2DX4 PROJECT 2021 – OBSERVE, REASON, ACT: MAPPING YOUR ENVIRONMENT USING TIME-OF-FLIGHT

1. Introduction

You are to design and build an embedded spatial measurement system using time-of-flight to acquire information about the area around you. Using a rotary mechanism to provide a 360 degree measurement of distance within single vertical geometric plane (e.g., y-z), you must integrate fixed distance samples along the orthogonal axis (e.g., x-axis). Mapped spatial information is stored in onboard memory and later communicated to a personal computer or web application for reconstruction and graphical presentation.

2. Rationale

Commercial Light Detection and Ranging (LIDAR) equipment is expensive and bulky. Our application requires a less expensive and smaller custom system that is suitable for indoor exploration and navigation. For most engineers, at some point in their career they will need to acquire data. Often there are numerous systems available, but they can be expensive, limited in capability, and/or too complex for your requirements. As a result, data acquisition becomes too complex or expensive. Ultimately, engineers seek to measure physical phenomenon accurately at as low a cost possible.

The experience with this project will also give the student insight into how the commercial/industrial data acquisition systems operate.

One of the primary objectives of 2DX4 is that the student leave with the capability of collecting data using the microcontroller and then be able to process and communicate that data. This knowledge will be directly applicable to future design courses, most senior capstone projects, and certainly beyond.

3. Overview

For this project you will be working though a design-test-build approach for the development and demonstration of a data acquisition system. It is strongly recommended to work through lectures, studios, labs, and assigned work to complete the recommended milestones. Keeping up with milestone will allow for your best opportunity to do well on the project.

Figure 1 illustrates a simplified data acquisition system.

4. Technical Requirements

The overall design of a data acquisition system project was described in lecture when introducing the Analog-to-Digital Converter module, illustrated in figure 2 and described below:

: **Quantify the analog signal** - range of amplitude, frequency, source, impedance [continuous signal].

: **Build/Select the appropriate transducer** - pressure, sound, temperature, etc.

: **Precondition signal** - amplification, filtering, and/or level shift to conform to ADC design.

: **Analog-to-Digital Conversion (ADC)** - determine voltage range (min, max), resolution, sampling frequency [discrete data].

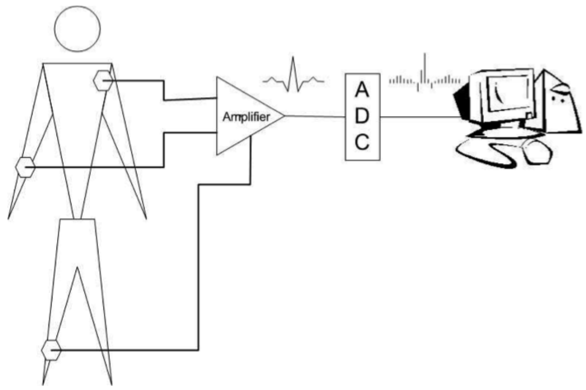

FIGURE 1. Example data acquisitions system

: **Data processing** - read data from ADC and store/process/transmit under time constrains to return for next ADC.

: **Control/Communicate** - micro controllers are implemented with specific purpose for acquired data, implement an algorithm that meets the objective with hardware and timing constraints.

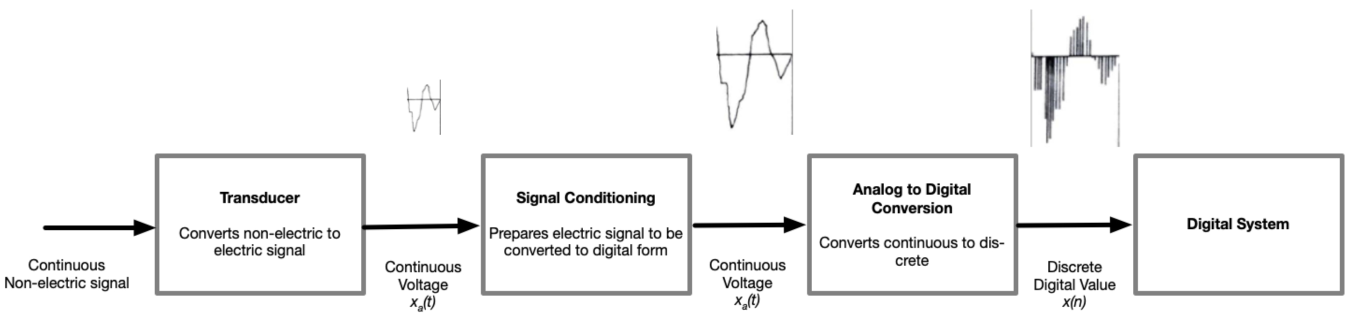

FIGURE 2. The ADC process

For this project we have selected a transducers that provide digital output. Thus, the data acquisition can be generalized as shown in figure 3.

