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UHF Tags Array for Holographic Target Localization and Wireless Health Monitoring

Aline Eid*†, Jiang Zhu*, Luzhou Xu*, Jimmy Hester†, and Manos M. Tentzeris†
*Device & Service Product Area, Google LLC, Mountain View, CA, USA.
†School of Electrical and Computer Engineering, Georgia Institute of Technology, Atlanta, GA, USA.

***Abstract*—This work presents a contactless, low-cost, scalable technique capable of localizing close targets and detecting their breathing rates based on an array of UHF RFID tags. To create a hologram of the target and extract the desired information, the system collects the phase and RSSI information from each unique tag in the array, processes the data using digital beamforming algorithms and reconstructs the image based on holographic methods. The paper highlights the hardware choices that play a critical role in constraining the dominant propagation paths and presents the localization and vital signs estimates of the system. The current system can localize targets angularly and can be readily extended to 3D localization, without interfering with daily activities.**

***Index Terms*—Target Localization, Vital Signs, UHF, RFID, Holography, Healthcare.**

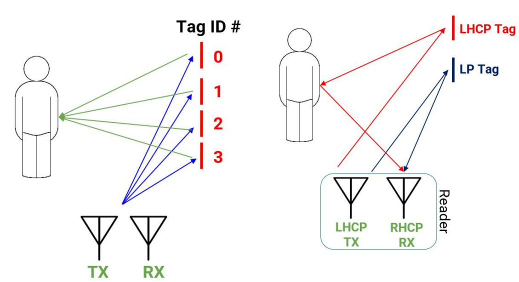
I. Introduction

OUR era is witnessing an increased interest and development in the fields of wireless health and activity monitoring combined with target localization. Systems capable of the real-time monitoring of vital signs while providing information on the position of the target can answer questions about the physical and mental health of individuals and, to a great extent, help with disease early diagnosis and prevention. While intrusive techniques [1] are abundantly available and provide relatively accurate results, they are considered cumbersome and uncomfortable, especially for elderly or child care. Therefore, the development of a contactless long-term health monitoring techniques, capable of efficiently extracting vital signs in cluttered environments, is highly desirable [2]. Radar-based solutions proposed in the literature, equipped with wide bandwidths and large antenna systems, succeeded to demonstrate accurate localization and real time vital signs monitoring in scenarios involving multiple targets [3]. However, those solutions are costly, power-hungry and not readily-available on the market. A potential commercially-available and low-cost alternative lies in the Ultra-High Frequency (UHF) Radio Frequency IDentification (RFID) technology via the implementation of off-the-shelf (OTS) UHF RFID readers and cheap, compact, and batteryless RFID tags. However, the restricted bandwidths ($26\,\mathrm{MHz}$) available in ISM UHF bands lead to limited resolutions and low localization accuracies. An alternative to scanning in the frequency (radial) domain lies in the potential ability to sample in the angular domains to determine Angles of Arrival (AoAs). However, active antenna arrays quickly become unmanageably large and expensive in the UHF band. Instead, the proposed solution enables a similar outcome by employing a groundbreaking method consisting in the holographic projection of envrionmental targets over ultra-low-cost UHF RFID tag arrays [4].

In this work is presented the HoloTag system, a scalable and low-cost solution relying on a passive array of UHF RFID tags. The proposed system is capable of achieving combined target localization and breathing rate (BR) extraction in a cluttered environment involving multiple targets by merging holography with adaptive beamforming techniques. By arraying the cheapest element in the system–the RFID tag–and with prior knowledge of their position as well as that of the TX/RX antennas locations, the system is able to create a hologram of the target.

II. Hardware Choice and Setup

The realization of a contactless wireless health monitoring system depends on the clean extraction of line-of-sight signals reflected by human targets while minimizing the interference created by multipath. The implemented hardware and setup play a critical role in the enhancement of information-carrying wave propagation paths. A major advancement in this research, aiming to highlight the response from a human target while minimizing the direct communication link between the tag and reader antenna(s), was proposed in [5]. In Fig. 1b is described the difference between the propagation path models resulting from the deployment of either a circularly polarized (CP) or a linearly polarized (LP) tag in the presence of a human target of interest. The wave emitted by a Left-Hand CP TX reader antenna is used to optimally energize the tag before its backscattered signal needs to change polarization by reflecting on environmental scatterers (including the the human target of



(a) (b)

Fig. 1. (a) Schematic describing the proposed solution based on an array of UHF RFID tags, (b) Schematic describing the difference in dominant propagation path for a CP tag versus an LP tag.

