RFID monitoring for Assistive Technologies beyond the Clinic

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***Abstract*—A UHF RFID tilt angle and location sensing system is described for tracking users of assistive or rehabilitative technologies in their homes. Results show 3-axis accelerometer angles can be read at 10 Hz, and location within a room can be determined within 0.5 m resolution. A skin-mounted microstrip patch antenna is proposed for the RFID communications and power harvesting.**

***Index Terms*—epidermal antenna, RFID sensing, UHF RFID Antenna.**

I. Introduction

When a user of Assistive or Rehabilitative Technology (ART) is given new equipment for use at home or outside, clinical professionals currently have very little data about how regularly or effectively the equipment is used. This is sub-optimal for the user and an inefficient use of healthcare resources [1].

AART-BC is a funded project comprising RFID and antennas researchers together with partners specializing in Biomedical Engineering, Rehabilitation, Biomechanics and Orthopedic technologies. The focus of the RFID tag antenna work is to provide a skin-mountable wireless system to determine a user's position and movement data within the wireless coverage footprint. Additionally, metal mounted tags are being created for integration directly into ART equipment such as walking frames to locate the equipment relative to the user. The tags also offer additional functionality including 3-axis accelerometer data which is communicated by the UHF RFID link to a ceiling mounted reader. Powering the sensing electronics requires the implementation of RF energy harvesting on the tag. This paper outlines the multidisciplinary work to create a low energy, long-term UHF RFID sensing platform for mounting on skin to provide information for clinicians, carers, and end-users.

II. AART-BC RFID Wireless Monitoring System

Patch-based sensors to mount on the user's skin are being created to communicate with commercial-off-the-shelf (COTS) smart beam switching UHF RFID readers. This will enable indoor location of identifiable tags to be tracked over time.

The reader is a ceiling mounted Impinj xArray Rain RFID Gateway, which provides 52 switched beams to calculate x and y floor position with a stated lowest accuracy of 1.5 m [2]. When mounted at 2.6 m (domestic ceiling height), positional accuracies of 0.5 m or better are obtained within a coverage radius of 3 m, making it suitable for tracking of a user's general position in relation to tagged assistive equipment.

The accelerometer epidermal tags will enable the assessment of small-scale movements and limb tremors in addition to the larger scale positional information available from the switched beam reader. The need for routine battery recharge and replacement is eliminated through the exploitation of passive backscatter based RFID for the communications links, with sensor system power obtained through RF energy harvesting. This allows the tags to be worn for extended periods without the need for removal or recharge.

III. Sensing Tag

The tag system schematic is shown in Fig. 1. There are 3 subsystems consisting of the UHF RFID communications link, an RF energy harvesting antenna and rectifying frontend, and a sensing system with a low power microcontroller. The sensing system and RFID transponder are powered by the energy harvester. The sensor implemented in this prototype was a MEMS accelerometer (ADXL345). Ultimately, flexible substrates will be used to fabricate the tag electronics, while the initial prototypes were created on 30 x 30 mm^2 PCBs, Fig. 2. Although they are not flexible, it is possible to encapsulate these small size boards within medical plasters without causing discomfort to the user.

