FMCW-Interferometry Hybrid Radar Sensor with Continuous Beam Steering for Motion Tracking and Vital Sign Measurement

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***Abstract*—This report gives a brief overview of the outcomes of the project "FMCW-Interferometry Hybrid Radar Sensor with Continuous Beam Steering for Motion Tracking and Vital Sign Measurement". This project aims to develop advanced motion tracking and vital sign measurement using FMCW-interferometry hybrid radar sensor with continuous beam steering capability. Prototypes working at 5.8 GHz and 24 GHz have been developed. Real-time range-Doppler imaging has been implemented into these prototypes. Experiments of the two prototypes with different applications have been performed to reveal their capabilities in range detection, vital-sign measurement, and range-Doppler processing etc. In addition, a K-band portable FMCW radar with beamforming array has been realized. Experiments with a human subject revealed its capability to discriminate a human target from other objects based on the vital-Doppler effect.**

***Index Terms*—FMCW radar, Doppler radar, beamforming, vital-Doppler**

I. Introduction

SHORT-range localization and vital-sign tracking are two hot research topics in the fields of consumer electronics, medical care surveillance, driver assistance, and indoor navigation for robots and drones. Typically, mechanical steering system or phased array is necessary for a radar system to perform a two-dimensional or three-dimensional scan. It is known that mechanical steering systems increase the size, weight and cost while limiting the reliability. For consumer electronics, the size of the system is usually essential in order to be mounted on existing devices and equipment, such as automobiles and medical instrument, without affecting their profiles and functions. Phased array radar systems, which feature light weight, low profile and high steering speed, overcome the drawbacks of mechanical beam steering systems. However, a conventional phased array is expensive, especially at frequencies above the K-band. This is mainly because conventional solutions require high-frequency phase shifters, which have a limited number of manufacturers and are expensive.

Regarding the radar systems, continuous-wave (CW) radars have advantages of low transmitted power, simple structure, and high sensitivity, which make their applications spread into various areas. The interferometry (Doppler) radar and the frequency-modulated continuous-wave (FMCW) radar are two popular types of CW radars. Interferometry (Doppler) radars feature high precision in displacement measurement (e.g., can easily achieve sub-millimeter motion detection accuracy). However, it has difficulty to get absolute range information of targets. the FMCW radar can obtain accurate range information. In addition, it is also able to extract Doppler information related to the velocity of the targets if the coherence property of the system is achieved. Transceiver architecture based on six-port features simple structure and high performance, and has been used in biomedical interferometry radars and FMCW radars.

The aim of the project, as well as my entire PhD research, is to realize a portable, low-cost, high-sensitivity radar system and seek new applications for radar sensors.

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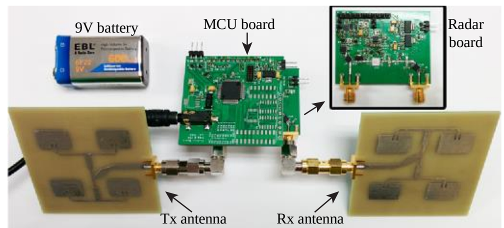


Fig. 1. Photo of the 5.8-GHz multi-mode radar prototype.

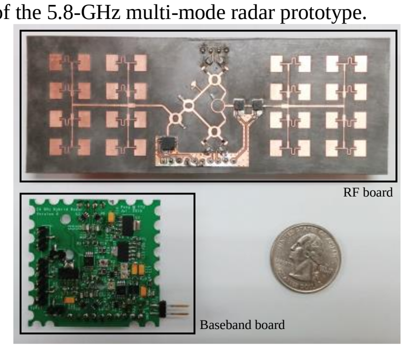
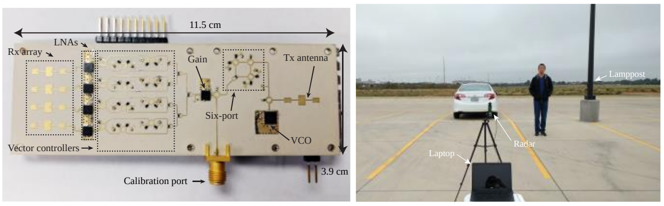


Fig. 2. Photo of the 24-GHz multi-mode radar prototype.

