal baseline. The baseline is a single-pole IIR filtration with a coefficient of 0.2. The filtering is essential since signals during walking contain significant drift; see Fig. 5. The validity of the ID number is checked by verifying the correct amount of symbols between the *start/stop* marks. No checksum was used because the transmission time had to be minimized. However, a checksum will be introduced in future designs if the symbol rate can be increased.

II.4. Scanning Procedure

The 19-m² test room was completely covered with a 9 x 16 sensor matrix. The floor's update rate is 4.5 Hz,

which corresponds to a maximum latency of 222 ms. There is also an additional 215-ms delay, which is caused by signaling and processing delays. Using the encoding described above, a 128-point sample is needed to read the tag, which takes up 106 ms. Therefore the foot targeted for ID sampling must stay still for 321-543 milliseconds, depending on the phase of the update cycle of the floor.

Since there is no time to constantly search for IDs in the whole NFI sensor matrix, the following ID scan procedure was developed for this application. As a person typically activates a couple of sensors at a time, the sensor nearest to the centroid of this pattern is subjected to the ID sampling. Three sequential attempts are performed on each person in the room. If one read event is successful, the ID number is attached to the person and the location is tracked using dedicated algorithms [24]. Eventually, the ID can be lost because of multiple targets merging when people come into close proximity to each other. Therefore the IDs of all targets are updated every fifteen seconds.

Younger adults may have walking speeds up to 1.5 m/s [11], which means that the sensor targeted for sampling lags up to 0.5-0.8 meters behind the person. Therefore, the tags are seldom detected during walking.

II.5. In-house Tests

To characterize the technique, the maximum read range and SNR were measured using different coupling modes. A human body phantom described in our earlier work was used [2], because it allowed the tag to be elevated in 0.5-millimeter steps. The tag was elevated until the ID was unreadable or an incorrect ID number was read. The elevation was measured from the surface of the floor. It consisted of 3-mm PVC flooring, which was secured on top of the NFI sensors. The following coupling modes were used: A, B, and A and B together.

The next step was to measure a success rate and a detection delay in a fixed location and in a random location. The success rate is the proportion of correctly identified test events in all test events. The detection delay is the time between the start of the event and the first successful identification.

A real person wore the tagged shoes and entered the test room, stepping on fixed footprints placed in optimal positions in relation to the sensors. The test was repeated 100 times using coupling mode B in both shoes. The test was also performed in 100 random locations and was repeated five times using different coupling modes; B in one shoe, B in both shoes, A in one shoe, A and B in one shoe, and A and B in both shoes. The results were compared to simulations, which were based on the 2D geometry of the sensor matrix.

II.6. Field Test

The field test was performed in a ward for the

demented in the Kustaankartano center for the elderly in Helsinki, Finland. The tagged shoes were issued to two nurses, and two rooms that each had two actual residents were configured to scan the tags. The coupling mode to be used in the shoes was determined on the basis of the in-house tests.

As the test was intended to last two weeks, we could not observe the test in person. To confirm successful and phantom detections of the tags, we installed buttons with indicator lights in the rooms. The nurses were instructed to press the button and confirm that the indicator light came on every time they entered the room wearing the shoes. They were also instructed to press the button when leaving and confirm that the indicator light went off. The state of the indicator light was logged, as were the ID numbers read with the floor. The criterion for successful tag detection was a correct ID number and it had to be detected while the indicator light in that room was on.

The application presented in Fig. 1 was also used in the field test. Its usefulness was evaluated on the basis of the feedback from the nurses.

III. Experimental Results

III.1. In-house Tests

The maximal read ranges of each coupling mode are shown with dashed vertical lines in Fig. 7. SNR values are shown as a function of the tag elevation from the floor. The read ranges varied from 3 to 5 mm. While the shoe was touching the floor, the SNR values varied from 11.6 to 16.9.

