Wireless Heartbeat Sensing: A Radar System for Non-Contact Pulse Measurement in MRI

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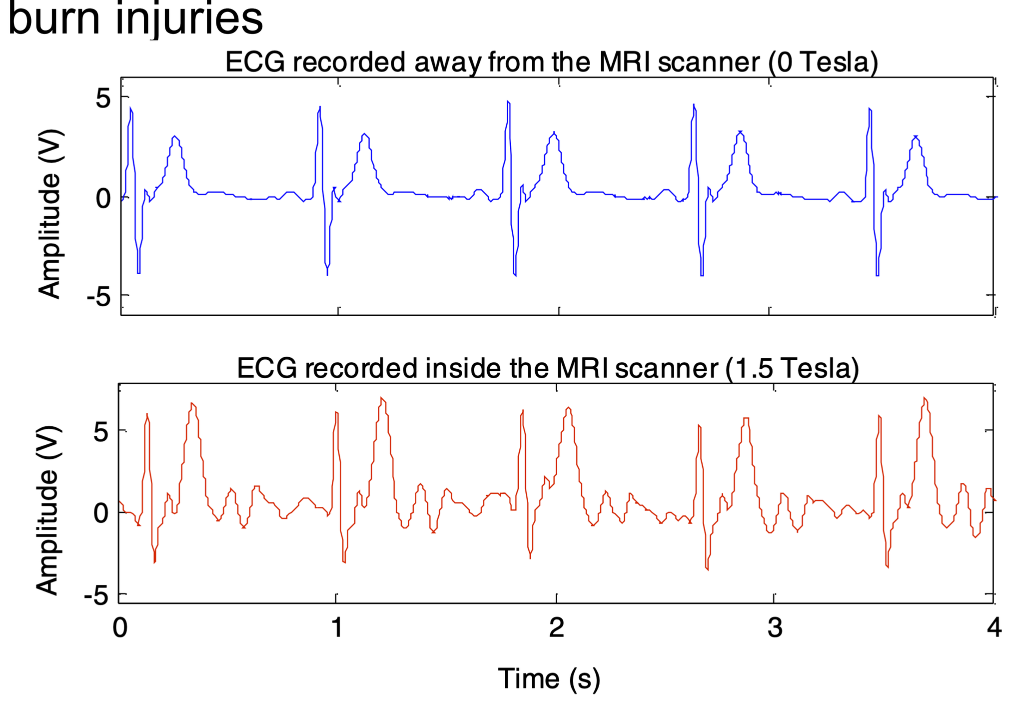
Background

Currently, electrocardiograms (ECGs) are used in MRI to synchronize image captures with the cardiac cycle to minimise motion artefacts and aid in image reconstruction. However, there are several problems with this method:

- Leads must be stuck to the patient's skin, leading to discomfort and increased setup time
- Strong magnetic fields and radio frequency (RF) pulses can interact with the blood and ECG leads, causing distorted signals and inaccurate readings
- RF pulses can cause ECG leads to heat up, which has led to serious burn injuries



