LIDAR COLLISION AVOIDANCE SYSTEM WITH AUDIO FEEDBACK FOR VISUALLY IMPARIED INDIVIDUALS

Julian Maravilla, Haruka Shimada, and Hua Lee
University of California, Santa Barbara
Department of Electrical and Computer Engineering
Santa Barbara, CA 93106
julianmaravilla@ucsb.edu, bmq1091@mail4.doshisha.ac.jp, hualee@ucsb.edu

Faculty Advisor:
Hua Lee

ABSTRACT

In this paper, we present the 4th-generation, light-weight low-power collision avoidance system. For this new version, the ultrasound transmitter of the data-acquisition component is replaced by a Lidar to avoid multi-paths in complex environments. The estimate of the target range is quantized into a frequency bin and represented by acoustic waveforms within the human hearing range. The bearing angle of the target is utilized to produce the temporal offset between the twin channels of the corresponding acoustic waveforms. This wearable and hearable device is designed for real-time navigation for the blind.

INTRODUCTION

The anti-collision systems have evolved from unmanned vehicle navigation to aids for visually impaired individuals. Traditional collision avoidance aid for visually impaired individuals involves using a probing cane. More experienced individuals can detect the time delay of their own tongue clicks to locate upcoming obstacles. This method can be applied electronically by utilizing a scanning range finder with audio feedback. Bearing angle generation can be used to pinpoint the location of upcoming obstacles. Therefore, individuals can lose their dependency on a probing cane for a device that is light weight and compact. Scanning range finders are still relativity expensive. Therefore, a single receiver/transmitter Light-Detection-and-Ranging (Lidar) system can be used to replace a probing cane by providing audio feedback in the form of amplitude shifting or alternating audio signals depending on the distance to the nearest obstacle. A single Lidar module allows for a low power, low cost consumer friendly device that can compete with the traditional probing cane.

PRIOR GENERATIONS AND APPLICATIONS

This device is the 4th-generation of the single-transmitter twin-receiver collision avoidance system. So, it is important to review the previous generations in order to clearly illustrate the design concept and objectives.

The first generation was a radar system developed for aerial vehicles. The transmitted signals from the centered antenna are microwave waveforms, with a frequency band from 1 GHz to 2

GHz. Two tracks of echoes are detected by the twin receiving antennas. The time delays with respect to the transmitted signal can be used to determine the range distance. The accuracy of the time-delay estimation is governed by the bandwidth of the transmitted waveforms,

$$\delta_t = 1/B$$

The range resolution is thus,

$$\delta_r = v/2B$$

where *v* is the propagation speed. The additional factor of two is due to the round-trip travel. For the 1 GHz bandwidth, the range resolution in air is *15 cm*.

The relative time offset between the two received echo tracks determines the bearing angle of the target. The bearing angle can be estimated from the time offset between the two signal tracks from the twin receivers as,

$$\sin(\theta) = v\Delta t/BD = \Delta r/BD$$

The main advantage of this system is the accuracy in range and bearing-angle estimation. The major barriers include the size, weight, costs of the electronics, the computation complexity, and latency due to the procedures for data acquisition and signal processing. Figure 1 shows the flight path of collision avoidance experiments.

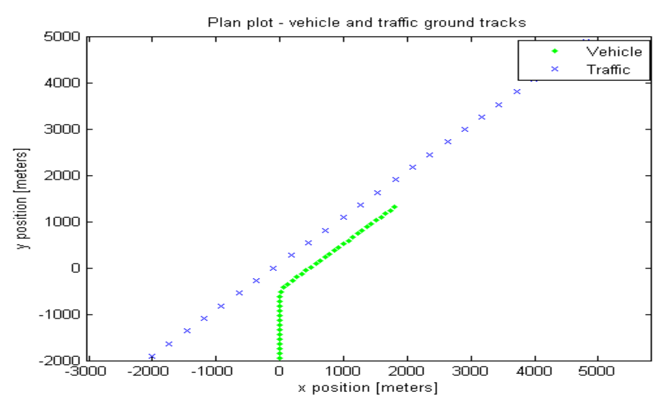

Figure 1 Flight path of collision avoidance experiments.

