# REMOTE DETECTION AND GEOLOCATION OF BREATHING SUBJECTS BY HIGH-PERFORMANCE FMCW MIMO MICROWAVE IMAGING SYSTEM

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## ABSTRACT

This paper presents the remote detection and geolocation of breathing targets, for the purpose of effective search and rescue. The key objective is to detect and locate micro oscillatory movement through high-performance sensing, such that breathing targets can be clearly identified from the stationary background image. The presentation of this paper includes theoretical analysis, structure of the imaging formation algorithm and data-acquisition hardware, and full-scale field experiments.

## INTRODUCTION

As real-time microwave imaging systems become feasible, detecting and tracking of moving targets has been a research subject of great importance and interest. However, the focus of the research effort has been limited to mainly the translational displacement. And the most challenging object remains to be the detection and geolocation of non-displacement motion, such as small periodic movement of stationary objects. The most direct and immediate application is the imaging and detecting of breathing, in search and rescue missions, which is one of the most critical elements in medical telemetry. This effort requires real-time high-resolution systems with high-performance image formation algorithms.

In this paper, we describe the development of a high-resolution portable ultra-wideband MIMO radar system and present the high-performance imaging algorithm for the detection and geolocation of breathing targets. The image formation algorithm is capable of producing two components from the image sequence, separating dynamic profile from the stationary background profile, which enables us to visualize the location of breathing human subjects accurately. With the assistance of camera units, this high-performance imaging system allows us to perform remote search for survivors efficiently and effectively.

## SYSTEM DESCRIPTION

The hardware system used to verify the breathing detection algorithm is a stepped FMCW radar operating over a frequency range of 500 MHz to 2 GHz. The instantaneous peak output power of the radar over the frequency band is 17 dBm, while the average output level depends on the number of stepped frequencies specified by the user. There are 16 user selectable hopping rates that vary from 5 to 90,000 data points per second. All of the system operating parameters are controlled by user through a software interface, and can subsequently be tailored for specific operating objectives. The open interface allows users to acquire, store, and replay data, as well as to develop, test, and implement special signal processing algorithms such as ones for breathing detection and geolocation.

An antenna switch interface board allows the radar to operate with an array of four planar Vivaldi antennas in a MIMO mode. The antennas are directional with beam-widths covering approximately 60° at 500 MHz to 30° at 2 GHz. The gain varies between 5.5 and 10 dBi over this same frequency band. These antennas were placed approximately 33 cm apart. Each of the antennas can act as a transmitter or receiver but only a single pair is active at a time. In operation, the antenna array is scanned end to end sequentially through all of the transmit/receive antenna pairs, with a complete frequency sweep taken for each pair. The fast data acquisition rates available mean that for practical applications, each antenna pair in the same sweep can be treated as being approximately simultaneous.

Scanning the array produces a set of data from each antenna pair that can be transformed into a high-resolution range profile of all the scatters in the field of view. A complete image frame uses the set of data associated with scanning through all the transmit/receive pairs in the array a single time. Conventionally, complex superposition of data from the antenna pairs is performed to produce a reconstructed image of the illuminated scene.

Breathing machines with adjustable breathing rates and depths are used as simulators for stationary individuals. Each breathing machine is constructed of a 0.43 m diameter slightly convex metal plate attached to a linear bearing that is driven by an electric motor to produce a horizontal sinusoidal motion. The typical setting for the breathing depth was 1.3 cm, while the period varied between 0.2 Hz and 0.33 Hz to simulate the typical range of human breathing rates.

