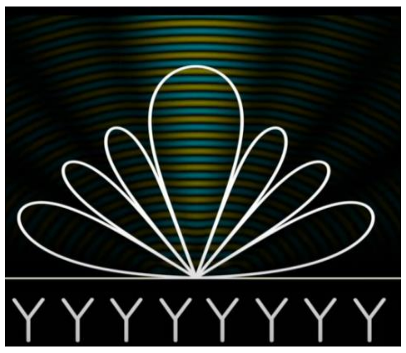
Contactless Detection of Physiological Signal using a 4-Transmitter Phased Array Ultrasound System

Presenter : Ming-Feng Hsin Advisor : Men-Tzung Lo, Lin Chen
Department of Biomedical Sciences and Engineering, Nation Central University, Taiwan

Abstract

Accurate heart rate measurement and monitoring are crucial for diagnosing diseases, yet traditional equipment like ECG is often costly and inconvenient for regular use. To overcome these challenges, we have developed a cost-effective, contactless heart rate monitoring system utilizing a 4-transmitter ultrasound phased array that focuses on the chest area to monitor respiratory motion and offering a practical solution for continuous heart rate monitoring, ideal for rural areas and home care applications.



Material & Method

$$\Delta\phi = \frac{2\pi\, d \sin\theta}{\lambda} \quad (2\pi = \lambda)$$

$$\theta = \sin^{-1}\left(\frac{\Delta\phi\lambda}{2\pi d}\right)$$

$$\Delta\phi = 2\pi f \Delta t$$

$$\theta = \sin^{-1}\left(\frac{2\pi f \Delta t \lambda}{2\pi d}\right)$$

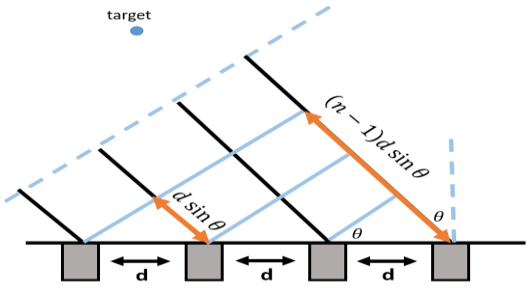


Figure 1. phased array

- By delaying the emission time and carefully controlling the phase of each element in the array, we can steer the beam towards a specific target.

