Autonomous UAVs with Radar-Based Vital Signs Detection for Search and Rescue

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Abstract and Motivation

With the effects of climate change and increasingly dense populations, large emergencies like natural disasters will displace more human lives through catastrophic building collapse, fires, flooding, and more. In many of these scenarios, search and rescue plays a vital role in locating missing persons. This study investigates the use of autonomous Uncrewed Aerial Vehicles (UAVs) equipped with ultra-wideband (UWB) radar for locating and remotely monitoring the vitals of missing persons. Impulse UWB radar is ideal for this task due to its relative high resolution and ability to 'see' through physical objects (e.g., rubble) while measuring the displacement that occurs during respiration and heart beats.

Fig 1. Real Life Scenario
Overhead view of collapsed buildings and rubble in Turkey after the 2023 earthquake.

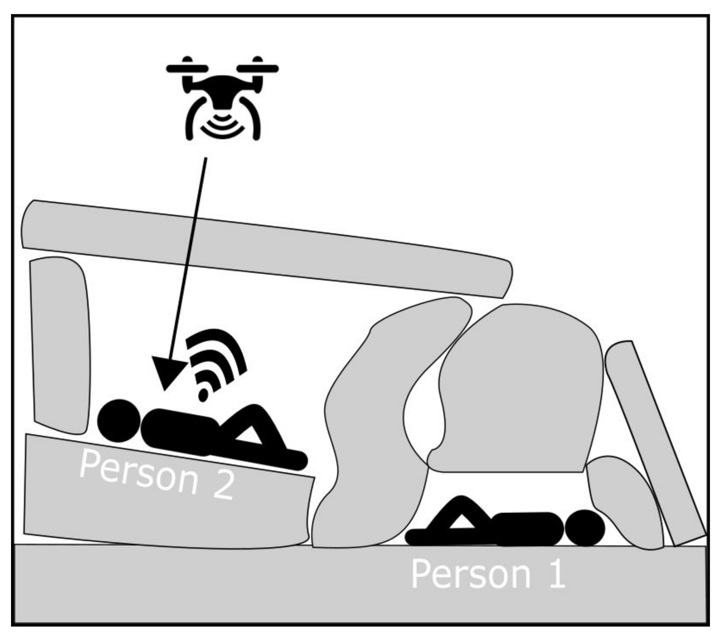
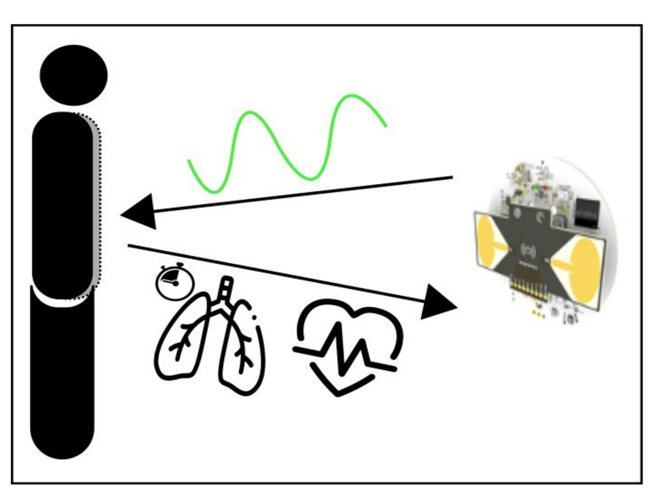


Fig 2. Possible Use Case
A UAV-mounted radar can quickly scan through material and detect vital sign signatures through rubble.

Background Information

Radar has historically been explored for non-invasive vital signs monitoring in hospitals. Since search and rescue requires mobile equipment, UAV-mounted radar is an ideal choice for remote vital signs monitoring.

Fig 3. Illustration of Radar Mechanism
The radar sends out impulses and records the time for the echo to return to calculate physical displacement. Over many impulses, respiratory and heart rate can be found.