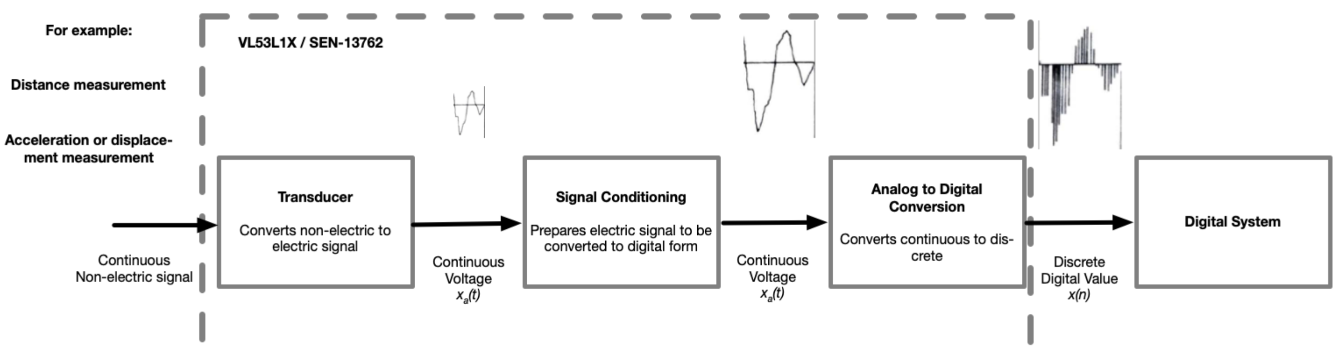

FIGURE 3. The ADC process

There are two types of measurements to collect: distance (y-z plane) and displacement (x-axis). You will need to consider the assembly of these components as a part of your final design – this may require minor construction with wood, plastic, 3D printing, Lego piece, etc. for which you are responsible. Figure 4 shows an example of how the stepper motor and the ToF sensors are mounted using Lego and a shoe box.

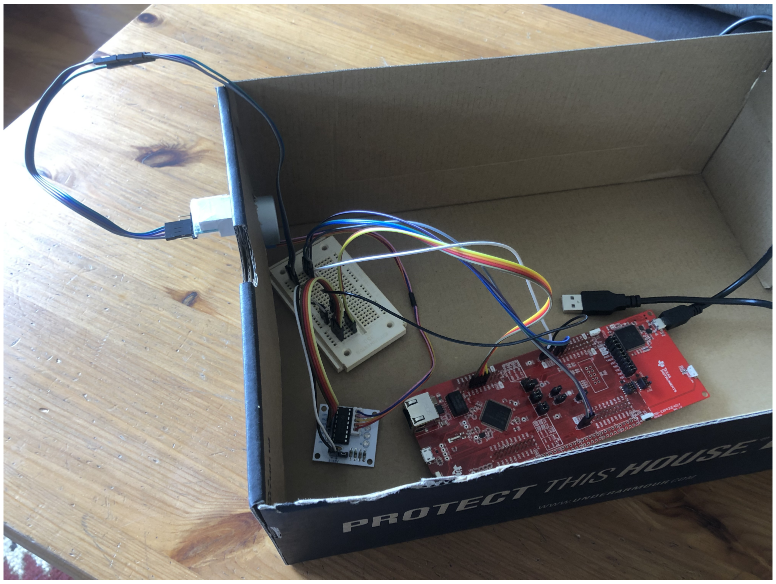

FIGURE 4. A mounting option

To measure distance you will be using the VL53L1X on a predesigned breakout board[1]. This sensor will be mounted to a stepper motor for a sampling of measurements throughout a full 360 degrees or rotation. Note the data sheet lists three distance modes 136cm (4.5ft), 290cm (9.5ft), and 360cm (11.8ft). A serial interface (I^2C) for communicating with the microcontroller shall be used.

For measuring displacement you should move your stepper motor/time of flight sensor combo manually and gather readings at regular distances (e.g. every 30 cm).