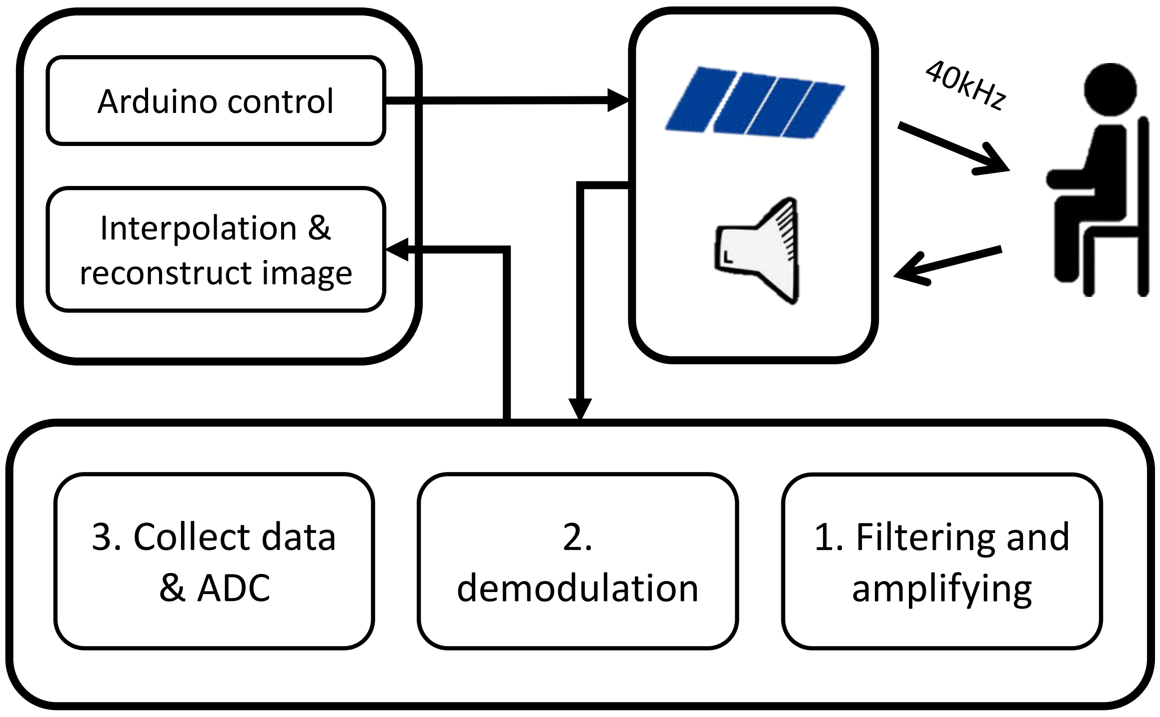


Figure 2. workflow

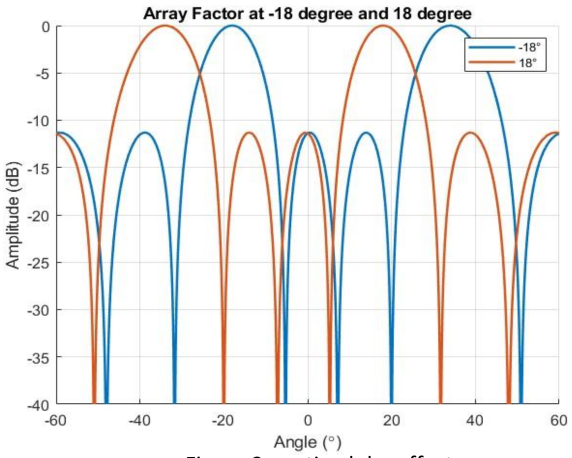


Figure 3. grating lobe effect

- Sometimes the effect of grating lobes is inevitable, even in multi-dimensional arrays. To eliminate the problem, the simplest approach is to calculate the effective detectable range, which is between -18° to 18° in our system.

- In the system, we do not use continue wave but pulse wave, since continue wave do not provide time information.

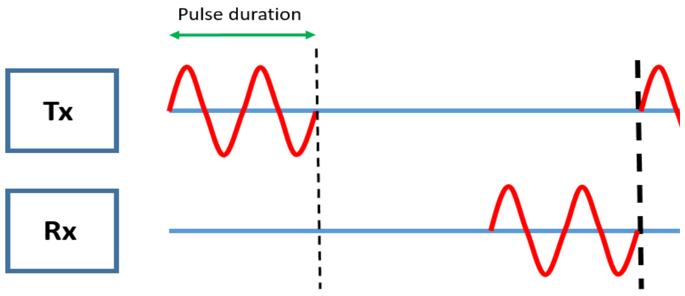


Figure 4. time resolution

And to have better time resolution, we need the short pulse. The short pulse help us see clearly on the time domain because it takes short step and have a wide range in frequency domain, which will help us dealing with Doppler shift and time delay mixing problem.

- In the figure, we could see the beam width, which is the width at the -3db at 0 degrees is 11°. As we start to steer the beam, the width also start to increase. The figure tells us that without the proper setting of phased array, the lateral resolution could be terrible, making it harder to distinguish the object that is too close to each other. We could use more elements or higher frequency to increase the resolution, the need for smaller element and sacrificing distance will give us headache, though.