The second-generation device is designed and developed as a forward looker for underwater manned vehicles. The transmitted signal is a high-frequency acoustic waveform in order to achieve the desired resolution. For real-time implementation, the signal processing electronics are simplified significantly, and the returned echoes from the twin receivers are down converted to the human hearing range for direct hearing by the users. The simplification enables real-time system implementation. The distance between the receiver pair is set to be the same of the separation between the ears such that the user can have accurate perception of the bearing angle from the audio tracks. Because of the lack of time reference with the transmitted signal, the perception of the range is largely based on the magnitude of the echoes. User experience becomes important in order to compensate for the deficiency due to poor range resolution. In complex environments, the system also introduces significant multi-path echoes.

The third generation of the system is also a single-transmitter twin-receiver device with a similar configuration. The transmitted signal is a wideband ultrasound waveform. An ultrasound probing signal is used for this device to avoid interfering with the audio signals in the hearing frequency range. The received echoes are down-converted to the hearing range in a similar manner. The distance between the two receivers is also set to be the same as the distance between the ears of the user for accurate perception of the bearing angle from the arriving echoes. The transmission power is adjusted according to the desired operating range. The core signal processing component is a mixer for down-conversion and a bandpass filter to place the resultant signals to a frequency band within the hearing range preferred by the user. Thus, in terms of system complexity, this version is considered basic in both hardware and software. The main objective of this system is to operate in air for the navigation of the visually impaired. The advantage of this system is the simplicity in hardware implementation, which enables real-time capability. However, it shares the similar deficiencies of the 2nd-generation system with range ambiguity and multi-path interferences. Figures 2 and 3 show prototype systems for the ultrasound navigation.

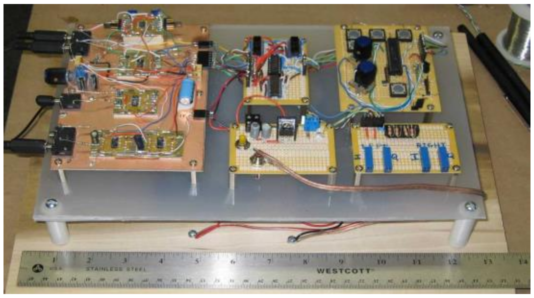

Figure 2 First prototype system for the ultrasound navigation.

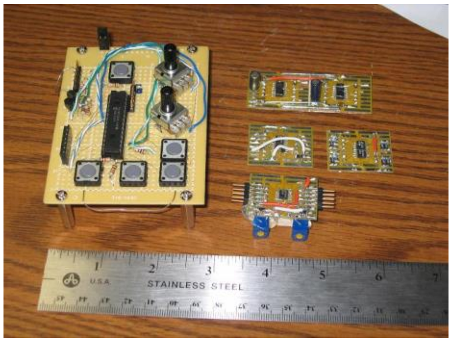

Figure 3 Second prototype system for the ultrasound navigation system.

The 4th-generation system shares the same application with the 3rd-generation system, which is for the navigation of the visually impaired. The objective is to overcome the technical barriers and disadvantages to achieve the capability of

- Real time
- Light weight, low cost, small size
- Wearable and hearable
- Accurate in range and bearing-angle estimation
- Without multi-path interferences.

The data-acquisition component is now replaced by a Lidar in order to achieve high accuracy in range and bearing-angle estimation without multi-path interferences. Signal processing procedures are embedded into hardware for real-time implementation. Hardware components are all commercially available for low cost and high reliability. The system is also developed with small-size, low-power, and light-weight constraints, in order to be wearable. Because it is designed for the visually impaired, all outputs are designed to be in audio format. The design objectives and specifications are summarized in Table 1. Table 2 outlines the advantages and deficiencies of the previous systems.

Generation	*systems*	*transmitted waveforms*	*system output*
1	*Aerial vehicles*	*microwave*	*electronic*
2	*Manned underwater vehicles*	*acoustic*	*audio*
3	*Navigation for the visually impaired*	*ultrasound*	*audio*
4	*Navigation for the visually impaired*	*Lidar*	*audio*

Table 1 Design objectives and specifications of prototype systems.

Generation	*advantages*	*deficiencies*
1	*accuracy*	*electronic and computation complexity*
2	*simplicity*	*poor range resolution and multi-path interferences*
3	*simplicity*	*poor range resolution and multi-path interferences*

Table 2 System performance of the prototypes.

