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24GHz RFID for Orientation Detection and Tracking Applications in Human Activity Recognition and Motion Capture

Ajibayo O. Adeyeye, Charles A. Lynch III, Manos M. Tentzeris
School of Electrical and Computer Engineering
Georgia Institute of Technology
Atlanta, Georgia, USA
aadeyeye3@gatech.edu

Jimmy Hester
Atheraxon Inc.
Atlanta, Georgia, USA

***Abstract*—Utilizing technology derived from a combination of modulated backscatter and FMCW radar, a simple low cost and highly accurate means to report and track the orientation of a tagged structure is reported. The system is comprised of a pair of closely spaced 24 GHz RFID tags interrogated by an FMCW radar and uses a method of phase difference to infer the orientation of the tagged structure . The result is an ultra sensitive, low cost orientation detection system suitable for use in human activity recognition and motion capture applications.**

I. Introduction

Modulated backscatter radio frequency identification (RFID) has seen increasing traction in research and applications over the last few decades. This comes as a direct result of its very high energy efficiency. In backscatter RFID, the tag does not locally generate its own carrier signal for communications instead it reflects the incident signal. The backscatter front-end is able to dynamically adjust it's reflection coefficient varying as a function of the load presented to the terminals of its antenna. This singular attribute enables the development of communicating front ends that only need a minuscule amount of power for operation. Radar has also become more prominent as a low-cost means for sensing at millimeter-wave frequencies primarily for gesture recognition, human activity recognition and sensing [1], [2]. Frequency Modulated Continuous Wave (FMCW) radar specifically has been shown to be particularly advantageous over other radar schemes. It maintains a simple architecture allowing it to be manufactured and deployed at scale.

Radar and RFID concepts have been combined in literature to provide high performing RFID transponders that can be used for localization, detection and sensing applications [3], [4]. Radar and modulated backscatter produces a wide variety of benefits as shown in [4], high signal to noise ratio and highly accurate localization is possible by combining these principles. In this effort, the authors propose and demonstrate a system combining the principles of modulated backscatter and FMCW radar to develop a system capable of accurately detecting and tracking the orientation of a structure affixed with a pair of millimeter wave RFID tags. Orientation sensing systems utilizing backscatter RFID have been proposed in literature [5]. However, the shift to the millimeter wave regime allows for the deployment of lower form factor devices and finer resolution due to the shorter wavelength.

II. Proposed System

The proposed system is comprised of an interrogating FMCW radar operating at 24GHz and a pair of RFID tags closely spaced together. The tag is comprised of an RF front end and associated baseband circuitry. The RF front end includes the radiating element which in this case is a cross-polarized patch antenna and the switching circuitry. The CE3520K3 is used as the switching element and is driven by a modulation signal sourced from the baseband circuit. The baseband circuit includes a charged supercapacitor to provide power, a voltage regulator to ensure stability and resistor set oscillator to provide the modulating signal. 24 GHz is chosen for a variety of reasons including the ability to make small tags, the increased sensitivity to phase of RF signals at this frequency due to the short wavelength and also availability of low cost off the shelf components required for a reader system.

The operating principle of this system is that if there are two reference points on a given surface, the orientation of that surface can be determined and tracked because as one point gets closer to the reader, corresponding to a decreasing phase, the other point gets farther away from the reader which corresponds to an increasing phase. This is difficult to achieve in a passive radar scenario because bandwidth limitations necessitate the two reference points to be at least $60\,\mathrm{cm}$ apart which would be unsuitable in a practical application. In addition, for a set of reference points that far apart, a small degree change in orientation results in a very large change

