2022-2023 2DX3 PROJECT SPECIFICATION – OBSERVE, REASON, ACT: SPATIAL MAPPING USING TIME-OF-FLIGHT

1. Introduction

You are to design and build an embedded spatial measurement system using a time-of-flight sensor to acquire information about the area around you. Using a rotary mechanism to provide a 360 degree measurement of distance within a 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 2DX is that the student gains the capability to collect 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 milestones is your best opportunity to do well on the project.

4. Technical Requirements

The overall design of a data acquisition system project was described in lecture when introducing the Analog-to-Digital Converter module. The required tasks, corresponding to the steps illustrated in figure 1, are:

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

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

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

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

Date: Updated: April 2, 2023 @ 2100h.

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

: **Control/Communicate** - implement an algorithm that meets the objective with hardware and timing constraints.

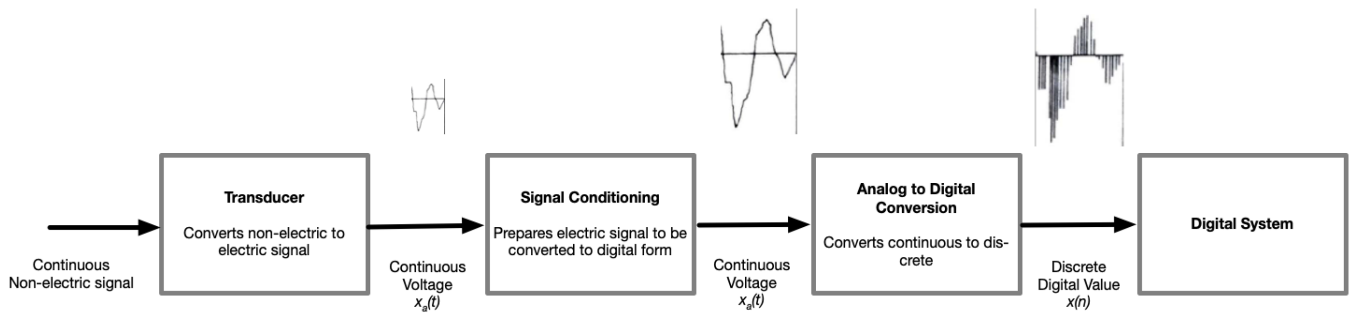

FIGURE 1. The ADC process

For this project we have selected a transducer that provides a digital output. Thus, the data acquisition steps can be thought of as being included in the transducer block as shown in figure 2. You will have to study the transducer closely to understand the data that it produces and to integrate it with the rest of your system, including design decisions about data processing.

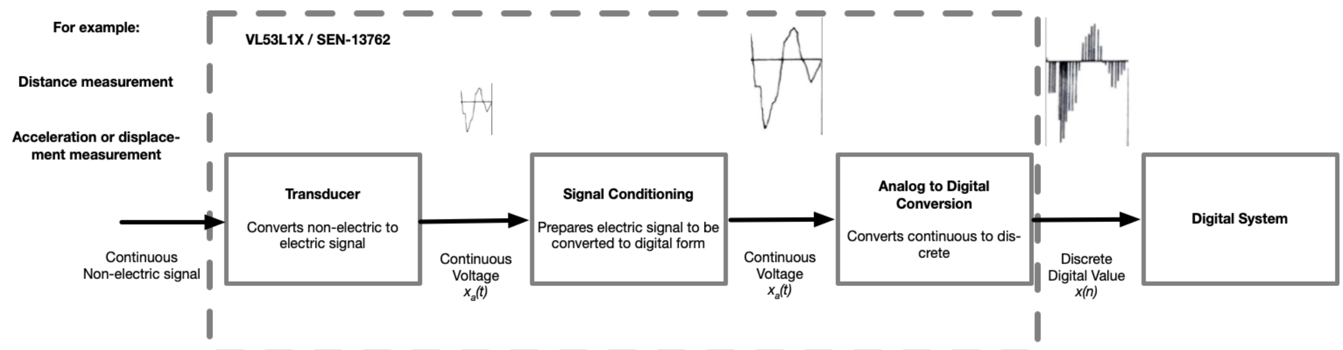

FIGURE 2. The ADC process

There are two types of distance measurements we could collect: spatial distance (y-z plane) and displacement (x-axis). For our project we will only me measuring the spatial distance and setting a fixed displacement. Combining the two will permit us to measure a 3-D area (x,y,z).

To measure the planar spatial distance you will be using the VL53L1X Time of Flight (ToF) sensor on a predesigned breakout board[1]. This sensor will be mounted to a stepper motor for that will rotate the sensor through 360 degrees while collecting measurements. Note that the data sheet for the ToF sensor lists three distance modes: 136cm (4.5ft), 290cm (9.5ft), and 360cm (11.8ft). Selecting the mode is one of the design decisions you will have to make for your project implementation. For all communication between the ToF sensor and the microcontroller, you will use a serial interface (I^2C).

For 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.