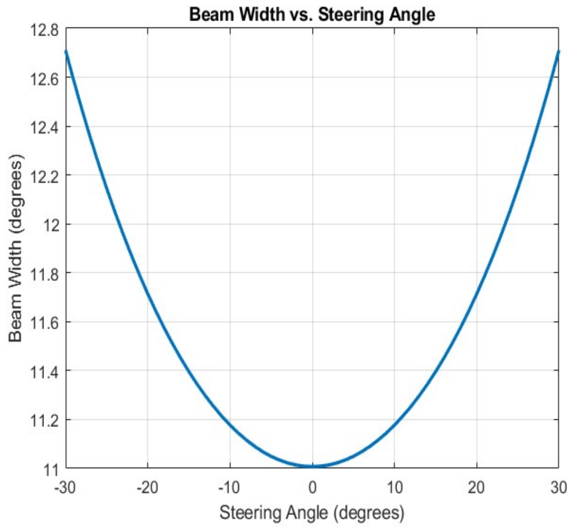


Figure 4. angular resolution

Result

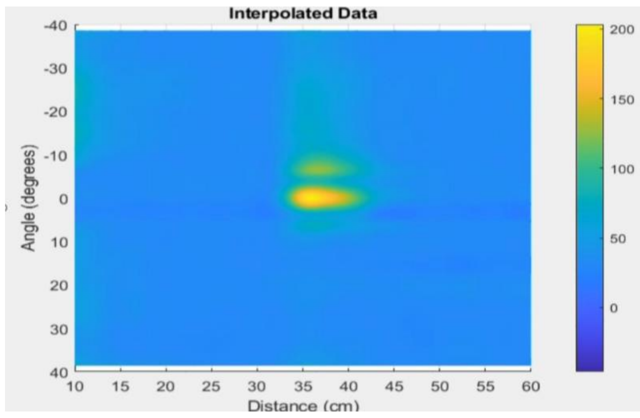


Figure 5. object at 0 degree

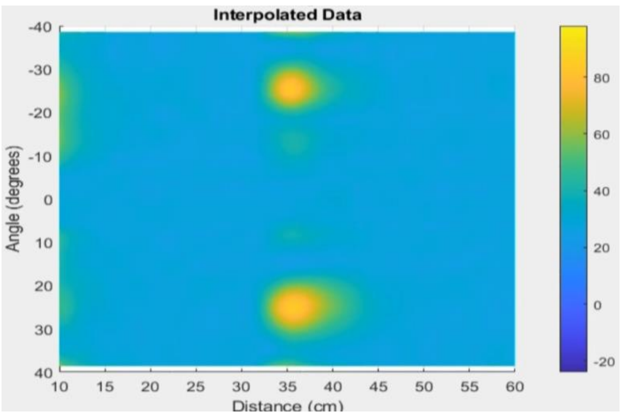


Figure 6. object at 25 degree

- As we change the object's position, the bright area shifts in accordance with the previously calculated beam pattern, demonstrating that the beam steering is effective. We calculate the time difference of the echo signal at these angles to estimate the distance. Initially, we focus on only 19 distinct angles, so we use interpolation to estimate the data for the missing angles.

Conclusion

- We successfully constructed a system capable of detecting moving object and its location.
- In the next stage, we can improve the resolution by adding more elements and adjusting the array configuration, even using more advance method like FMCW.
- To enhance the system function, we plan to try to rewrite the firmware and software code to realize real-time operation.

Reference

[1] Wang, A., Nguyen, D., Sridhar, A.R. *et al.* Using smart speakers to contactlessly monitor heart rhythms. *Commun Biol* **4**, 319 (2021). https://doi.org/10.1038/s42003-021-01824-9

[2] T. Wang *et al.*, "Contactless Respiration Monitoring Using Ultrasound Signal With Off-the-Shelf Audio Devices," in *IEEE Internet of Things Journal*, vol. 6, no. 2, pp. 2959-2973, April 2019, doi: 10.1109/JIOT.2018.2877607.

[3] (2008). Conventional Beamforming Techniques. In: Microphone Array Signal Processing. Springer Topics in Signal Processing, vol 1. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-540-78612-2_3