II. Project Outcomes

A. 5.8-GHz & 24-GHz Multi-Mode Radar

Two multi-mode radar prototypes have been developed for this project. These radar prototypes can be configured to work at the Doppler mode or the FMCW mode through an on-board micro-controller. These multi-mode radars combine the advantages of both the Doppler radar and the FMCW radar. Thus, they have the capabilities in high precision displacement



(a) (b)

Fig. 3. (a) Photo of the proposed radar prototype. (b) Experimental environment of short-range localization with a human subject and two object targets using the proposed radar prototype.

measurement, as well as high accuracy range detection.

The photo of the 5.8-GHz prototype is demonstrated in Fig. 1. The design details of the 5.8-GHz can be found in [1]. Experiments of 5.8-GHz radar revealed the capabilities of range detection, vital-sign measurement, range-Doppler imaging [1], [2], industrial wind turbine monitoring [3], and fall detection [4].

Figure 2 illustrates the photo of the 24-GHz prototype. This prototype has been used for in-door human tracking [5], ISAR imaging to isolate moving targets [6], industrial wind turbine monitoring [3], and non-contact speech sensing [7].

B. K-Band FMCW Radar with Beamforming Array

With this project, a K-band portable FMCW radar with beamforming array was also developed [7]. To the best of the authors' knowledge, this is the first PCB realization of short-range localization radar with beamforming capability in K-band. Fig. 3(a) is the photo of the built beamforming array radar. The beamforming array is a four-element linear array. Each element is a series-fed microstrip patch array antenna. The beam of the array can be continuously steered with a range of ±45° on the H-plane through an array of vector controllers. The vector controller is based on the concept of vector sum. However, different from previous works that are either based on integrated circuits or bulky modules, this design realizes the concept in K-band by simple microwave structure and PIN diodes on a printed circuit board (PCB). Details of radar system can be found in [8].

The short-range localization experimental setup with the customized prototype is shown in Fig. 3(b). In this experiment, a human subject stood in front of the car and the lamppost. The scanning angle also started from -45° to 45° with a step size of 2.5°. Fig. 4 illustrates the measured result. Signatures of the car, the lamppost and the human subject can be clearly seen. It should be noted that the signature of the human subject is not consistent, because of the vital-Doppler effect. To identify the human subject, 10 sequence of FMCW scans were performed and the standard deviation of the detected range spectrum is drawn in Fig. 5. With this method, the signatures of the car and the lamppost are suppressed and the human signature can be extracted, achieving human-aware localization.

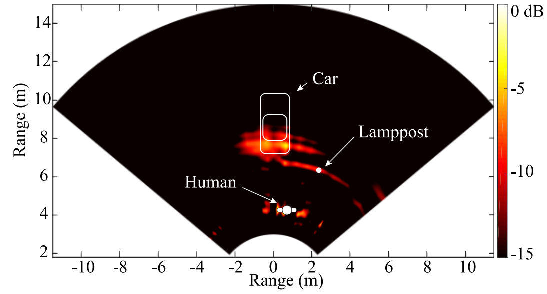


Fig. 4. Measured result of the short-range localization experiment with a human subject and two object targets using the proposed radar prototype.

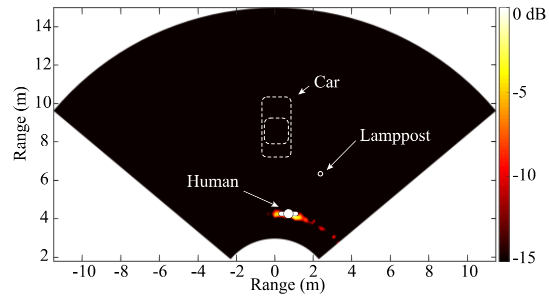


Fig. 5. Human target extracted with standard deviation of 10 sequencing scans.

III. Career Plan and Fellowship Impact

I would like to sincerely thank the MTT-S fellowship which has encouraged and facilitated me to complete this research. It provided me not only the financial support during my PhD study, but also the recognition of my work. This prestigious honor encouraged me to pursue my future career in the field of microwave engineering either in academia or industry.

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