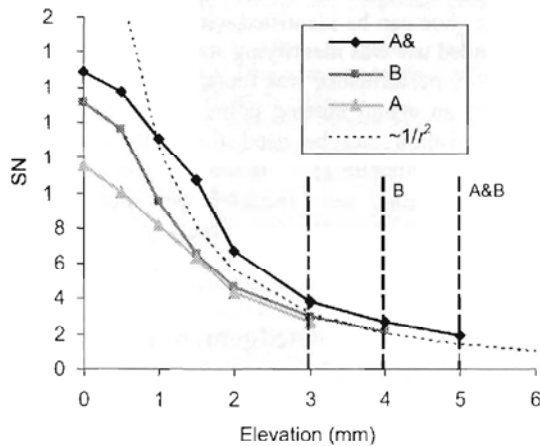


Fig. 7. SNR (linear scale) as a function of height of the tag from the floor. Maximal read ranges are marked with dashed vertical lines. The dotted trace shows a fitted curve proportional to $1/r^2$

The fixed location test indicated perfect performance. All of the 100 events were detected correctly. No false positives or incorrect ID numbers were detected. The average detection delay was 430 milliseconds, with a standard deviation of 130 milliseconds.

The results of the random location test are shown in Table I. Simulations show the expected values based on the 2D geometry. Since the best success rate was obtained by using coupling modes A and B in both shoes, this configuration was used in the field test.

TABLE I
SUCCESS RATES IN THE RANDOM LOCATION TEST

Coupling mode	Measured success rate (%)	Simulated success rate (%)
B in one shoe	64	65
B in both shoes	80	88
A in one shoe	80	29
A and B in one shoe	85	80
A and B in both shoes	93	88

Measured percentages include 100 repetitions.

III.2. Field Test

The field test lasted for 14 days. The button was used 14 times, indicating a nurse entering one of the rooms. 13 of these were detected with the tag, yielding a success rate of 93%. The only room entry which was not detected lasted for less than 2 seconds. The average delay from the button being pressed to the first tag observation was 36 seconds, with a standard deviation of 49 seconds. Over the two-week period 4 incorrect ID numbers were found. These were all detected when the button signal was not active.

IV. Discussion

IV.1. In-house Tests

As can be seen in Fig. 7, the configuration using coupling modes A and B together produces the highest SNR and read range. The SNR while the shoe was touching the floor was 16.9 and the read range was 5 mm. An SNR of 10 is usually considered to be sufficient [32]. Since this is achieved at elevations below 1.5 mm and the maximal read range is 5 mm, we conclude that the tag should touch the floor to achieve good reliability.

When observing the SNR values as a function of elevation in Fig. 7, one can notice that the curves follow the dotted trace. It is a fitted curve proportional to the inverse value of the square of the distance. This behavior was expected as the electric field distributes into a spherical surface, such as one with a point charge, as in (2)

$$E = \frac{Q}{4\pi\epsilon_0 r^2} \quad (2)$$

where E is the electric field strength, Q is the charge, and r is the distance. Below 1.5 mm this dependency decreases because the electrode geometry resembles a

parallel plate capacitor where the exponent of the distance r is 1.

The test with a fixed location verified that the technique is valid and works swiftly. The latency of 0.4 seconds is comparable to common contactless keycard readers.

In the random location test 93 out of 100 locations were detected correctly. The causes of the false negative results in the remaining seven percent were explained by the simulations; the reason is the lack of intersecting surfaces between the floor sensor elements and the tag antennas, which causes a weak signal. This occurs when the person steps on a gap between the sensors or on a wire bundle feeding them. These take up 19 percent of the entire room area.

The success rates in random locations seem to follow the simulated tests very closely. This confirms that the coupling modes behave as expected. The only exception is seen in row 3 of Table I; the simulation suggests that the success rate of coupling mode A in one shoe should be significantly lower than was found in the test. This was most likely due to leakage between the antenna plates in the shoe, and coupling mode B was also present.

A successful detection includes not only the tag ID, but also the location of the sensor it was read with. Our earlier work indicated that the mean positioning accuracy is 21 cm and two targets can be discriminated with a 90% certainty if the gap is 78 cm [24]. Therefore multiple targets, including their identity, can be tracked inside the same room. This creates a solid base for context-aware computing. For example, members of the staff could receive patient records with their cell phones while standing next to a certain bed.