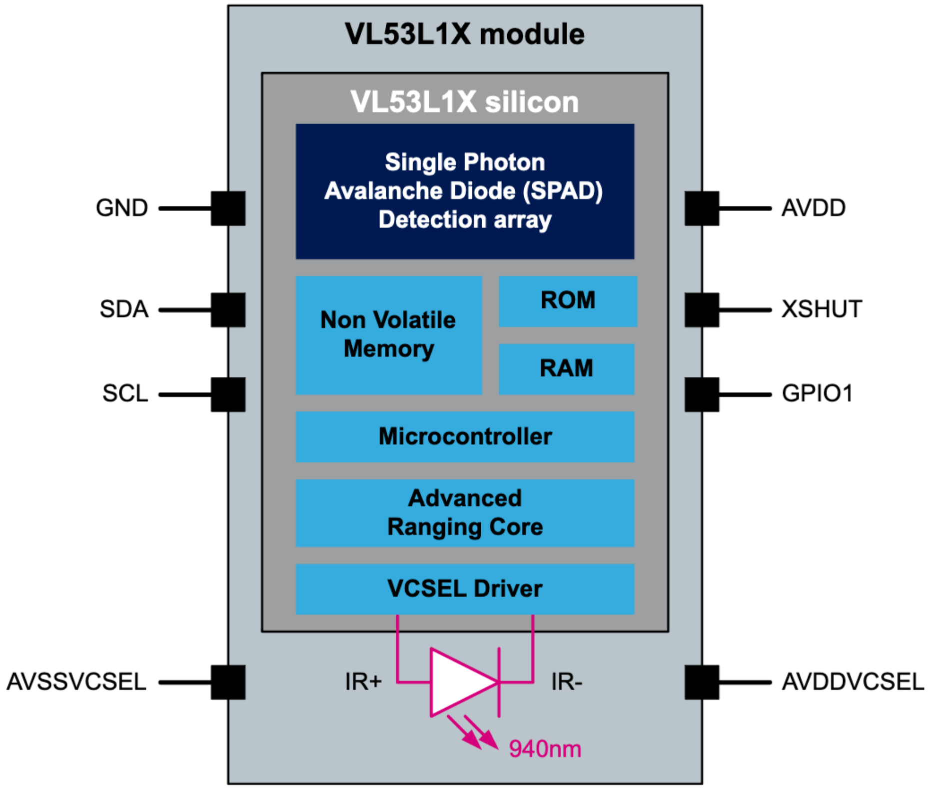

FIGURE 3. Time of flight (ToF) breakout board

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 pieces, 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.

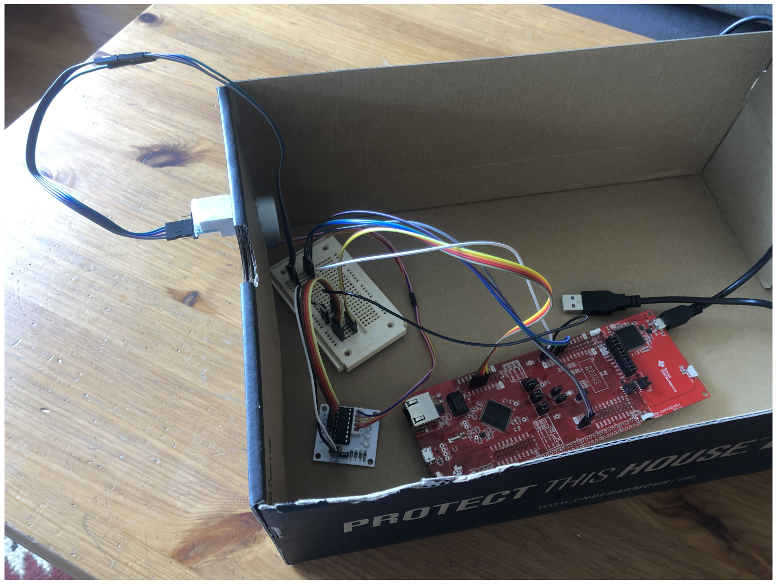

FIGURE 4. A mounting option

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 it 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.). The components required are:

(1) Digital I/O: Momentary push button to start and stop data acquisition process
(2) Digital I/O: Momentary push button to start and stop the stepper+ToF rotation and measurement
(3) Digital I/O: LED status of each distance measurement
(4) Digital I/O: LED for additional-status and/or troubleshooting
(5) Transducer/sensor 1: ToF sensor to measure distance of vertical plane (e.g., y-z plane)
(6) Data processing: coordinate collection, computation, and storage of distance and displacement
(7) Manually activate collection of new distance data (360 degrees) once defined fixed displacement reached
(8) Implementation mode: polling or interrupt design
(9) Control: control the rotation of the stepper motor to support ToF sensor
(10) Communicate/Control: communicate data between ToF sensor and microcontroller.
(11) Map an instructor defined location on campus based on student number. This information will be posted via Avenue.
(12) Communicate: communicate stored distance and displacement data to PC application
(13) 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 5.

