LiDAR System with B-L475E-IOT01A board

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I. Introduction

The project is focused on creating a LiDAR (Light Detection and Ranging) system to improve the daily lives of the elderly, particularly by assisting the elderly in moving around their living areas with safety and independence. The LiDAR system includes five essential components: a Time-of-Flight (ToF) Sensor, QSPI Flash, UART, OLED display screen and a DAC Speaker. With the integration of these features, the team successfully developed a LiDAR system capable of accurately measuring distances and generating a virtual map of the user's surroundings. This functionality serves to prevent collisions with obstacles, enhancing the overall safety and autonomy of the elderly individuals using the system.

II. System Overview

The project aims to develop a LiDAR (Light Detection and Ranging) system to better facilitate the elderly in various ways, specifically to aid the elderly in navigating their living spaces safely and independently. The LiDAR system measures distance accurately and creates a virtual map of the user's surroundings, effectively preventing collisions with walls and obstacles.

At its core, the system employs ToF (time of flight) sensors that continuously scan the environment, detecting and measuring distances to objects and walls in real-time. The retrieved data from the sensor is then stored in QSPI flash, the non-volatile memory feature of the flash allows advanced data processing such as showing the average of the distance measured in a given period. A sophisticated algorithm is implemented to create a dynamic and real-time virtual map of the surrounding obstacles, allowing the system to identify potential hazards or obstacles in the user's path.

A key feature of this LiDAR system is its user-friendly interface, which is designed to be intuitive and easy for the elderly to understand and interact with. Alerts and guidance are provided through audio signals generated from the DAC speaker, ensuring that users are aware of their proximity to obstacles without causing any discomfort or confusion.

As shown in Fig. 1, the four pins on the display screen, arranged from left to right, are connected to GND, 5V, D14 (SDA), and D15 (SCL) on the board, respectively.

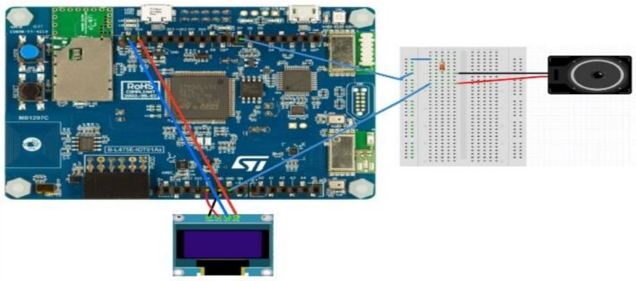


Fig. 1. Block diagram showing the system overview

III. Design Approach

A. Design Overview

To achieve accurate distance measurement, real-time alarms, and smooth value display, four main blocks need construction for this LiDAR system: a precise distance sensor for measurement, large non-volatile storage for data retrieval, simultaneous task processing for real-time updates, and visual, sonic, and analytical results display.

The team chose the Time-of-Flight (ToF) Sensor to implement the measuring task because its principle is based on the speed of light, theoretically making its measurements fast and accurate. Tests of this single component were conducted, and the accuracies are shown below. It can be observed that the results are consistent with our assumption.

After successfully obtaining distance values from the sensor, the QSPI Flash was implemented for data storage. This approach refrains from creating large buffers and occupying vast memory space. Furthermore, by taking advantage of the non-volatile feature of the Flash, the LiDAR system does not lose its sampled data even when powered down, which could be vital for future data analysis.

In terms of writing and accessing data, the LiDAR system requires continuous sensor reading, and the display should be able to react concurrently. This real-time responsiveness was achieved by using the Operating System (OS) and multitasking implementation. This project was structured into three main software tasks: GetDistance, ReadDistance, and Draw, responsible for obtaining sensor data, reading data from flash and displaying it on the terminal, and real-time drawing on the screen, respectively. All tasks were set to run simultaneously, while a further optimization method, the Mutex, was dedicated to blocking the reading process before obtaining new data from the sensor. In the multithreading environment of our system, these two tasks are accessing the flash concurrently with the same priority, which can cause the reading task to perform multiple readings while the distance value in the flash has not been updated, while a further optimization method mentioned below was dedicated to blocking the reading process before obtaining new data from the sensor.