IV.2. Field Test

The performance found in the field test was similar to that of the in-house test (93% vs. 93%). The performance was satisfactory, but was not adequate for crucial applications. However, the nurses were very satisfied with the identification feature because it saved the effort of acknowledging alarms with a PC. They were especially satisfied by the fact that further alarms were automatically turned off when they were present. Some complaints were received about the shoes; the sole was too rigid and made their feet tired.

It was found that the nurses sometimes forgot to press the button. This is evident when the log is observed, as there were eight occasions when the same tag was detected in the same room at least two times in a row, and these were distributed over a period of several minutes. The probability of these being false positives is very low. Therefore the exact false positive rate cannot be calculated from the log, since the absence of the button signal does not mean that the nurse was not present.

There were four cases during the two-week period which were confirmed as false positives, as nonexistent ID numbers were read. Since they were detected in the absence of a nurse, we suspect that they were generated by noise in the signal. The number of false positives should be capable of being easily reduced by introducing a checksum in the transmission.

The mean detection delay was 36 seconds. This delay is largely defined by the 15-second re-attempt delay of the scanning procedure. Furthermore, the nurses apparently move around a lot until they stop and allow the tag to be read.

IV.3. Future Work

In future field tests, the users will be instructed to stop on marked footprints immediately after entering the room. In addition, the floor will be configured to scan only this area for IDs. These procedures should reduce the average detection delay to 0.4 seconds, as shown in the in-house tests.

Our future work also includes speeding up the sampling rate and the update rate of the NFI floor sensor. This would shorten the NFI observation latency and the duration of the ID transmission. This could enable walking people to be identified, as the scan can take place before the person lifts the foot which has been targeted for sampling. The false positive rate will also be reduced as there would be time to add four bits for a checksum.

V. Conclusion

This paper shows that embedding a capacitive RFID tag into a shoe can be identified with a NFI floor sensor. The intended use was identifying staff in a nursing home. Satisfactory performance was found in the laboratory, as well as in an actual nursing home. The results suggest that the method can be used for context-aware and ubiquitous computing. Besides the technical performance, good user feedback was obtained. The nurses that wore the shoe tags were very satisfied with the application.

Acknowledgements

Special thanks go to the staff of Kustaankartano's building 'A', 3rd floor. The authors also thank MariMills Oy for support.

References

- [1] J. Hightower, G. Borriello, Location systems for ubiquitous computing, *Computer*, vol. 34, n. 8, August 2001, pp. 57 – 66.
- [2] H. Rimminen, M. Linnavuo, R. Sepponen, Human tracking using near field imaging, *The 2nd International Conference on PERSVASIVE COMPUTING TECHNOLOGIES FOR HEALTHCARE*, January 30-February 1, 2008, Tampere, Finland.