ECG signal comparison outside and within an MRI scanner

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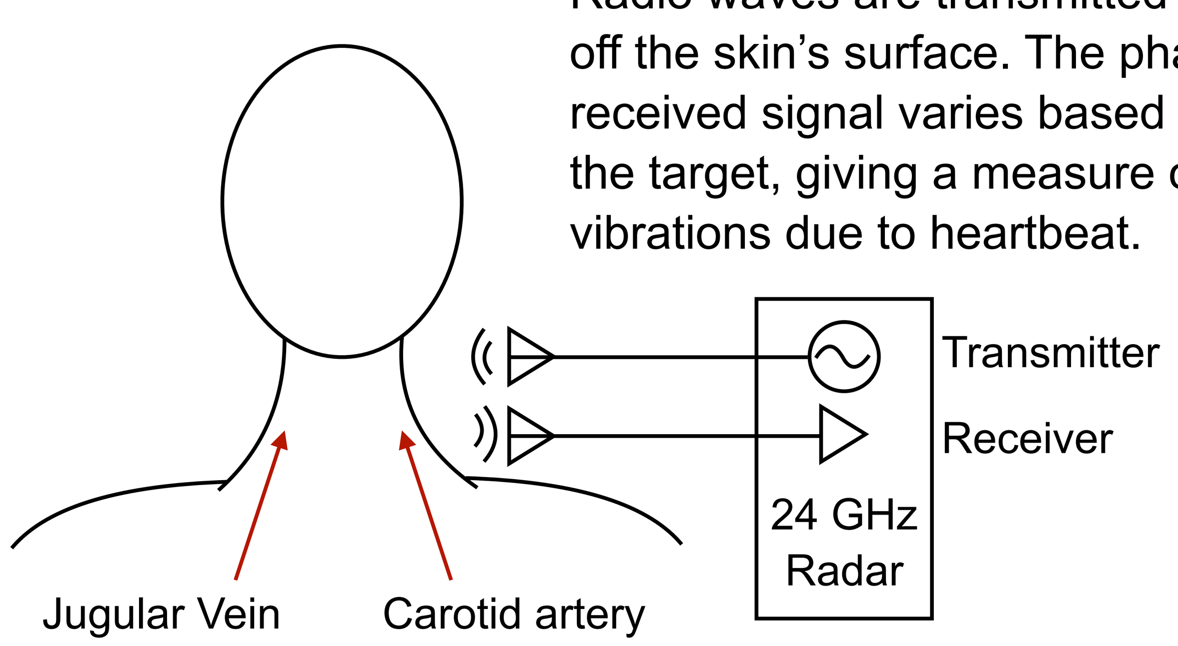
Proposed Solution

We aim to develop a system to measure the cardiac cycle in an MRI scanner which is:

- Non-contact: Lower setup times, lower patient discomfort and no risk of patient burns
- Robust: Not susceptible to distortion due to magnetic field interactions with blood (magnetohydrodynamic effects)

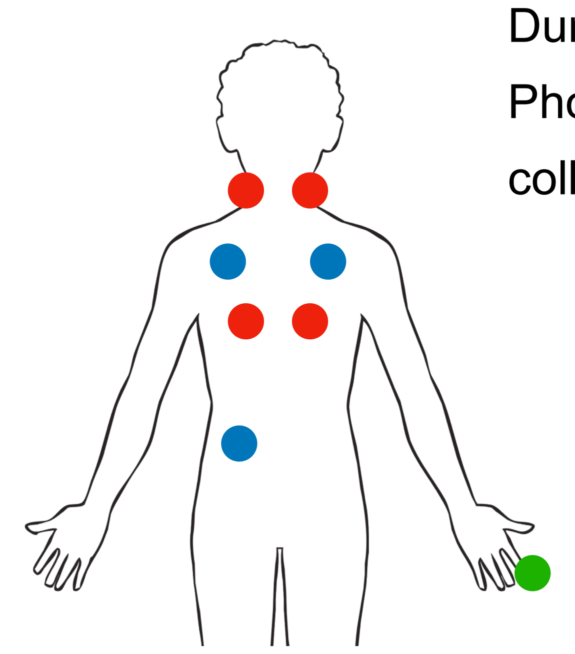
Our solution is to use four 24 GHz continuous wave (CW) radars placed above the left and right sides of the neck (jugular vein and carotid artery) and chest to measure heartbeat from small pulsatile skin motion.

Radio waves are transmitted and reflected off the skin's surface. The phase of the received signal varies based on distance to the target, giving a measure of skin vibrations due to heartbeat.