For the final and vital part, the system should trigger an alarm when the obstacle is getting too close. The threshold was set to 160 mm, analogous to future real-life applications, considering a limited sensor range (20-1800mm). To generate a fixed sound when the distance value was below the threshold, a speaker was used, and the waveform it played was transmitted through direct memory access (DMA). This eliminates the need for a timer interrupt callback, saving CPU cycles for other tasks and reducing power consumption. A user interaction using the pushbutton with UART transmission was also implemented. When a button press was detected, an interrupt would be triggered, and the average of all stored data would be computed and transmitted to the terminal. Otherwise, the terminal would keep displaying the precise distance values in millimeters. Furthermore, for better visualization, the team incorporated the system with an OLED Display Board supporting two colors. Each distance value would be mapped to the 128x64 screen coordinates and represented by a single pixel. Values below the threshold were drawn in a different color. As the reading of values was continuous, this LiDAR system achieved a wave-like real-time distance visualization.

B. *Design Problem*

In developing a practical LiDAR system to enhance assistance for the elderly, the team encountered several key design challenges. Balancing a limited budget against providing good assistance for users demands a thoughtful approach.

To improve user experience and better serve the elderly, the team has opted to report the average of collected data regarding the distances of detected obstacles. The average value offers crucial information on road conditions, helping the user to make better decisions about their routes. However, the significant challenge lies in ensuring the permanent storage of this data, even when the device is powered off. The team has come up with a solution to address this challenge, which will be discussed later in this report.

Furthermore, real-time feedback is essential for keeping users informed about their surroundings and the proximity of obstacles. To achieve this, our team has integrated an OLED display screen that visually represents the real-time distance data. Considering the purpose of our LiDAR system, which was designed for walking sticks, the display screen is intentionally designed to be compact. Therefore, displaying real-time data seamlessly requires a carefully considered approach.

In addition, maintaining the reliable performance of the LiDAR system in various environmental conditions, such as varying brightness and the presence of obstacles with reflective surfaces, posed challenges. The team had to carefully address the limitations of the Time-of-Flight (ToF) sensor to guarantee the accuracy of reported data.

C. *Solution*

To meet the requirement of a robust data storage solution, the team has successfully integrated flash technology. Implementation of flash technology allows for the preservation of crucial information even when the devices are powered down. When an obstacle has been detected, the corresponding distance data would be written into the flash memory. Unlike RAM, flash storage enables users to access historical information at their convenience. This feature empowers users to retrieve comprehensive reports, including average data summaries, providing valuable insights whenever needed.

Our team has developed a sophisticated function to plot real-time data on the screen. This involves mapping the collected data to corresponding pixels, creating a visual representation of the distances from detected obstacles. Our system is designed to efficiently manage screen space – when the screen is full, the entire screen is swiftly cleared within a neglectable timeframe to make room for new data. This process ensures that our LiDAR system provides users with seamless and high-efficiency visual representation, allowing for immediate insights into surrounding scenarios. Notably, to enhance user safety, our system includes an alert mechanism for distances less than 160mm from an obstacle. This is achieved not only through an audible alarm but also by dynamically altering the color of displayed plots to yellow, ensuring users are informed about approaching obstacles.

