High-Resolution Robotic Sonar

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Introduction

Traditionally, robotic obstacle avoidance has relied on ultrasonic sonar range finders, which have the drawback of one-dimensional perception, requiring multiple systems operating in conjunction to achieve a desired field of view. This also results in poor angular resolution, directly dependent on the beamwidth of the transmitters used. By using multiple receivers detecting the signal of a single transmitter, the angular resolution and field of view can be greatly improved upon. The project described on this poster attempts to do exactly that with both custom hardware and software being created to make it possible.

An increasingly-popular alternative to sonar is the use of stereoscopic or time-of-flight (TOF) vision systems, which create 3-D depth maps, which allow obstacles to be identified. In order for the final project to be useful for any practical application, its performance must at least match that of 3-D imaging systems such as the Microsoft Kinect [1]. Additionally, while this prototype is not intended for actual use on a robotic platform, size and weight specifications constrain the system such that it can be later modified for this purpose.

System Architecture

The simplified architecture of the system is shown in Figure 1.

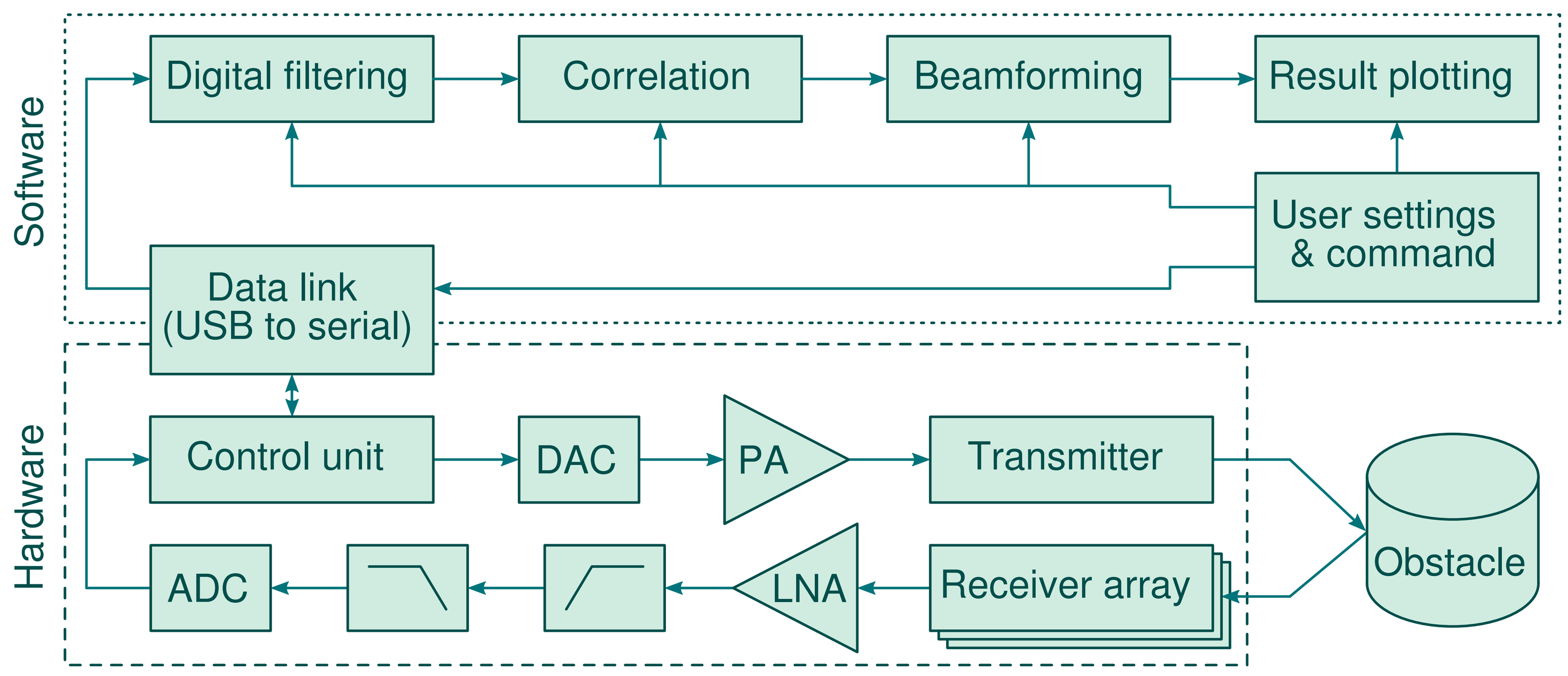

Figure 1. High-level functional block diagram of the complete system.

Signal processing and user interfacing are done on a general-purpose computer. The flexibility achieved in this way allows different algorithms and parameters to be experimented with more easily than on dedicated hardware.

Custom hardware is required to interface with the ultrasonic transducers. On reception, this mainly comprises amplification, anti-aliasing filters and analogue-to-digital converters (ADCs). The transmission circuitry primarily involves the generation of the high-voltage signal (up to 400 V peak-to-peak) necessary to drive the electrostatic transducer.

Ultrasonic Transducers

A high-bandwidth electrostatic transducer, capable of generating greater than 110 dB SPL, was chosen as the transmitter. However, this transducer has the drawback of high directionality, limiting the field of view (FOV). This is solved by making use of a 3-D printed acoustic waveguide to focus transmitted signals through a vertical slot, thereby increasing the horizontal beamwidth.

A surface-mount microphone with exceptional response at ultrasonic frequencies was selected for use as the receiving transducers.

Signal Processing Simulation

A simulation was set up to predict the result of reflection in an anechoic environment, given various parameters. Results are returned as intensity as a function of angle and range. The simulation proceeds as outlined below.