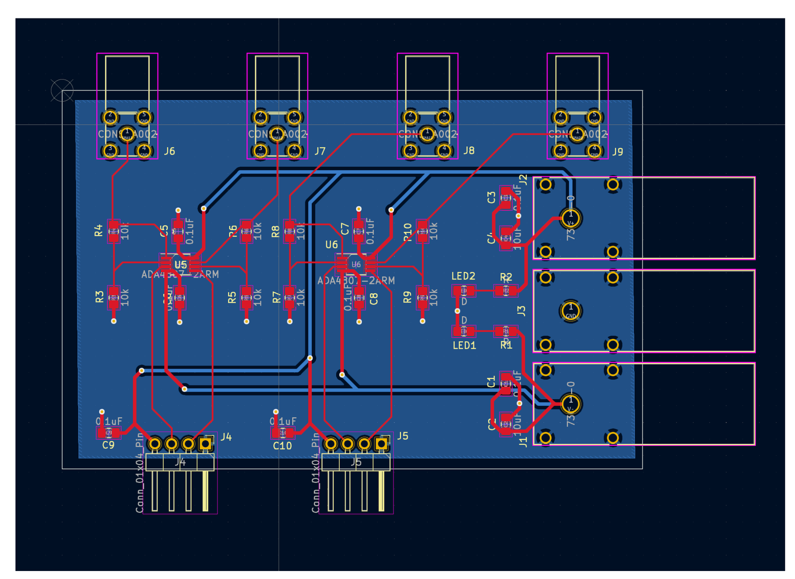
Method

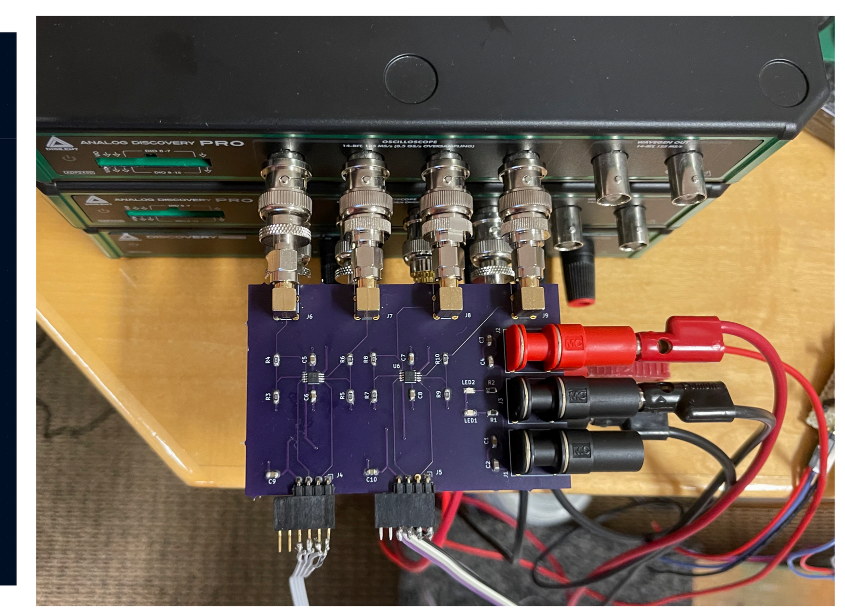
During experiments the CW radars, ECG and Photoplethysmography (blood volume) sensor collect data for 10 seconds at 10 kHz.