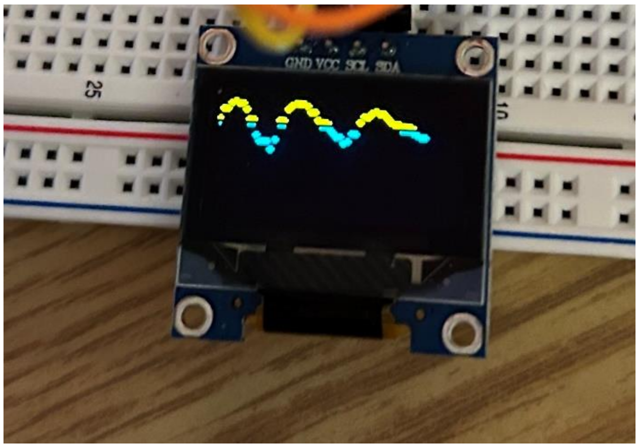


Fig. 2. OLED display screen plotting real-time data

As previously indicated, the Time-of-flight (ToF) sensor exhibits optimal performance within a range of 20-1800mm. To guarantee the sensor provides precise and meaningful information, the LiDAR system exclusively considers values greater than 20mm and less than 1800mm as effective and valid. This helps our LiDAR system keep the data accurate, sticking to our goal of providing trustworthy insights within our system's working range. Even when the environment gets unpredictable, these rules help the LiDAR system maintain the reliability and accuracy of collected data, ensuring the system performs well under varying conditions.

D. *Testing and Evaluation*

To fully testify the functionalities of the LiDAR system, firstly, the individual components as well as the system as a whole should be tested. The quantitative analysis of these test results ensures a deep understanding of the system's performance and the efficacy of the design approach made. Apart from the quantitative analysis of the test results, the user experience test should also be conducted at the end of the testing phase to provide insight into the system's usability and overall user experience.

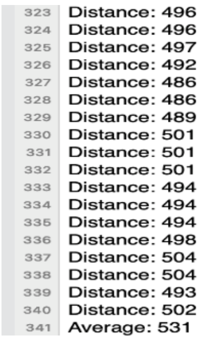
a) Distance Accuracy Testing: The team compared displayed distance result with the manually measured data.

The same tests are carried out using ultrasonic sensors as an alternative design choice for comparative analysis. The precision and time cost of ToF is much satisfying compared to ultrasonic sensor.

TABLE I. RANGE TEST FOR SENSORS

Acutal distance/mm	*Ultrasonic sensor output/mm*	*ToF sensor output/mm*	*Ultrasonic sensor Percentage of errors/%*	*ToF sensor percentage of error/%*
1800	out of range	1790	N/A	0.56
900	890	896	1.1	0.44
300	295	298	1.6	0.67

b) Flash memory storage: The QSPI flash storage enables history data retrieval and reliable data storage. The data accessing and content of the QSPI flash should be compared to data without the usage of mutex. The reduction in number of repetitions of similar data is expected.



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323 Distance: 496
324 Distance: 496
325 Distance: 497
326 Distance: 492
327 Distance: 486
328 Distance: 486
329 Distance: 489
330 Distance: 501
331 Distance: 501
332 Distance: 501
333 Distance: 494
334 Distance: 494
335 Distance: 494
336 Distance: 498
337 Distance: 504
338 Distance: 504
339 Distance: 493
340 Distance: 502
341 Average: 531
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Fig. 3. Output of reading from Flash

c) Alarm system: The alarm system is implemented to trigger accurately under 160mm. To test whether the alarm will respond to the threshold, a wood board is used to approach the LiDAR system and verify the alarm activation when the object is within the predefined threshold.

TABLE II. ALARM TRIGGERING TEST RESULT

ToF sensor output/mm	*Alarm triggered*
60	yes
150	yes
170	no
1750	no

IV. CHOICE OF PARAMETERS

Based on comprehensive investigation and testing, we've come to the realization that our current selection of the threshold for triggering an alert is not the most effective. In order to optimize and enhance the overall performance, we have implemented an adjustment in the selection of the threshold.

After conducting a more detailed investigation into human reaction times, we discovered that the reaction times of adult humans tend to decrease with age, slowing down by a rate of 2–6 milliseconds per decade in response to simple tasks [1]. Given our LiDAR system is designed to better assist the elderly, we have decided to increase our threshold for triggering the alarm from 100mm to 160mm. This adjustment provides aging individuals with more reaction time when faced with approaching obstacles, and it helps reducing the risk of harm. From our test results after making this optimization, as shown in table two, the revised threshold has proven effective in eliminating false alarms. This modification contributes to the stability and consistency in essential aspects of our LiDAR system.