1. A linear FM chirp is generated.
2. Reflection off of an ideal point target is simulated by applying the estimated time shift and propagation loss for each receiver.
3. The received signals are sampled and quantized.
4. Time- and spatial-domain windowing is performed on the received signals.
5. A Hilbert transform is applied to both the received and transmitted signals, and complex correlation performed.
6. Iterating over range and angle, beam forming is performed by summing the correlation result from each receiver for the corresponding time-of-flight from each transmitter. This beam forming process is similar to that described by [2], but differs in that both angle and range are used as inputs (far-field operation is not assumed).

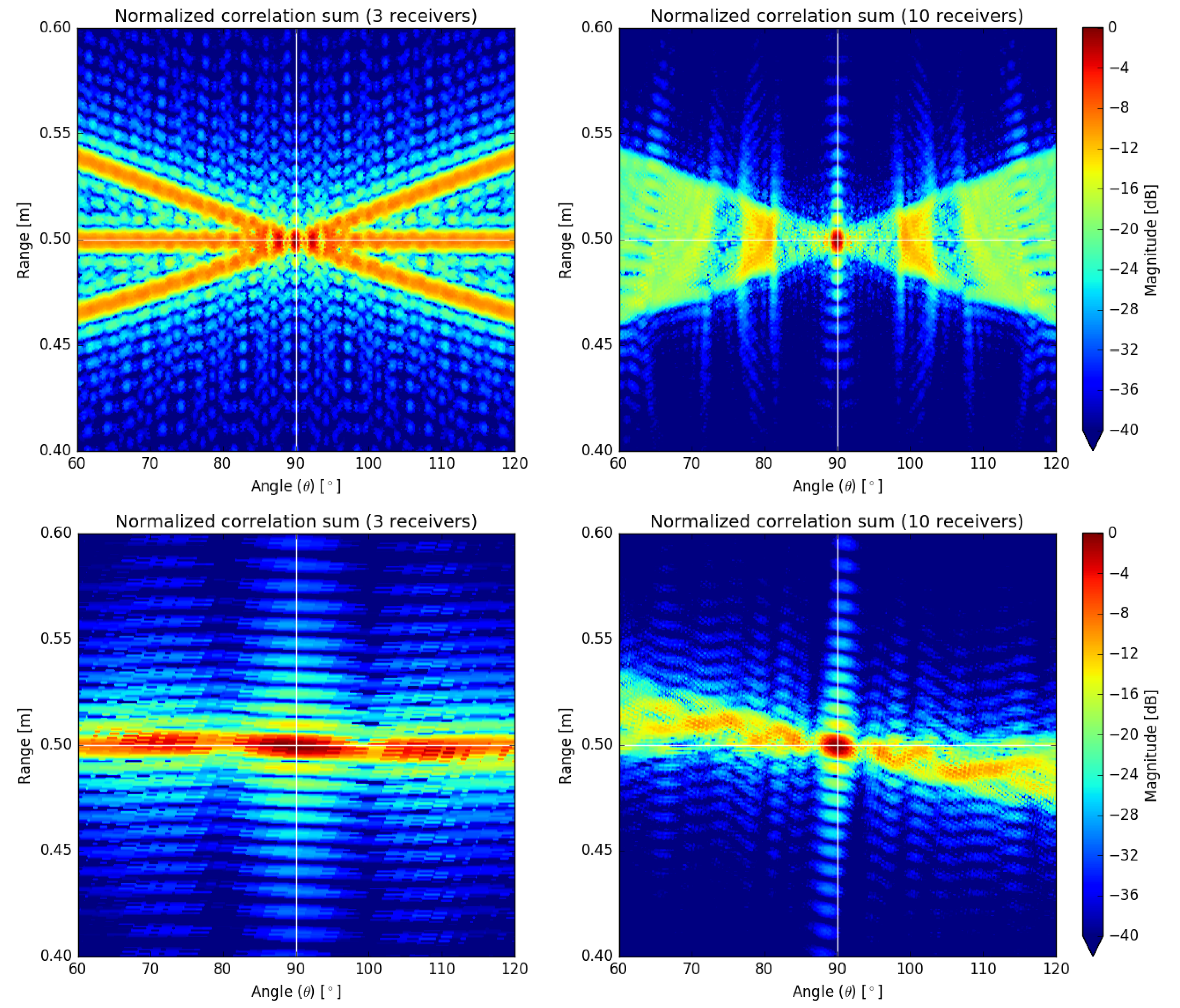

Figure 2. Simulated return form an ideal point target placed at a range of 0.5 m with θ = 90º. The top two results are obtained using a linearly-spaced array of receivers, and the bottom two using an array generated by using the process described in [3].

As Figure 2 illustrates, a greater number of receivers improves the resolution of the system. From these simulations, an estimate of the number of receivers required to achieve a given angular resolution specification can be obtained.

Conclusion

Successful implementation of the described system would demonstrate the viability of a multi-channel sonar system for robotic obstacle avoidance, and in turn robotic navigation. This would give an alternative to simple sonar range finders, and to computationally-intensive and lighting-sensitive stereoscopic and TOF systems.

References

[1] (2016, Sept.) Kinect – Wikipedia, the free encyclopedia. [Online]. Available: https://en.wikipedia.org/wiki/Kinect

[2] J. Steckel, A. Boen and H. Peremans, "Broadband 3-D Sonar System Using a Sparse Array for Indoor Navigation," in *IEEE Transactions on Robotics*, vol. 29, no. 1, pp. 161-171, Feb. 2013.

[3] W. P. du Plessis, "Ultra-wideband array synthesis using the IFT technique," *International Conference on Electromagnetics in Advanced Applications (ICEAA)*, Cape Town, 2012, pp. 820-823.

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