- 24 GHz Radars
- ECG leads
- PPG Fingertip Sensor

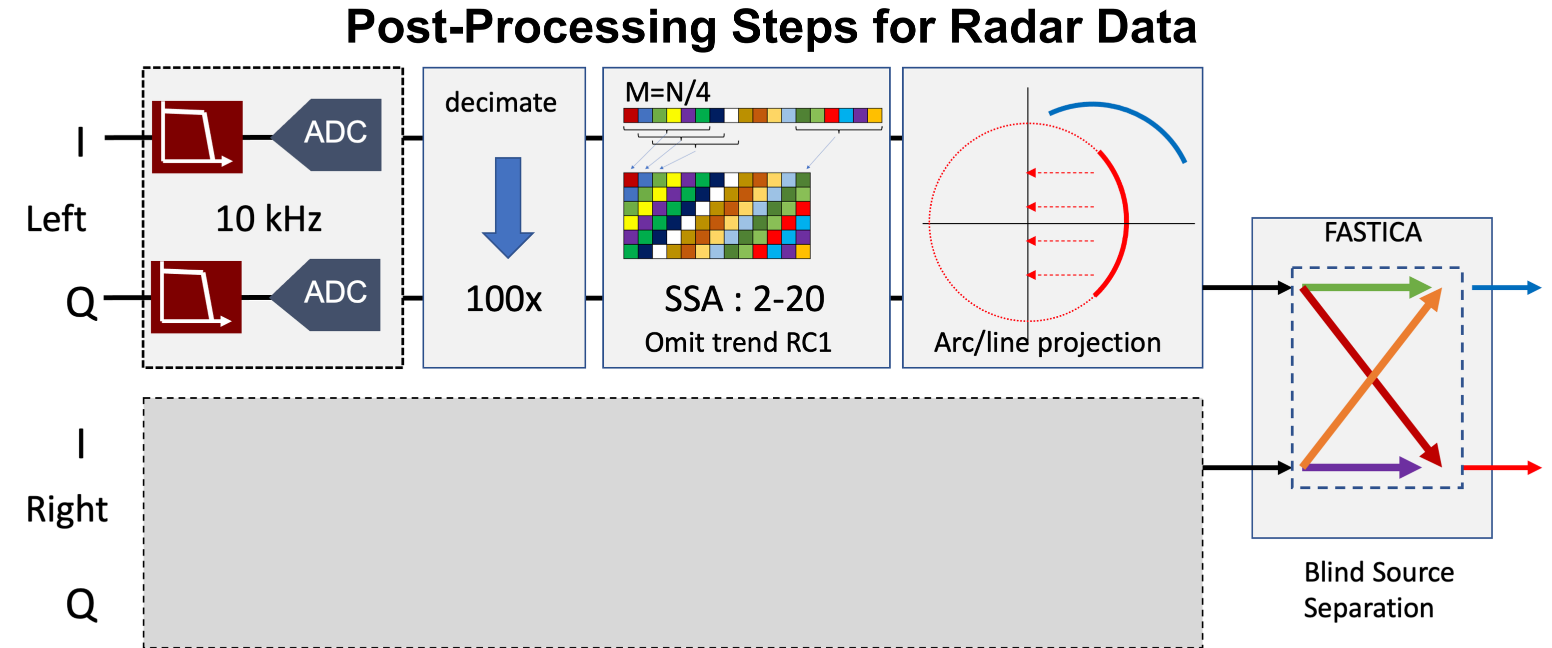
Radar transceivers are placed ~5 cm away from the body





The radar I and Q signal data were amplified with 10x gain op-amps and recorded with analog discovery oscilloscopes. A custom interface PCB was designed and fabricated for this stage.

Post-Processing Steps for Radar Data



Left/Right pairs – separate "common mode" and "differential mode" motions

Decimation: The collected data were decimated 100x (keeping 1 out of every 100 samples) for lower computational load

Singular Spectrum Analysis (SSA): Acts as a data-defined filter which reconstructs data and minimizes noise. When reconstructing the data, we omit the 1st reconstructed component (RC), which is typically bulk motion, and use RCs 2-20.