- [3] M. Harville, Stereo person tracking with adaptive plan-view templates of height and occupancy statistics, *Image and Vision Computing*, vol. 22, n. 2, February 2004, pp. 127 – 142.
- [4] Y. Chen-Rong, W. Chao-Lin, L. Ching-Hu, F. Li-Chen, Human Localization via Multi-Cameras and Floor Sensors Smart Home, *The IEEE International Conference on SYSTEMS, MAN AND CYBERNETICS*, October 8–11, 2006, Taipei, Taiwan.
- [5] D. López de Ipiña, P. Mendonça, A. Hopper, TRIP: A low-cost vision-based location system for ubiquitous computing, *Personal Ubiquitous Computing*, vol. 6, n. 3, May 2002, pp. 206 – 219.
- [6] M.D. Addlesce, A. Jones, F. Livesey, F. Samaria, The ORL active floor, *IEEE Personal Communications*, vol. 5, n. 4, October 1997, pp. 35 – 41.
- [7] R.J. Orr, G.D. Abowd, The smart floor: a mechanism for natural user identification and tracking, *The Conference on HUMAN FACTORS IN COMPUTING SYSTEMS*, April 16, 2000, The Hague, Netherlands.
- [8] S. Pirttikangas, J. Suutala, J. Riekkilä, J. Rönkä, Footstep identification from pressure signals using hidden Markov models, *The FINNISH SIGNAL PROCESSING Symposium*, May 3, 2003, Tampere, Finland.
- [9] C. BenAbdelkader, R. Cutler, L. Davis, Stride and cadence as a biometric in automatic person identification and verification. The Fifth IEEE International Conference on *AUTOMATIC FACE AND GESTURE RECOGNITION*, May 21, 2002, Washington, DC, US.
- [10] M. Williams, Better face-recognition software. *Technology Review*, May 30, 2007.
- [11] S. Willis, S. Hclal, RFID information grid and wearable computing solution to the problem of wayfinding for the blind user in a campus environment, *The Ninth IEEE International Symposium on WEARABLE COMPUTERS*, October 18-21, 2005, Osaka, Japan.
- [12] D. Hähnel, W. Burgard, D. Fox, K. Fishkin, M. Philipose, Mapping and localization with RFID technology, *The IEEE International Conference on ROBOTICS & AUTOMATION*, April 26, 2004, New Orleans, LA, US.
- [13] M. Motoki, I. Sadanori, T. Ryoze, S. Taro, K. Susumu, An Empirical Study of an RFID mat sensor system in a group home, *Journal of Networks*, vol. 4, n. 2, April 2009, pp. 133 – 139.
- [14] A.D. Chock, Y. Li, Ubiquitous interaction with positioning and navigation using a novel light sensor-based information transmission system, *Personal and Ubiquitous Computing*, vol. 12, n. 6, August 2008, pp. 445 – 458.
- [15] R. Want, A. Hopper, V. Falcao, J. Gibbons, The active badge location system, *ACM Transaction on Information Systems*, vol. 10, n. 1, January 1992, pp. 91 – 102.
- [16] P. Hii, A. Zaslavsky, Improving location accuracy by combining WLAN positioning and sensor technology, *The Workshop on REAL-WORLD WIRELESS SENSOR NETWORKS*, June 20-21, 2005, Stockholm, Sweden.
- [17] M. Ficco, M. D'Arizeno, G. D'Angelo, A Bluetooth infrastructure for automatic services access in ubiquitous and nomadic computing environments, *The 5th ACM international workshop on MOBILITY MANAGEMENT AND WIRELESS ACCESS*, October 22, 2007, Crete, Greece.
- [18] H. Cho, M. Kang, J. Park, B. Park, H. Kim, (2007) Performance analysis of location estimation Algorithm in ZigBee Networks using Received Signal Strength, *The 21st International Conference on ADVANCED INFORMATION NETWORKING AND APPLICATIONS*, May 21-23, 2007, Ontario, Canada.
- [19] B.D.S. Lakmal, D. Dias, Database correlation for GSM location in outdoor & indoor environments, *The 4th International Conference on INFORMATION AND AUTOMATION FOR SUSTAINABILITY*, December 12-14, 2008, Colombo, Sri Lanka.
- [20] N.B. Priyantha, *The Cricket Indoor Location System*, Ph.D. dissertation, Dept. of Elect. Eng. and Comp. Sci. Massachusetts Institute of Technology, Cambridge, MA, 2005.
- [21] M. Hazas, A. Ward, A Novel Broadband Ultrasonic Location System, *Lecture Notes in Computer Science*, vol. 2498, January 2002, pp. 264 – 280.
- [22] M. Kuhn, Z. Cemin, B. Merkl, Y. Depeng, W. Yazhou, M. Mahfouz, A. Fathy, High accuracy UWB localization in dense indoor environments, *The IEEE International Conference on ULTRA-WIDEBAND*, September 10-12, 2008, Hannover, Germany.
- [23] T.G. Zimmerman, J.R. Smith, J.A. Paradiso, D. Allport, N. Gershenfeld, Applying electric field sensing to human-computer interfaces, *The SIGCHI conference on HUMAN FACTORS IN COMPUTING SYSTEMS*, May 7-11, 1995, Denver, CO, US.
- [24] H. Rimminen, J. Lindström, R. Sepponen, Positioning Accuracy And Multi-Target Separation With A Human Tracking System Using Near Field Imaging, *International Journal on Smart Sensing and Intelligent Systems*, vol. 2, n. 1, March 2009, pp. 156 – 175.
- [25] M. Valtanen, J. Maentausta, J. Vanhala, TileTrack: Capacitive human tracking using floor tiles, *The IEEE International Conference on PERSVASIVE COMPUTING AND COMMUNICATIONS*, March 9-13 2009, Galveston, TX, US.
- [26] T.G. Zimmerman, Personal area networks: Near-field intrabody communication, *IBM Systems Journal*, vol. 35, n. 3 & 4, 1996, pp. 609 – 617.
- [27] K. Partridge, B. Dahlquist, A. Veiseh, A. Cain, A. Foreman, J. Goldberg, G. Borriello, Empirical measurements of intrabody communication performance under varied physical configurations, *The 14th annual ACM symposium on USER INTERFACE SOFTWARE AND TECHNOLOGY*, November 11-14, 2001, Orlando, FL, US.
- [28] M. Fukumoto, M. Shinagawa, CarpetLAN: A Novel Indoor Wireless(-like) Networking and Positioning System, *The 7th International Conference on UBIQUITOUS COMPUTING*, September 11-14, 2005, Tokyo, Japan.
- [29] R. Oksanen, S. Paldanius, J. Nykänen, M. Linnavuo, K. Raivio, K. E. Segerstam, R. Sepponen, L. Pohjola, H. Finne-Soveri, Testing and adopting floor-sensor solutions in daily practice for patient safety in Kustaankartano nursing home, *Journal of Nutrition Health and Aging*, vol. 13, supplement 1, July 2009, pp. S361 [abstract] and *The 19th IAGG world congress of GERONTOLOGY AND GERIATRICS*, July 5-9, 2009, Paris, France, [poster].
- [30] M. Linnavuo, H. Rimminen, Localization and monitoring of people with a near-field imaging system – boosting the elderly care, In A. Coronato, G. De Pietro (Eds.), *Pervasive and smart technologies for healthcare: ubiquitous methodologies and tools*, 4 (Hershey, PA: IGI Global, 2010, 78-96).
- [31] K. Finkenzeller, *RFID handbook: fundamentals and applications in contactless smart cards and identification* (John Wiley and Sons, 2003, 49-52).
- [32] D. M. Dobkin, *The RF in RFID: Passive UHF RFID in Practice* (Elsevier, 2007, 72-73).