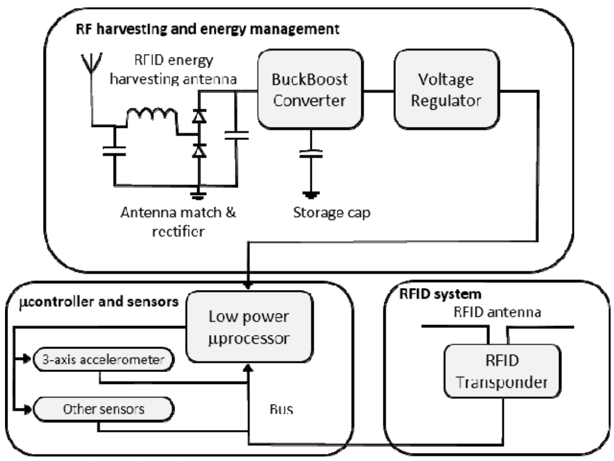


Fig. 1. Schematic of tag system

Accelerometer data is streamed from the worn sensing tag to the ceiling mounted RFID reader. The xArray returns location data based on a 52 switched beam footprint which is generated by the provided 3 x 3 microstrip patch array. Tag *x-y* location accuracy is quoted by the manufacturers as 1.5 m, which is the width of the beams at the outer edges of the read zone. The data is communicated from the reader to a remote server via ethernet, for classification, storage and generation of notifications. For a reader mounted at 2.5 m ceiling height for a typical room, to cover a 6 x 6 m2 floor area, it is necessary for the wearable tags to have a 4 m read range. This is challenging for a passive skin-mounted tag as typically tissue loss reduces antenna gain to as low as -20 dBi. Even with low threshold power tag transponders, read range is limited to around 1 m [3] and [4].

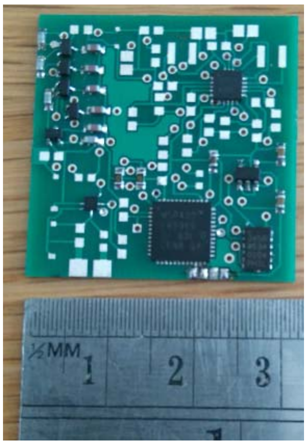


Fig. 2. Tag energy harvesting and sensor system

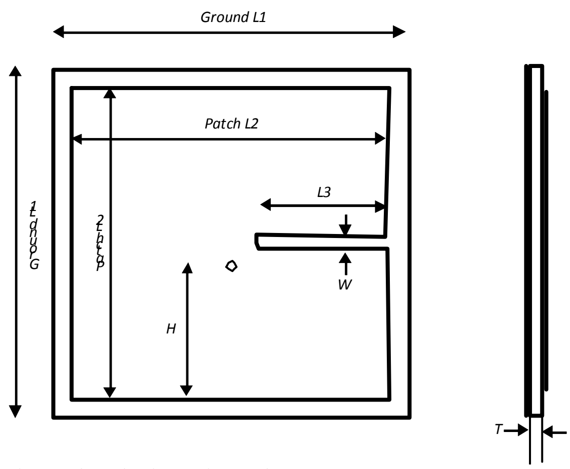


Fig. 3. Slotted Microstrip Patch Antenna

IV. Epidermal Tag Antenna

The tag antenna is a probe fed, reduced size slotted microstrip patch [5] on a flexible silicone substrate, Fig. 3. The antenna principal dimensions are given in Table I.

TABLE I PRINCIPAL PATCH DIMENSIONS

All dimensions in mm						
L1	L2	L3	H	W	T	ε_r
85	75	29.5	33.5	3	1.5	3

The microstrip design was selected owing to the relatively low profile and the ability of the rear ground plane to screen the patch from the skin, offering significant efficiency improvements. The antenna was simulated with CST Microwave Studio® on a layered block phantom representing the arm, Fig. 4(a), resulting in a return loss of 25 dB, Fig. 4(b). The efficiency of the patch was simulated to be -4.4 dB, which compares well with reported typical values ranging from -13 to -20 dB for on-skin RFID antennas [3] and [4].