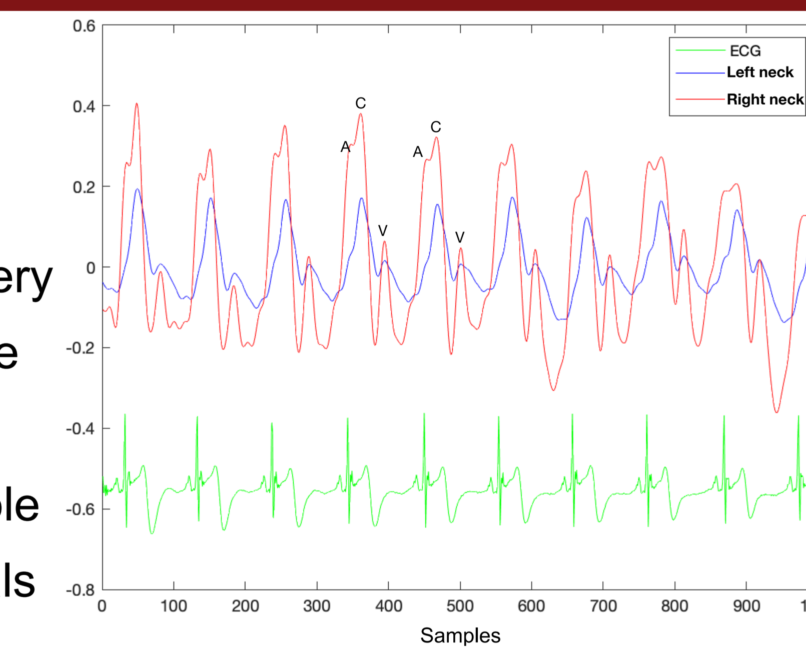
Arc/line projection: The complex IQ signal is fit to an arc of a circle to account for measurement inaccuracies before arctan demodulation.

Independent Components Analysis (ICA): Attempts to mathematically separate independent signal sources (eg. Breathing vs heartbeat).

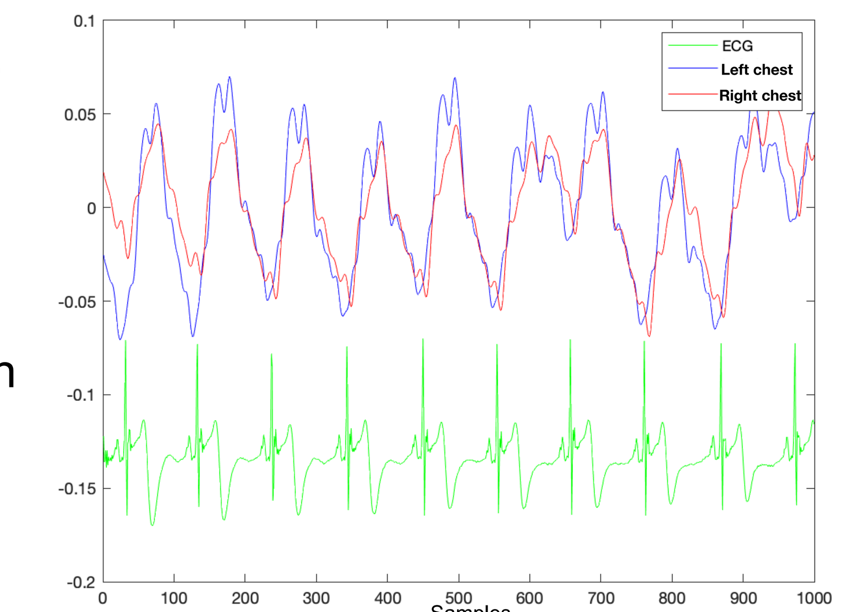
Results

Breath-Hold Data

- Neck radars provide good windows into the jugular venous pulse and carotid artery
- On the right neck, we can see the JVP pressure waves
- Signals are highly reproducible in three subjects and ~80 trials