SCANNING LIDAR ANTI-COLLISION AUDIO FEEDBACK SYSTEM WITH BEARING ANGLE GENERATION

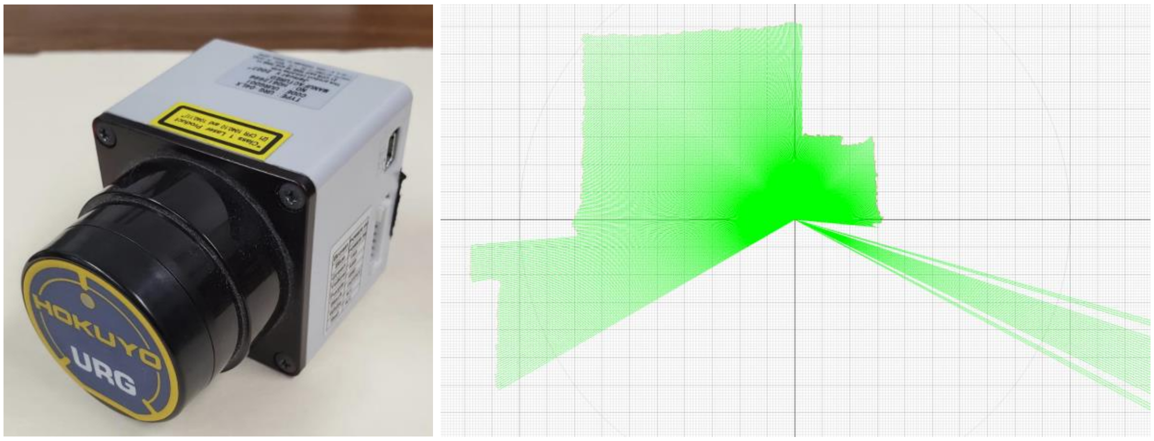

Figure 4 Hokuyo URG-04LX w/Data Map.

The 4th-generator device begins with the utilization of a scanning range finder. The Hokuyo URG-04LX is an advanced scanning laser range finder [2]. The URG-04LX can produce a planar point map with *638* distinct points. Data received from the URG-04LX is in the form of a magnitude and an angle corresponding to each of the *638* points. Application software provided by Hokuyo is utilized to receive range data for the *240°* angular-range. The scanning laser is designed to have a range of *4 m* with an accuracy of *1 mm* (*0.36°* angular resolution).

To avoid self-detection with the scanning range finder, the angular range is reduced to *180°*. This field of view is sufficient for obstacle detection. The *180°* range is sub-divided into a set number of regions each representing a different bearing angle for the audio feedback. A simple 5-region break down is presented, however this can be extended into more sub-divisions.

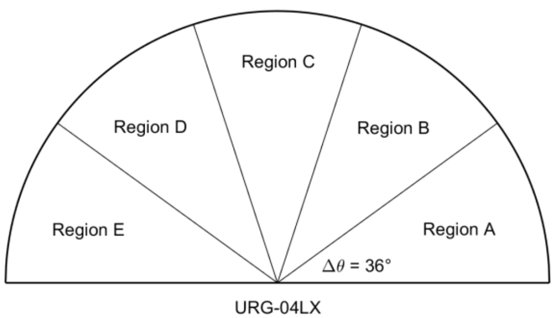

Figure 5 Division of Angular Range.

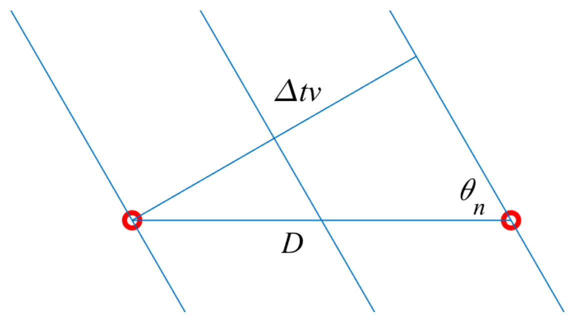

Figure 6 Bearing Angle Model.