## IMAGE FORMATION

Consider the range profile *R(r).* At a range distance *r*, the time delay to the receiver is

$$\tau = \frac{r}{c} \qquad (1)$$

where *c* is the propagation speed. Then, the received wave-field sequence is in the form of

$$e(k) = \int R(r)\, exp(-j2\pi f\,(r/c))\, dr \qquad (2)$$

Because the frequency of the stepped-frequency FMCW illumination is in the form of $f = f_o + k\Delta f$, the equation becomes

$$e(k) = \int R(r) \exp(-j2\pi f_o (2r/c)) \exp(-j2\pi k\Delta f (r/c)) dr \qquad (3)$$

We now group the first two terms for simplicity,

$$R'(r) = R(r) \exp(-j2\pi f_o (r/c)) \qquad (4)$$

The equation is now simplified down to

$$e(k) = \int R'(r) \exp(-j2\pi(k\Delta f /c) r) dr \qquad (5)$$

Hence the received wave-field data sequence is in the form of the Fourier transform of the range profile, evaluated at the discrete spatial frequencies of

$$f = k (\Delta f /c) \qquad (6)$$

This suggests that the range profile can be estimated by taking the Fourier transform of the FMCW data sequence. During one data-acquisition cycle, 12 data sequences are obtained from the radar array. Traditionally, after Fourier transformation, these 12 range profiles are mapped to the region of interest to form one image frame by complex superposition. For the purpose of detecting breathing movement, an additional Fourier transform is implemented to separate the micro oscillatory movement from the stationary component.

## FIELD EXPERIEMNT

A field experiment was conducted to illustrate the capability and performance of this portable radar imaging-sensing system. Figure (1) shows the 4-antenna radar unit and the setup of the outdoor field experiment.

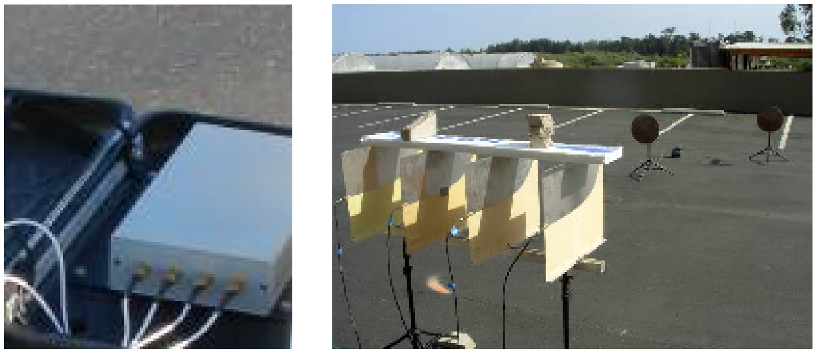

Figure (1): 4-antenna radar unit and the setup of the field experiment

For accuracy, two breathing machines were stationed in the target area, operating at the breathing rates of 0.2 Hz (12 breaths per minute) and 0.28 Hz (17 breaths per minute) respectively.

The data acquisition was conducted by a radar system with 4 antennas, operating in FMCW mode. The operating frequency band was from 0.5 GHz to 2.0 GHz. The system scanned through 1024 frequency steps in 0.035 seconds, generating 12 bi-static tracks of data sequences corresponding to 12 transceiver pairs. The data sequences were then converted to 12 range profiles by Fourier transformation. Figure (2) show a typical range profile.

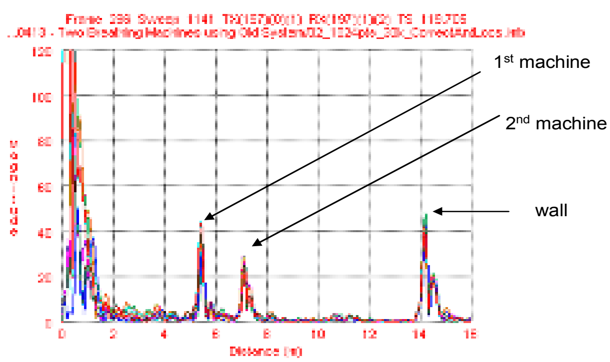

Figure (2): A range profile from one transceiver pair

The conventional approach is to form one instantaneous image frame form the 12 range profiles through complex superposition. Subsequently, motion detection can be conducted from the image sequence. However, this image-sequence based method is ineffective in separating the breathing movement from stationary background component.