Research Problem and Proposed Solution

Due to the vibrations and swaying from the UAV, an extensive list of digital processing steps must be taken to isolate the respiratory and heart rate frequencies found in the raw radar data. Below is a simplified flowchart of steps taken.

Get RF Radar Frames → Remove Clutter → Filter Slow-Time Frequencies → Acquire Target Range Bin and/or Use Autocorrelation → Perform VMD and Slow-Time STFT → Find Respiration Frequency and Isolate Heart Rate Frequency

To validate the first principles model, an experimental setup (**Fig 4**) using contact sensors for respiration and heart rate was designed for comparison with the quadcopter-mounted UWB radar module.

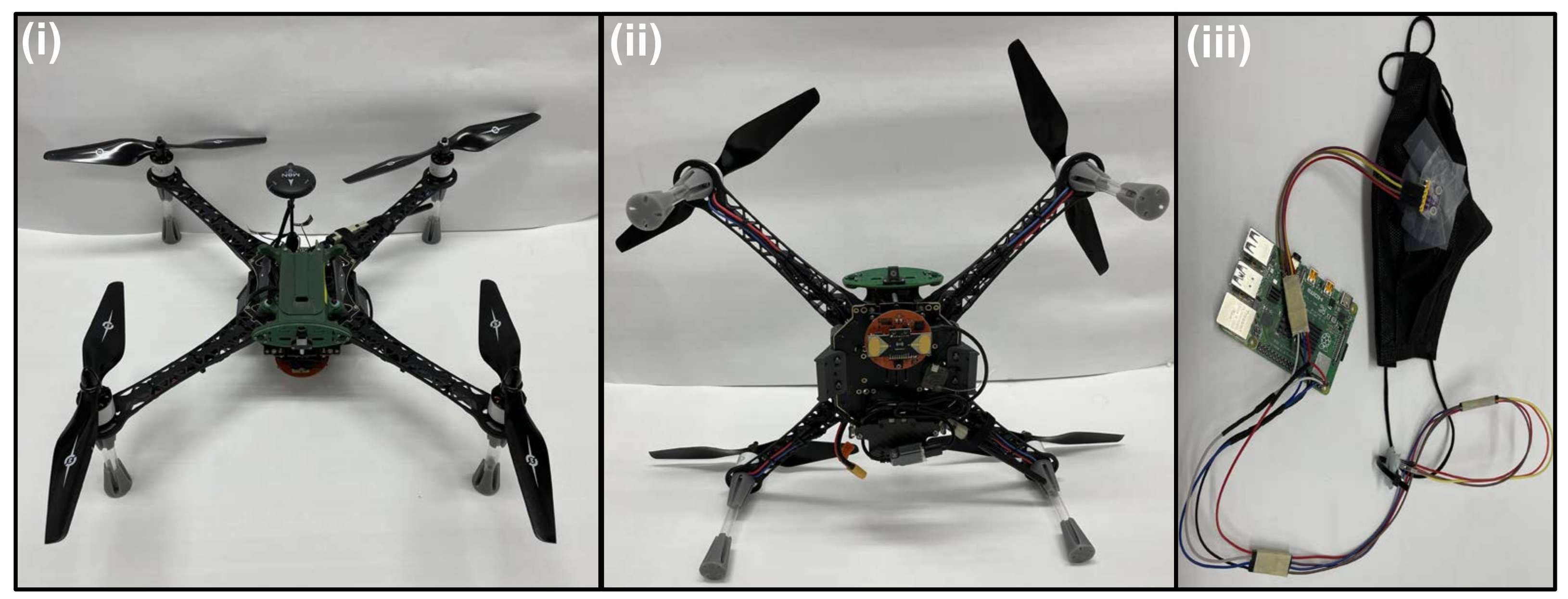
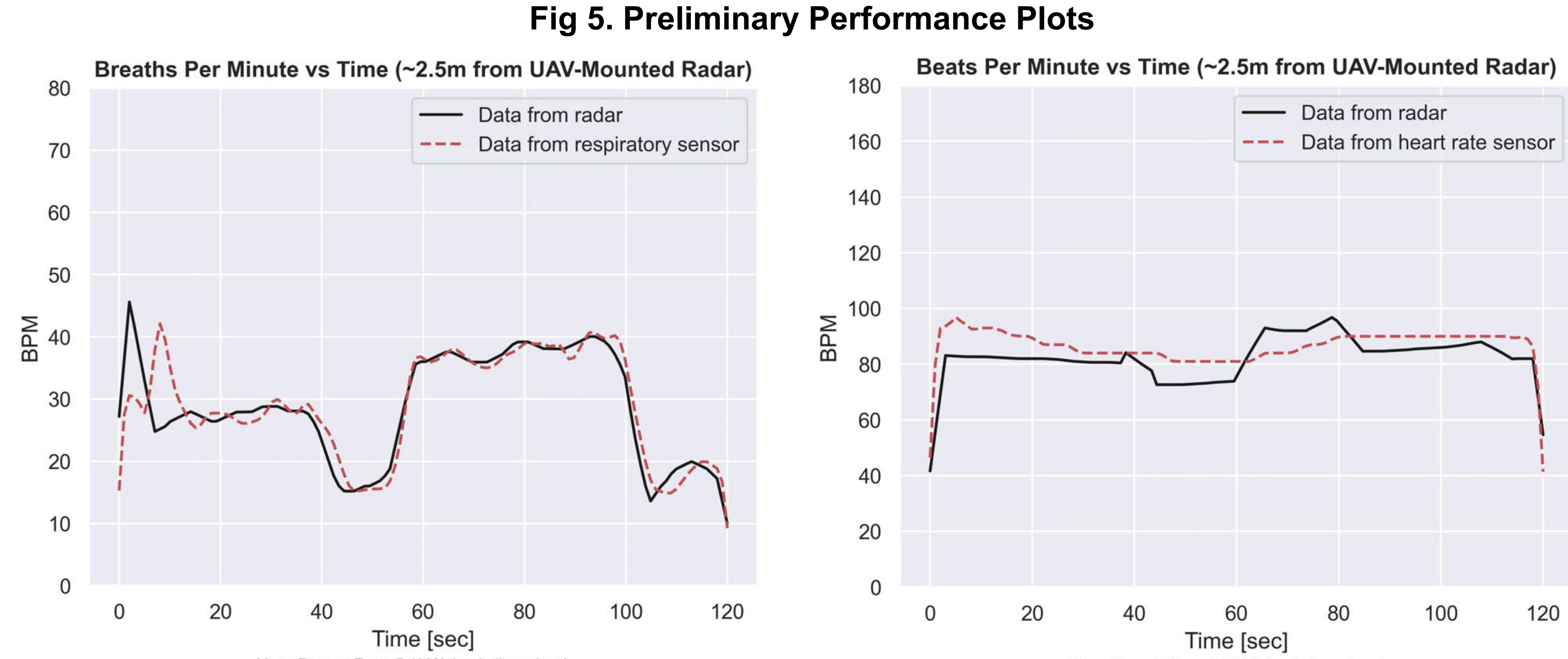