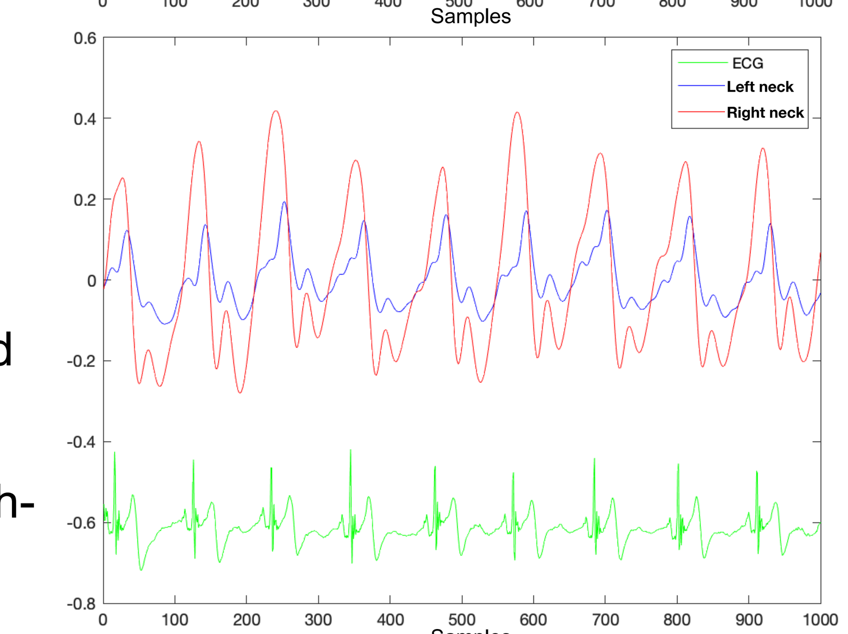


- Chest radars give a view into atrial/ventricular systole/ diastole
- Chest wall appears to lower down during heart contraction (aligned with QRS complex)
- Not as reproducible

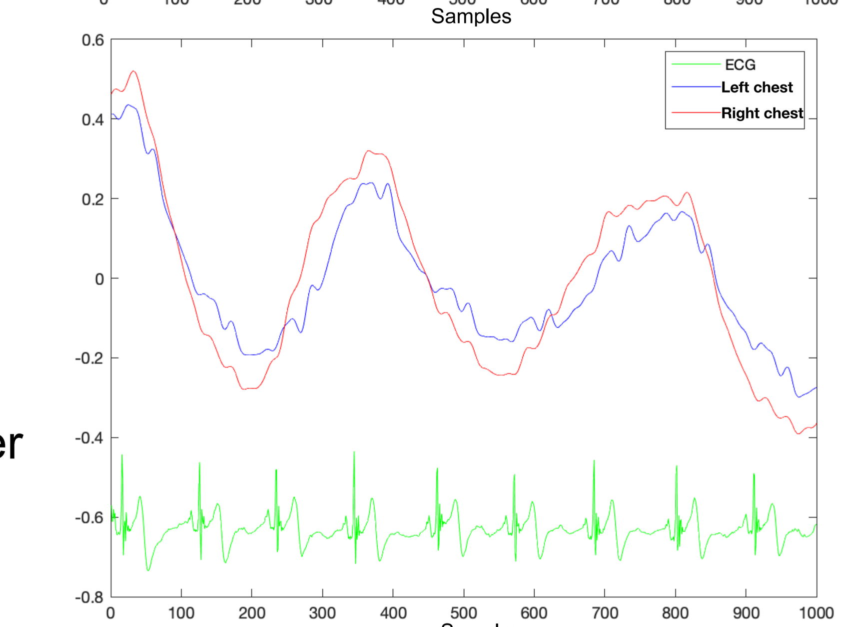


Free-Breathing Data

- Neck radars provide similar waveform to breath-hold
- SSA pipeline appears to preserve pulse waveform and subtract breathing motion
- Less reproducible than breath-hold



- Current method fails to separate breathing from heartbeat in chest radars
- Tuning SSA/ICA pipeline for this purpose could yield better results



Further Work

- Assessing signal robustness:
  - Varying radar position/distance from patient
  - Different patient physiologies
  - Swallowing motion and other artefacts
  - Better breathing/heartbeat separation in free-breathing tests
- Testing radars in MRI scanner on head coil/with a neck pillow
- Neuroimaging deep learning reconstruction algorithms for pulsatile motion artefact reduction