[1]Important note: This product might ship with a protective liner covering the sensor IC. The liner must be removed for proper sensing performance.

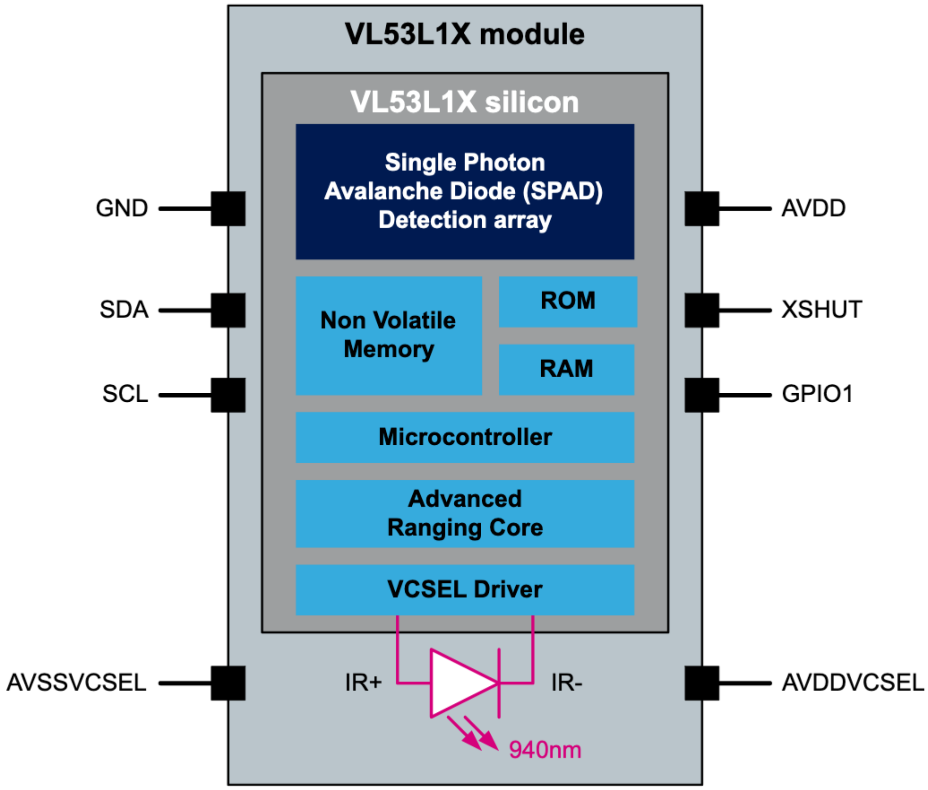

FIGURE 5. Time of flight (ToF) breakout board

4.1. **Core Components.** The technical requirements of this project are to build an embedded system which integrates measurement modalities and device control such that can be used to map indoor environments, such as hallways, for use as a component of other systems (e.g., robotics navigation, autonomous drone, layout mapping, etc.):

(1) Digital I/O: Momentary push button(s) to start and stop data acquisition.

(2) Digital I/O: LED status of each distance measurement

(3) Transducer/sensor 1: ToF sensor to measure distance (e.g., y-z plane)

(4) Data processing: coordinate collection, computation, and storage of distance and displacement

(5) Manually activate collection of new distance data (360 degrees) once defined fixed displacement reached

(6) Implementation mode: polling or interrupt design

(7) Control: control the rotation of the stepper motor to support ToF sensor

(8) Communicate/Control: communicate data between ToF sensor and microcontroller.

(9) Communicate: communicate data to PC application stored distance and displacement data.

(10) Communicate: communicate data to PC application to graphically view data (Student choice of non-autographing application: Matlab, Java, Python etc.). Alternatively, generating a 3D model in standard file formats (e.g., STL) may use pre-existing software packages to display the model (e.g., Autodesk Inventor Viewer, MS 3D Viewer, etc.)

An example of a graphical view of data is shown in 6.