The regions are labeled *A* through *E*. A model for the bearing angle is presented in Figure 6. A positive angle represents a delay for the left audio channel and a negative angle represents a delay for the right audio channel. For simplicity, the right audio channel is fixed allowing the left channel to alternate between leading and lagging samples. The audio signal can be represented by a discrete signal $f[n]$ whose sampling frequency is *44.1kHz*. The mono track is played on both the left and right audio channels. The fixed right channel (1) maintains the original mono audio signal while the left channel (2) is actively shifted depending on the desired bearing angle. Incoming sound is modeled as a planar wave front that hits two receivers (an individual's ears). Basic geometric relationships reveal the relationship between the time delay associated with signal receival and the desired bearing angle [1]. Normal bearing angle estimation uses correlation between the two signals to reveal the power spectrum which contains a peak at time Δt which is the time delay between individual signal receival utilized to estimate the bearing angle. For this system the bearing angle is generated by locating the number of leading or lagging samples. Therefore, the limiting factor in accuracy comes down to the angular resolution determined by the sampling rate of the audio signal.

$$f_R[n] = f[n] \quad (1)$$

$$f_L[n] = f[n-N(R)] \quad (2)$$

$N(R)$ is a function corresponding to the lead or lag of the left channel depending on the bearing angle. The sampling period of the signal ($T_s = 1/f_s = 22.676\mu s$) is the time resolution used to locate the angular resolution. The angular resolution will be used to determine the number of leading or lagging samples for the left channel.

$$sin\theta = v\Delta t/D$$

$$sin\Delta\theta = v\, T_s /D$$

$$\Delta\theta = sin^{-1}(v\, T_s /D) \quad (3)$$

Assuming a fixed speed of sound ($v = 343\ m/s$) and using the average distance between the ears ($D = 21.5\ cm$), the angular resolution $\Delta\theta$ is $2.0732°$ (3). The Hokuyo URG-04LX has better angular resolution, therefore its limitations can be ignored. Increase the sampling rate of the audio will produce better angular resolution. The angular separation between Regions *A* through *E* is *36°*. Therefore, the midpoint angle in each region will be used to map the delay function *N(R)* (4). $\theta(R)$ corresponds to the angle θ_n in Figure 6 with respect to the region of interest. A bearing larger than *90°* hits the left ear before the right ear leading to a time lead on the left audio channel. Therefore, *N(R)* is rounded to the nearest integer and is negative when the object is closer to the left of the sensor allowing the user to recognize the location of the object.

$$N(R) = \theta(R)/\Delta\theta \quad (4)$$

	θ(R)	*N(R)*
Region A	*72°*	*35*
Region B	*36°*	*16*
Region C	*0°*	*0*
Region D	*-36°*	*-16*
Region E	*-72°*	*-35*

Table 3 Example of *N(R)* Mapping.

Table 3 shows the mapping for a 5-region division of the angular range. This concept is implemented in code. A function taken from Hokuyo's programming library is implemented in order to record real time data [2]. Each region is surveyed until the region with the closest object is determined. The left audio channel will then adjust its delay to meet the desired bearing angle in the direction of the nearest obstacle. Therefore, the user will be able to estimate the location of the nearest obstacle. As the user gets closer to the object the amplitude of the signal *f[n]* will increase to warn the user. Audio feedback is provided by a pair of standard headphones. All data processing can be completed on a Raspberry-Pi. The entire set up will be light weight and power efficient however the cost of the Hokuyo UR-04LX is too high to be a reasonable replacement for a probing cane. Therefore, a simpler anti-collision device is presented with a single transmitter, single receiver Lidar.

Figure 7 TFMini Module and Range Information Displayed in Terminal.

The TFMini infrared range finder is a single beam LIDAR system that uses time of flight to determine the distance between the sensor and its nearest obstacle with respect to the direction of the beam [3]. Equations that describe time of flight estimation are shown below. A factor of one half is used to correct for the round-trip travel of the laser (5). Data received from the TFMini is in the form of a memory address (9 bytes in length L_a). This memory address contains range, strength, and checksum information. By converting the hexadecimal range information into a Python variable, real-time range information can be recorded and displayed. Data processing is completed on a Raspberry-Pi. Any Raspberry-Pi model that supports GPIO can be utilized to interpret the range information. The baud rate used for GPIO is *115,200 bits per second* (defined as B_R). With this information the time between range samples can be calculated as in (6).

$$D = c\Delta t/2 \tag{5}$$

$$\delta t = 8L_a/B_R = .625ms \tag{6}$$

A Python function taken from the TFMini-RaspberryPi repository [4] is used to record the R_x signal from the range finder module. The Pigpio module is utilized to treat any GPIO port as a serial interface. Therefore, a while loop can be used to continuously read time of flight data from the range finder. The time module in Python is used to control the rate of data receival.