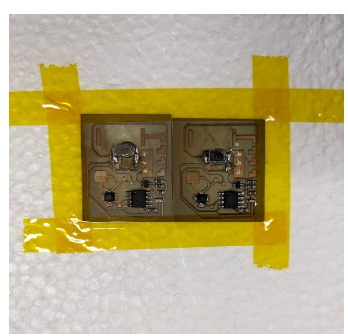

Fig. 1. Closely spaced mmWave RFID tags

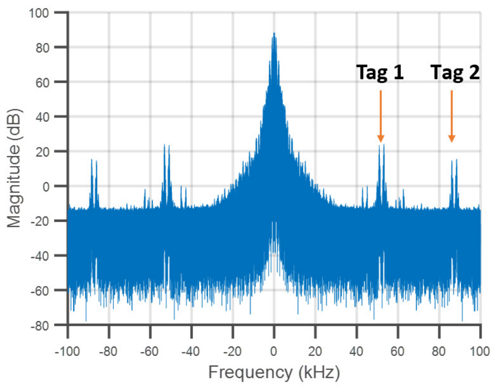

Fig. 2. Magnitude Spectrum

Fig. 3. Measurement Setup

in the difference in phase of the returned signal between the two reference points and thus resolving ambiguities becomes untenable. The closely spaced tags are shown in figure 1 The benefit of using modulated backscatter in conjunction with an interrogating FMCW radar is evident because in the proposed system although the tags are closely spaced together, they are easily distinguished beyond the bandwidth limitation because they can be divided in frequency by ensuring the two tags in use have different modulation frequencies so that the required phase information can be extracted from both. This is illustrated in the spectrum shown in figure 2.Tags 1 and 2 were set to modulate at $52\,\mathrm{kHz}$ and $87.5\,\mathrm{kHz}$ respectively. This large spacing in frequency allows the tags to be easily distinguished from each other with no interference.

III. Measurement and Results

The proposed system was designed to enable continuous tracking of the orientation of a pair of closely spaced millimeter wave RFID tags. The two RFID tags were placed together on a rectangular surface as shown in figure 1 and then displaced at a distance of about $1\,\mathrm{m}$. The tags were affixed to a DC motor to enable the pair of RFID tags to be swept across the horizontal plane of the interrogating antennas. This measurement setup is shown in figure 3.

In the measurement carried out, the tags were initially displaced in front of the reader at approximately $0°$ relative to the plane of the interrogating antennas. The motor was then programmed to rotate the fixture first by $+60°$, then by $-120°$ so that the fixture was rotated in the opposite direction and then finally rotated again by $+60°$ to bring the fixture back to its initial position. Figure 4 shows the phase response of the tags over the period of $20\,\mathrm{s}$ through which the measurement

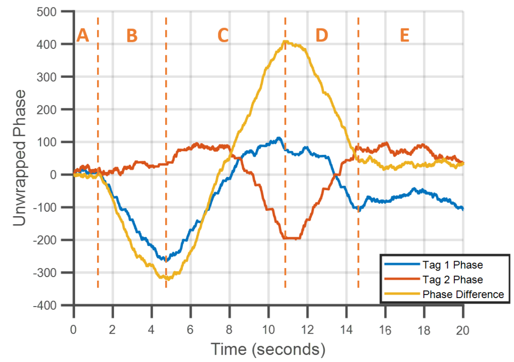

Fig. 4. Individual tag phase and resulting orientation profile

is carried out. It is seen in this figure that there is an opposite response in the unwrapped phase of the tag over time. The phase difference between the two tags which describes fully the orientation profile is also shown. The profile is divided into 5 regions corresponding to the state of the structure being tracked. Region A is while the structure is at rest, region B corresponds to the initial rotation towards $+60°$, region C shows the profile as the structure is rotated through an angle of $-120°$, region D shows the return back to the initial position and region E shows the structure back at rest.

IV. Conclusion

In this work, the authors show a practical application of millimeter wave RFID in conjunction with FMCW radar. The proposed system is able to accurately track the orientation of a tagged surface over a period of time while in continuous motion. This work builds upon pre-existing systems showing the applicability of millimeter wave backscatter for spatial localization applications and opens up avenues for applicability in human activity recognition, motion capture and augmented/virtual reality systems. The system described here can be further enhanced for full three dimensional orientation description through the addition of a secondary pair of tags in the orthogonal direction.

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