Considering various factors, we have maintained the parameters of delay time and the frequency of the DAC speaker the same as our initial design. We have chosen to keep the frequency of the DAC speaker at 1kHz and maintain the delay time at 100 milliseconds. Through testing, both in our initial design and after optimizing it, we have confirmed that these values not only meet our requirements but also contribute to the stability of our LiDAR system.

V. OPTIMIZATION

To offer real-time feedback to the user, the project uses a multitasking approach where the three primary tasks, collecting sensor data and storing it into flash memory, reading data from flash memory, and drawing on the screen are each assigned to sperate OS thread. By doing so, a great amount of CPU resources can be saved.

Since these threads run concurrently, they can execute independently without waiting for one another to complete their respective tasks. One of the outcomes is that the reading data task could be executed prior to the other tasks causing repeated reading operation. Mutex is implemented to ensure that only one task accesses the value at one time, and the reading task will wait until the writing of new data is complete.

To implement Mutex, the thread dedicated for reading the data would call osMutexWait () to lock the mutex. If the mutex is already locked by another thread, the calling thread will be blocked until the mutex becomes available. At the end of the thread, osMutexRelease () is called to release the Mutex such that other threads that currently wait for the same mutex will be now put into the state READY.

With Mutex embedded, it can be observed from the printed messages on the terminal that there was a considerable reduction in duplicated reading values, proving the effectiveness of this approach.

VI. RECOMMENDATION

As with any project, there are areas where improvements or alternative approaches could be considered to enhance working efficiency and overall quality. In the process of implementing the LiDAR system, the team has acquired valuable hands-on knowledge and experiences. Reflecting on the entire process, the team has identified several points where improvements could have been made, as outlined below.

First and foremost, connecting the motor to the microcontroller should be approached with utmost caution. The feedback current from the motor brings a significant risk to the microcontroller and requires careful handling. Additionally, simulating human walking with the motor is unnecessary, especially considering the unfavorable trade-off between the risk of feedback current and the achieved accuracy.

Moreover, better time management could improve our working efficiency. Assigning specific responsibilities to each group member is a crucial step. This enables parallel completion and greatly enhances our ability to successfully conclude the project with higher efficiency. With a higher working efficiency, the team could allocate more time for conducting comprehensive and thorough testing.

Last but not the least, instead of only doing alpha test, which takes place within our team, user testing with the elderly or individuals with similar needs should be also conducted. Direct feedback from users can be valuable for making improvements and addressing any issues that users may encounter in real-world scenarios.

The process of building this LiDAR system has been a dynamic learning process, highlighting the importance of continuous improvement. These insights serve as valuable lessons that could greatly contribute to the success of future studies in similar domains. Recognizing these factors helps us approach future projects with a better understanding, enabling us to implement improvements and, given the opportunity, achieve even greater success in our endeavors.

VII. CONCLUSION

The team has demonstrated an approach to developing a LiDAR system for assisting the elderly. The integration of the Time-of-Flight sensor, QSPI Flash, UART, real-time multitasking, and visual representation through an OLED display addresses key challenges. Additionally, the introduction of Mutex further improves the performance of our LiDAR system. It helps to reduce the occurrence of repeated reading operations and ensuring efficient data handling. Noticing the significant drop in duplicated reading values in the printed messages on the terminal highlights the real effectiveness of these optimizations. This integration serves to significantly enhance the overall performance and functionality of the LiDAR system. As moving forward, these insights and accomplishments provide a solid foundation for future refinements and innovations. The team will keep improving and coming up with new ideas to make sure our technology meets the needs of the people we're trying to help.

REFERENCE

[1] Hardwick, R. M., Forrence, A. D., Costello, M. G., Zackowski, K., & Haith, A. M. (2022). Age-related increases in reaction time result from slower preparation, not delayed initiation. *Journal of Neurophysiology*. https://doi.org/JN-00072-2022