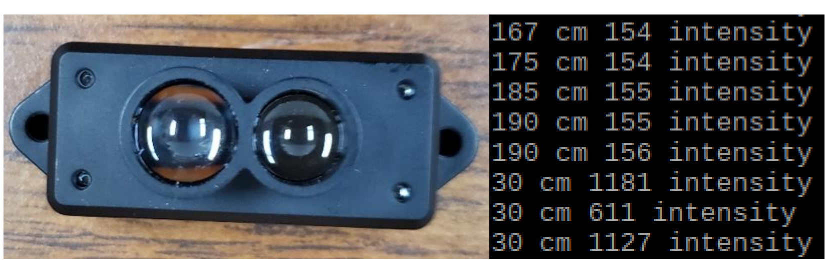

Figure 8 TFMini Module and Range Information Displayed in Terminal.

For audio feedback the PyGame module is used to load and play audio files. Threshold distances determine the type of audio feedback. As an example, piano keys from *A* to *E* are used for audio feedback. As the user reaches the first range threshold the *A* piano key will play continuous until they move away from the obstacle or trigger the next region. The piano keys will actively change as the time of flight is reduced. The final audio key *E* will be played once the last range threshold is met. In developer mode, the audio feedback can be altered. A user can select different audio files for play back. The sampling rate of range data needs to be adjusted to avoid audio clipping between different thresholds. Too fast of a sampling rate will cause audible clicking due to multiple audio files trying to be played at the same time. To prevent this, the sampling rate is reduced to ensure that the audio files have enough time to play and fade out in order to provide a smooth transition. For example, the piano key audio files are *0.3s* long and the data sampling rate is set at *0.45s* allowing the audio to fade out.

	Range Threshold	*Piano Key Played*
Threshold A	*110cm*	*A*
Threshold B	*90cm*	*B*
Threshold C	*70cm*	*C*
Threshold D	*50cm*	*D*
Threshold E	*30cm*	*E*

Table 4 Example of Range to Audio Mapping.

Table 4 is an example of audio to range mapping. To make this device universal for all individuals, a *3.5"* touch screen is added to adjust the range thresholds. A user might want different ranges and/or more regional thresholds. Therefore, the small touch screen provides a simple and cost-effective solution for easy adjustment. The user interface is generated by using the Python module Tkinter. Tkinter functions allow for the generation of a graphical overlay with multiple drop-down menus. The drop-down menus allow the user to adjust the ranging thresholds. Altering the ranging threshold variables will take place on the cycle proceeding the changes.

Figure 9 Raspberry-Pi and Touch Screen Module with User Interface.

The touch screen, Raspberry-Pi, and TFMini are all powered by 5V. A micro-USB interface provides power to the Raspberry-Pi. Two GPIO pins on the Raspberry-Pi provide 5V for the touch screen and LIDAR. Therefore, only the Raspberry-Pi needs connection to an external power source. A simple lithium-ion cell or portable charger can be used to power the device. For this prototype a simple modification to a Raspberry-Pi touch screen case is performed to provide a compact and lightweight design.

Future improvements to this design involve generating a 3D printed case for a more seamless design. More TFMini modules can be attached in order to generate a bearing angle estimator as previously performed with the Hokuyo URG-04LX scanning range finder. Audio amplitude scaling can also be implemented so the user can listen to their favorite music and still avoid obstacles. The amplitude of their music will increase as the time of flight decreases.

CONCLUSION

This 4th-generation anti-collision device takes the concept from the 3rd-generation and provides a solution to its size and multipath issues. The scanning range finder design utilizes the concept of bearing angle to provide audio feedback in the form of directional audio bearing in the direction of obstacles. High costs cause this design to be unfeasible now; however, Lidar technology progression will eventually allow for more cost-effective scanning range finder solutions. The single transmitter/receiver Lidar anti-collision device is designed to compete with the transitional probing cane. Its ability to provide amplitude shifting and/or adaptive audio feedback would allow visually impaired individuals improved mobility. Future work will involve adding more Lidars for multi-directional anti-collision systems for bikes and motorcycles.

REFERENCES

[1] Hua Lee, *Acoustical Sensing and Imaging*, CRC Press, 2015.
[2] M. Maeda and M. Shibuya, "Scanning Laser Range Finder URG-04LX Specifications", October. 2005.
[3] Benewake Co. Ltd. "TFmini Infrared Module Specification", 2018.
[4] D. Q. Weifeng, TFMini-RaspberryPi GitHub Repository, 2018. (Available on-line at https://github.com/TFmini/TFmini-RaspberryPi)