Authors' information

Applied Electronics Laboratory, Department of Electronics, Aalto University School of Technology, Espoo, Finland.



Henry Rimminen was born in Helsinki, Finland, in 1981. He received his M.Sc. (Tech.) degree in electrical engineering in 2006 from Helsinki University of Technology, Espoo, Finland.

He is currently working as a Researcher at the Applied Electronics Laboratory, Department of Electronics, Aalto University School of Technology, Espoo. He is currently working towards his D.Sc. (Tech.) degree in electrical engineering. His research interests are embedded systems and capacitive sensors.

Mr. Rimminen is a member of the Finnish Society of Electronics Engineers and the Finnish Association of Graduate Engineers.



Matti Linnavuo was born in Porvoo, Finland, in 1954. He received his M.Sc. (tech.) degree in 1978 and Lic. Tech. degree in electrical engineering in 1982 from Helsinki University of Technology, Espoo, Finland.

He has worked as Acting Professor in hardware technologies at Helsinki University of Technology, and as a project manager at Instrumentarium Corp., Finland. His present position is Laboratory Manager at the Applied Electronics Laboratory, Department of Electronics, Aalto University School of Technology, Espoo, Finland. His research interests are medical electronics and health care instrumentation.

Mr. Linnavuo is a member of the Finnish Society of Electronics Engineers and the Finnish Association of Graduate Engineers.



Raimo Sepponen was born in Lahti, Finland, in 1950. He received his D. Tech. degree in electrical engineering from Helsinki University of Technology, Espoo, Finland in 1986.

He has worked as a Manager of New Developments at Instrumentarium Corp., Finland. He is currently the Head of Department at the Department of Electronics and Vice-Dean of the Faculty of Electronics, Communications, and Automation at Aalto University School of Technology, Espoo, Finland. His main interests are MRI and biomedical instrumentation.

Dr. Sepponen is the Chief Engineering Counselor in the Finnish Supreme Administrative Court and a Board Member of the Finnish Society of Electronics Engineers. He received the Recognition for Finnish Engineering Achievement of the Year in 1986.