One full scan cycle, for all 12 transceiver pairs, requires approximately 0.42 second. Then, as an example, during a period of 54 seconds, each transceiver pair will produce 128 range profiles. If we perform an additional Fourier transformation with respect to time, a two-dimensional range profile can be constructed. As it can be seen from Figure (3), the breathing machines are clearly shown at the correct range distances and breathing rates.

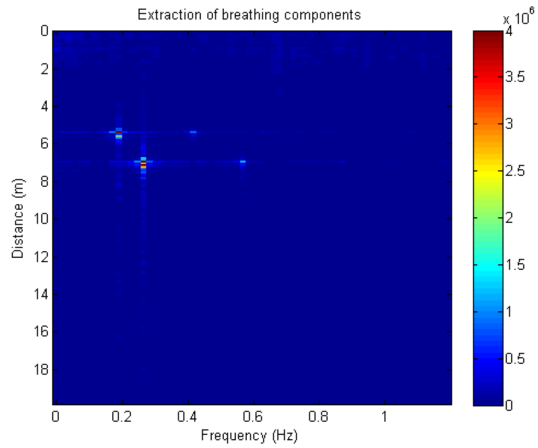


Figure (3): 2D spectrum of the data sequences from one transceiver pair

This implies the breathing components of the range profiles can now be separated from the stationary background distribution. The remaining DC component of the two-dimensional range profile is corresponding to the stationary background structure. This allows us to form a separate image of breathing elements from the background. Figure (4) shows the images of the breathing components.

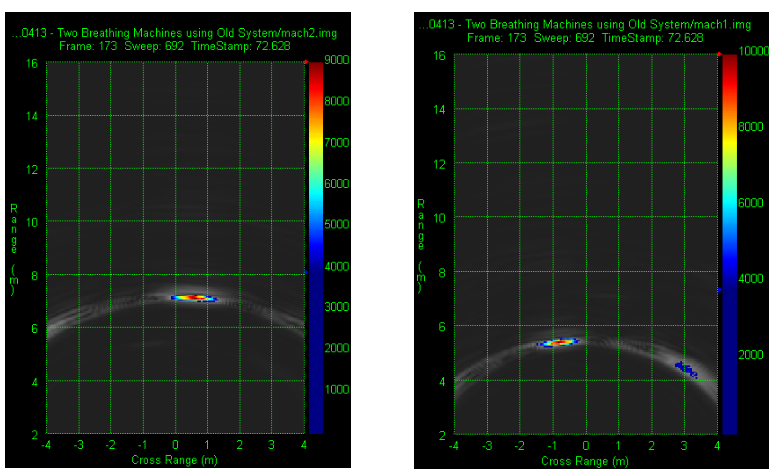


Figure (4): Images of the breathing components

More effectively, we can superimpose the breathing component to the stationary background, as shown in Figure (5), with colored version for the breathing elements and standard grey-scale image for the background wall.

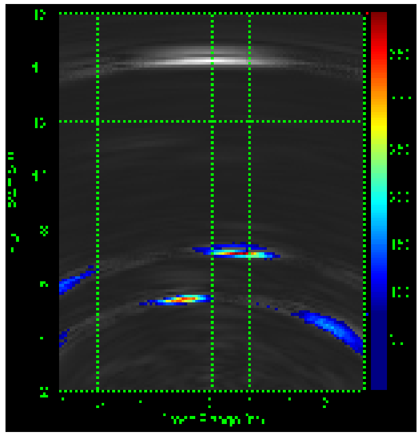

Figure (5): Composite image of the breathing elements and the background wall

## CONCLUSION

The objective of this research task is the design and implementation of image formation techniques, capable of detecting micro oscillatory movement with a portable radar sensing system. The main application is the remote detection and geolocation of breathing targets, for the purpose of effective search and rescue. Detecting spatial displacement with microwave imaging system has been a subject of great interest and importance. The detection of translational spatial displacement has been successfully implemented. Yet, the detection and geolocation of breathing elements have been extremely difficult due to insufficient spatial displacement. This paper presents an effective approach to the detection and separation of breathing elements from the stationary background structure, which allows us to significantly improve the execution of search and rescue operations.

## REFERENCES


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