Fig 4. Experimental Setup
(i) Overhead view of UAV
(ii) Underside of UAV highlighting miniature radar module
(iii) Contact breathing and heart rate sensors

Preliminary Results and Analysis

The experimental results (**Fig 5**) from a quadcopter hovering ~2.5 meters above a single participant indicate low error and appropriate time-localized data for variable vital signs data. The algorithm for obtaining respiration rate is more accurate and less computationally complex due to the larger displacement of the abdomen during respiration in comparison to the displacement of the heart during a heartbeat.

Fig 5. Preliminary Performance Plots



Current and Future Work

Robust Human Presence Detection (Current):
Current work involves using a data-driven neural network approach to improve vital sign detection accuracy and real-time vital signs detection in unstructured and dynamic environments where standard signal processing methods struggle.

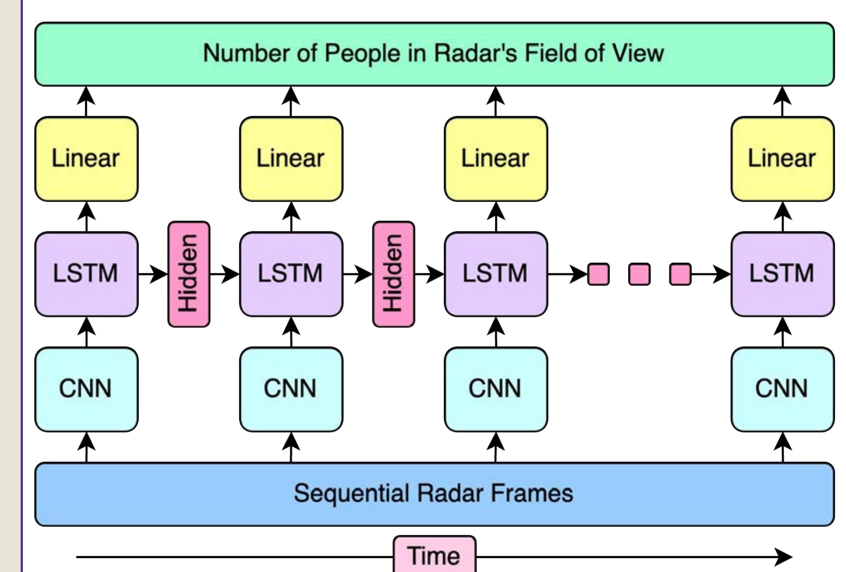
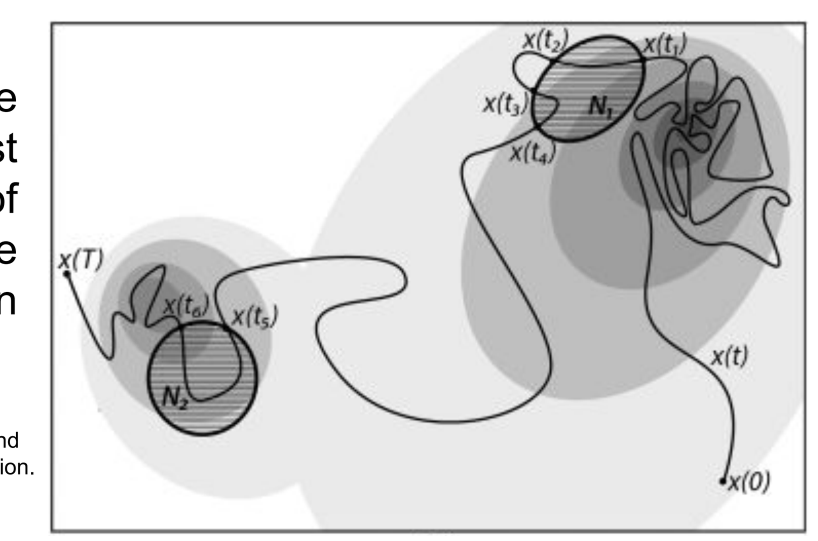


Fig 6. Neural Network Architecture
Using a long short-term memory network will give the neural network the ability to "remember" previous radar frames. The convolutional neural network layer is used to emphasize features from each frame and the linear layer resizes output.

Autonomous, Perception-Aware Control (Soon):
While a radar can detect humans even when obfuscated with rubble, the question of how to optimally search a given area for survivors remains. Recent advances in ergodic trajectory planning highlights methods to maximize information gain, which could be applied here to maximize physiological data obtained in a given time period.

Fig 6. Example Ergodic Path
Ergodic paths maximize the time spent in areas of interest (those with a high probability of having information) to retrieve the most information possible in the least amount of time.

Lauren M. Miller, Yonatan Silverman, Malcolm A. MacIver, and Todd D. Murphey. Ergodic exploration of distributed information. IEEE Transactions on Robotics, 32(1):36–52, 2016.



Acknowledgments

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