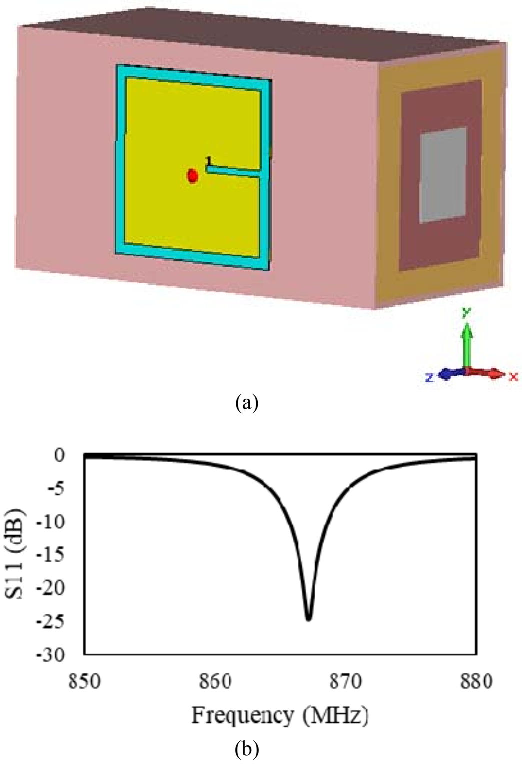


Fig. 4. (a) slotted patch antenna on layered arm phantom, layers represent skin, muscle, fat, bone. (b) Simulated S11

The simulated antenna was found to offer a gain of 0.4 dBi with the radiation pattern shown in Fig. 5. The ground plane screen not only brings the benefit of isolating the antenna from tissue losses, but also reduces detuning caused by the variability in complex permittivity of human tissues. This has been observed to differ significantly over different users, mounting sites, and also with time [6].

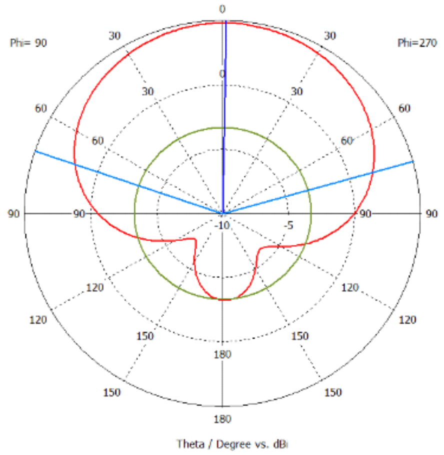


Fig. 5. Simulated slotted patch radiation pattern (y-z plane).

V. Measured Read Range

The patch antenna of Fig. 3 was integrated with the system of Fig. 1 using the NXP SL3S4011 transponder chip (input impedance = 13.8 – j210 Ω at 868 MHz, and power assisted sensitivity = -23 dBm). The accelerometer was an ADXL345 MEMS device. Conventional UHF RFID readers have sensitivities of around -70 dBm. This means that when active tags are used, a check should be made of whether the forward or reverse link will limit the overall link performance. However, as skin-mounted tags are inefficient compared to most antennas, it is found that the forward link usually will determine the read range despite the enhanced tag sensitivity offered by power assistance through energy harvesting or batteries. Overall read range was measured to be 5 m when the skin-mounted tags were interrogated by a reader with ERP of 2W at 868 MHz. This read range was determined to meet the requirement for the case of ceiling central mounted readers in domestic rooms.

VI. Sensing Results

A. Accelerometer Angles

The fabricated flexible patch was attached to the forearm of a healthy volunteer to establish the read operation and the ability to stream data from the accelerometer. Two tests were carried out as indicated in Figs. 6(a) and (b), and the accelerometer values are given in Figs. 7(a) and (b). In both cases the arm was bent such that the angle *x* was predominantly altered, with some variation in angle *y* also occurring. The data rate was 10 Hz and the values in Fig. 7 were captured from the reader.

B. Location

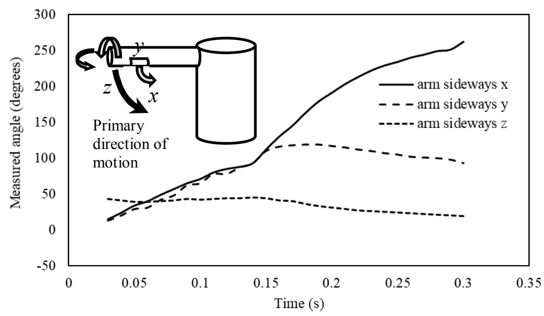
The manufacturer quoted *x-y* positioning accuracy of the xArray reader is 1.5 m which is the worst case situation corresponding to the periphery of the read area. However, measurements of static and moving tags demonstrated the average accuracy to be closer to 45 cm.