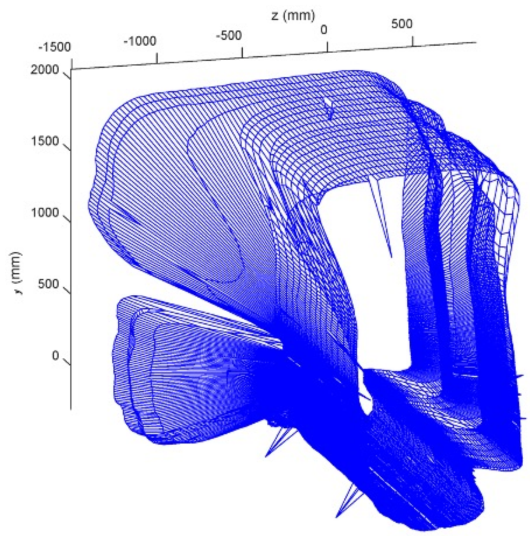

FIGURE 6. Graphical reconstruction of 3D mapping of a hallway

The project must acquire distance data (y-z) process the data and control the stepping motor, display status LEDs, serially transmit the waveform data to a PC, and graphically display this data as a 3D model. Displacement data (x) is determined manually. The student must be able to start and stop data acquisition using a physical momentary push button. LED status shall be presented realtime. The use and configuration of the ToF will be addressed in lab, lecture, and studio. If you would like to read ahead on these devices, please review the following links:

ToF sensor (VL53L1X) datasheet: `https://www.pololu.com/file/0J1506/vl53l1x.pdf`

4.2. **Student Specific Requirements.** Based upon student number each will be assigned different operational parameters. The example student number 123456789 (ABCDEFGHJ) will be used to illustrate each assigned parameter (written as a string of letters to refer to digit position instead of digit value). Please refer to lecture notes if you are not sure what is meant by LEAST SIGNIFICANT DIGIT (LSD) or MOST SIGNIFICANT DIGIT (MSD). These terms refer to positional notation and NOT the value of the number. For example, the LSD of the example student number is POSITION J (=9).

4.2.1. *Individualized Operational Parameters.*

Bus Speed: The default bus speed is 120MHz. Based upon the least significant digit "J" (remember, this refers to positional notation) of your student number you are to use the following bus speed:

Table 1. Individualized bus speed based upon least significant digit of student number ”J”

Least Significant Digit	Assigned Bus Speed (MHz)
0	80
1	96
2	48
3	60
4	24
5	30
6	12
7	16
8	30
9	96

Digital I/O LED Status: Distance measurement requires an LED for status indication. Based upon the second least significant digit ”H” (remember, this refers to positional notation) of your student number you are to use the following GPIO pin:

Table 2. Individualized LED status GPIO based upon second least significant digit of student number ”H”

Second Least Significant Digit	Distance Status
0	PN1
1	PN0
2	PF0
3	PF4
4	PN1
5	PN0
6	PF0
7	PF4
8	PN1
9	PN0

5. Documentation

Rather than a formal report, your documentation will be formatted as a data sheet and specification for your system that would be suitable for another engineer like yourself.

Consider some of the questions for inclusion in your documentation:

(1) Summarize any limitations of the microcontroller floating point capability and use of trigonometric functions.

(2) Calculate your maximum quantization error for each of the ToF module.

(3) What is the maximum **standard** serial communication rate you can implement with the PC. How did you verify?

(4) What were the communication method(s) and speed used between the microcontroller and the ToF modules?

(5) Reviewing the entire system, which element is the primary limitation on speed? How did you test this?

6. Milestones & Deliverables

As a second year student you are expected to set your own goals and timeline for completion for the final project – a Gantt chart should be generated for your own scheduling. Your project will be tested for performance and you will provide a video to demonstrate your knowledge about the project. Afterwards your documentation and files will be assessed.

The following are suggested milestones for your own progression. Deliverables are noted for interview and demonstration of project at the mid point and end of the development.

6.1. Milestone 1 - End of Week 2.

- ☐ Review the project specification.
- ☐ Identify target objectives based on your student number.
- ☐ Review available resources (e.g., pins) on the microcontroller board and record/map the initial pin layout.

6.2. Milestone 2 - End of Week 3.

- ☐ Establish a working push button and LED program.
- ☐ Generate a pin-assignment map.

6.3. Milestone 3 - End of Week 5.

- ☐ Establish a working stepping motor program.
- ☐ Have time left in lab? Work on your project requirements.

6.4. Milestone 4 - End of Week 6.

- ☐ Early integration – establish a working stepping motor + start/stop push button + LED status program.
- ☐ Have time left in lab? Work on your project requirements.

6.5. Deliverable 1 - Mid-Project Demonstration - Week 7.

- ☐ Confirm you have a scheduled interview time.
- ☐ Interview and Project milestones demonstration.