interest) to enable optimal reception by the Right Hand CP (RHCP) RX reader antenna. In this scenario, since the tag and the RX antennas are cross-polarized, the communication link between them is drastically attenuated while the signal carrying information about the target is efficiently received. In the case of the LP tag, the signal bouncing back from the tag dominates the signals coming from the target, leading to lower SNRs and challenging (if not impossible) information-extracting procedures. While other demonstrations stick to the use of a single duplex antenna, we have enabled–with the addition of a circulator–seperate transmission and reception modes with the Impinj Speedway R420 reader. The proposed architecture minimizes the crosstalk between the TX and RX channels and, thus, increases the receiver's sensitivity. The experimental setup, shown in Fig. 2, was installed in a busy environment surrounded with glass windows, concrete walls, chairs, and tables. Similar to antenna arrays, the number of tags and the spacing between them were studied and simulated 2D interference patterns were plotted, resulting in the optimal setup presented in Fig. 2, composed of four tags spaced by $3\lambda/4$ to minimize secondary lobes.

III. Combined Holography and Adaptive Beamforming

To address the problem of Direction of Arrival (DOA) estimation, adaptive beamforming techniques such as Delay & Sum and Capon algorithms were applied on the measured data, composed of the Received Signal Strength Indicator (RSSI) and phase. These algorithms were utilized to calculate and apply weights–determined based on the propagation path model and steering vectors—to the measured signals. The maximum of the frequency domain response of the steered signal was then extracted and plotted for every position in the room, resulting in a holographic 2D interference pattern. The proposed solution succeeded in localizing two closely-positioned targets and differentiating their BRs using a low-cost, simple, and static system. The result is shown in Fig. 3a (Target 1) and Fig. 3b (Target 2), where the exact (red circle) and predicted (yellow beam) angles coincide, demonstrating the ability to successfully locate the angular position of each target. In order to correlate each target with their BR, the spatially-filtered response (frequency domain response corresponding to each measured location) was extracted. An example of such response, plotted in Fig. 3c, displays the BR

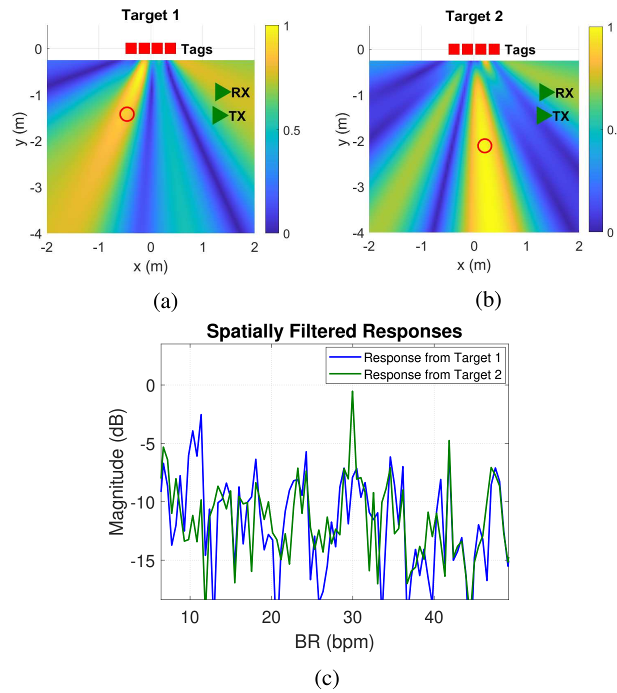


Fig. 3. Measured 2D patterns for (a) Target 1, (b) Target 2, (c) Measured spatially-filtered responses for both targets displaying their breathing rates depending on their location.

of each target based on their location, correlating a BR of around 11.5 bpm to target 1 and a BR of 30 bpm to target 2, remarkably similar to the ground truths set by a reference metronome.

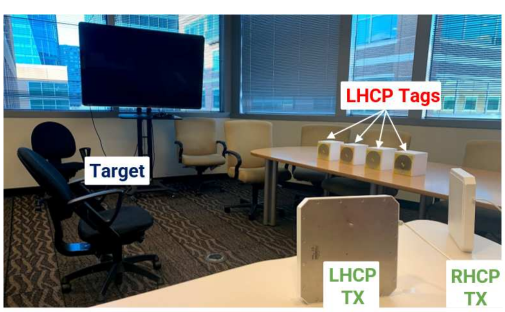


Fig. 2. Photo of the setup implementing four-tags linear array for target DOA estimation and BR extraction.

IV. Conclusion

The HoloTag system described here overcomes the limited bandwidth available at UHF frequencies for health monitoring systems with the unconventional implementation of low-cost large-aperture and, therefore, high-resolution imaging. While only a simple demonstration is presented here, the system can be scaled and customized to be more suitable for deployments in living and clinical environments. Combined with Machine learning, this solution paves the way for the emergence of affordable smart health care environments with high resolution capabilities.

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