(a)

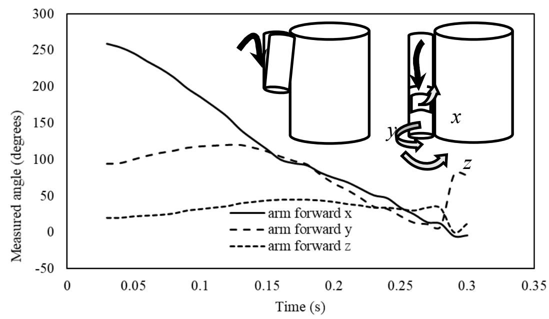
(b)

Fig. 6. Mounted tag positions

In both the static and moving cases, the error was obtained by time averaging the data and comparing it with the known tag position on a floor grid. Mounting the tags on the torso of a volunteer enabled their location to be tracked around the 3×4 m^2 grid and clearly showed interaction with a tagged wheeled office chair when it was pushed around the space. To offer diversity against tag dropouts, the user wore 3 tags on their front and 3 on their back. Analysis of a 56.5 s path walked around the grid revealed total dropouts, or high inaccuracies to occur for 7% of the time, Fig. 8. Two



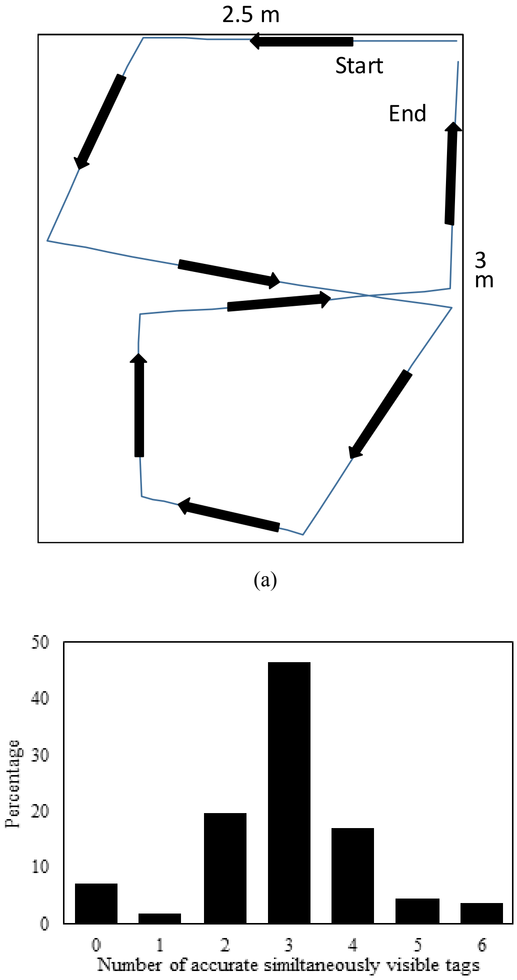
(a)



(b)

Fig. 7. RFID streamed accelerometer angles. (a) sideways arm movement, (b) forwards unfolding arm. Tilt axes x, y, z as indicated in the insets.

or more accurately placed tags are available for 91% of the time. With more than 1 tag visible, instantaneous averaging of their positions improves accuracy to the 45 cm observed for static tags with time averaging.



(b)

Fig. 8. (a) Random walk path, (b) accurately located tags during the 56.5 s walk.

VII. Conlcusions

A UHF RFID tag platform has been presented enabling the low power capture of movement for individuals wearing skin mounted patches. A slotted microstrip patch antenna is found to be suited for the application in terms of its low profile, ability to be mounted on a flexible substrate, and to offer an acceptable surface area and efficiency at 868 MHz. In particular, the presence of the rear ground plane enables the patch to offer efficiencies up to 30 times higher than for single layer skin-mounted antennas.

The anonymous volunteers gave informed consent and the study was carried out in accordance with the authors' institutional ethical framework.

Acknowledgment

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