6.6. Milestone 5 - End of Week 9.

- ☐ Establish a working button interrupt(s).
- ☐ Establish I2C and UART protocols.
- ☐ Establish a working fixed-position ToF
- ☐ Establish a working serial communication with PC and display measurement data (terminal, etc.).
- ☐ Have time left in lab? Work on your project requirements.

6.7. **Milestone 6 - End of Week A.**

- ☐ Establish a working 360 ToF + stepping motor + start/stop push button + LED status program.
- ☐ Establish and test 3D modelling protocol and format.
- ☐ Integration of functional modules

6.8. **Deliverable 2 - Due Thursday April 14 at 5:00 pm (firm deadline).**

- ☐ ~~Confirm you have a scheduled interview time.~~
- ☐ ~~Interview and~~ project demonstration.

7. Report Format

Your document should be structured similar to a datasheet. Your document must have the following sections, describing your project as a product:

(1) Device Overview (Approximately 1.5 pages)
   (a) Features
   (b) General Description
   (c) Block Diagram (Data flow graph)
(2) Device Characteristics Table (Focus on user's technical "need to know") (Approximately 0.5 pages)
(3) Detailed Description (Be concise) (Approximately 3 pages)
   (a) Distance Measurement
   (b) Visualization
(4) Application Example with Expected Output (Include steps to TA to use/setup your product without you) (Approximately 2-3 pages)
(5) Limitations (Answers to specification questions) (Approximately 1 pages)
(6) Circuit Schematic
(7) Programming Logic Flowchart(s)

7.1. **Typesetting Format.** The final report should be presented as a technical specification that must be complete, organized, and concise. As a guide, we do not expect the body of the report to exceed 9 pages (excluding schematic and flowcharts).

Font should be Times Roman, body and label text should be 12 pt, section headings should be 14 pt, and Title should be 18 pt. Margin should be no larger than 1in. Text should be single spaced and presented in a single or double column. Hand drawn images, calculations, etc. are not acceptable. Citations should follow the IEEE format. Should a student wish, s/he may typeset in LaTeX.

8. Course Bonus

The following are a list of bonuses available to students that meet and demonstrate all above core design requirements. These bonus marks will be applied up to a maximum of 110%.

8.1. **Bonus 0. After meeting all above core design requirements** assigned to the student, a 5% will be given to any student that implements a fully functional project.

8.2. **Bonus 1. After meeting all above core design requirements** assigned to the student, a 5% will be given to any student that implements a fully functional project implementing and demonstrating real-time distance measurement (e.g., continuous displacement instead of fixed displacement measure of y-z distance). Bonus marks are only awarded to projects that have first met all core objectives (this may require two version of project).

8.3. **Bonus 2. After meeting all above core design requirements** assigned to the student, a 5% will be given to any student that implements a fully functional project implementing and demonstrating continuous wifi data transmission of distance and displacement measurements. Bonus marks are only awarded to projects that have first met all core objectives (this may require two version of project).

9. Submission Requirements

Each student will be required to demonstrate their final project via video submission. There will be no in-person interview. Any project that is not accompanied by a complete final report will be assigned a 0 for the entire project.

For the video demonstration, students should expect to clearly answer specific questions about their design choices and their implementation of the project. If you cannot (or do not) answer or defend a design choice then you will not be awarded the grades for it.

Submit the following two items to Avenue (separately) at the end of the demonstration/interview:

(1) Final report - as outlined above. Ensure that includes full algorithm flowchart(s) and brief user's guide (application note). Must be a single file and in PDF format.

(2) A recorded 10-minute video answering specific questions and demonstrating the functionality of the project. To be posted on Avenue.

(3) Zipped file containing all source code (commented and templated). Must use the .zip compression. Test your compressed file, if it cannot be opened by us then we will not accept another submission.

Any student choosing to not submit the a complete report or full set of code will be considered a late submission. Once penalties accumulate to 100% of the entire project, the work cannot be accepted for evaluation. Similarly, an interview/demonstration that is MSAFed will be rescheduled; however, given this project will have been posted for several weeks, the associated report and files must be submitted by the end of the originally scheduled interview. The final grade in the course will be INC until the interview is completed. Should a rescheduled interview be missed, the entire project will be assigned a 0. You must be able to demonstrate and defend your project design AND submit all files (report and code) for our review.

10. Changelog

The following changes were recorded:

(1) Updated Jan. 7, 2021 by S. Shirani