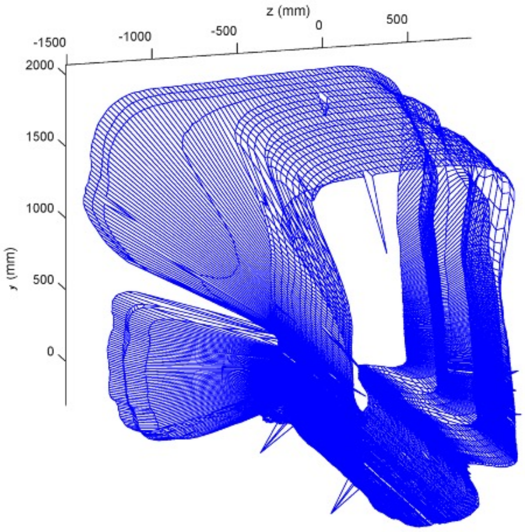

FIGURE 5. Graphical reconstruction of 3D mapping of a hallway

The project must acquire spatial data (control the stepping motor + ToF + status LED + manual displacement) of an instructor defined location, process the data, serially transmit the waveform data to a PC, and graphically display this data as a 3D model. 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:

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

4.2. **Student Specific Requirements.** Based upon student number, each student 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:

Digital I/O LED Measurement 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 one of the following on-board GPIOs (PN0, PN1, PF0, or PF4):

Digital I/O LED Additional Status: Additional and/or troubleshooting status requires an LED for status indication. You are to choose a meaningful aspect of the project Based upon the second least significant digit "H" (remember, this refers to positional notation) of your student number you are to use one of the following on-board GPIOs (PN0, PN1, PF0, or PF4):

TABLE 1. Individualized bus speed based upon least significant digit of student number "J"

Least Significant Digit	Assigned Bus Speed (MHz)
1	60
2	24
3	30
4	12
5	16
6	48
7	80
8	50
9	40
0	20

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

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

4.3. **Physical Demonstration Location.** You should use a room or a hallway that you have access to for early prototype testing. However, the project will have defined physical testing and demonstration location(s) for your project. These locations will be on McMaster's main campus.

In addition, you should expect to be asked to demonstrate scanning and functionality as component of your final interview.

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. What speed did you implement and 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 system 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 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 1) early integration point, and 2) end of the development.

The week of January 8, 2023 is defined as *Week 0.*

6.1. Milestone 1 - Start of Week 4.

- ☐ 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 4.

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

6.3. Milestone 3 - Week 6-7.

- ☐ Establish a working stepping motor program.
- ☐ Have time left in lab? Work on your Deliverable 1 and project requirements.

6.4. Milestone 4 - End of Week 7.

- ☐ Early integration – establish a working stepping motor + start/stop push button + LED status program.
- ☐ Have time left in lab? Work on your Deliverable 1 and project requirements.

6.5. Deliverable 1 - Mid-Project Demonstration - Week 8. For this deliverable :

- ☐ Confirm you have a scheduled interview time.
- ☐ You will be demonstrating Milestone 4 with your assigned operational parameters. You should be able to demonstrate:
  - (1) Control: control the rotation of the stepper motor (CW rotation, 45 degree steps).
  - (2) Digital I/O: Momentary push button to start and stop the stepper rotation.
  - (3) Digital I/O LED: Use Measurement Status to flash for each step of the stepper motor rotation.
- ☐ Attend the physical room on campus for interview and project milestones demonstration.

6.6. **Milestone 5 - End of Week 0xA.**

- ☐ Establish a working button (you may use a polling or interrupt(s) method).
- ☐ Establish I2C and UART protocols.
- ☐ Establish a working fixed-position ToF
- ☐ Establish a working serial communication with PC and display measurement data (terminal, etc.).
- ☐ Establish and test 3D modelling protocol and format.
- ☐ Integration of functional modules
- ☐ Have time left in lab? Work on your project requirements.

6.7. **Deliverable 2 - Week 0xB.** For this deliverable, please note the following:

- ☐ Confirm you have a scheduled interview time.
- ☐ Attend the physical room on campus for interview and project milestones demonstration.
- ☐ Submit final report by Wednesday April 12 at 11:59 pm (firm deadline). Refer to Section 9 Submission Requirements.

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, Instructions, and Expected Output. This section must include steps to TA to use/setup your product without you and have a side-by-side comparison of your assigned campus location photo vs. your 3D model based on your scanned data. (Approximately 3-4 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. Final Project 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% of the final project grade.

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 implementing and demonstrating an additional sensor that meaningfully enhances the core project objectives. For example, a 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).

8.2. **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 a self-resetting or "homing" functionality for the stepper-ToF sensor. You will need to define the home position (i.e., 0 degrees) of stepper-ToF sensor to reconstruct the spatial measurements. At each displacement along the x-axis the stepper-ToF sensor will conduct a y-z scan of the area. If the scan process stops mid-scan then your system will return the stepper-ToF sensor to its home position and then permit the scanning to continue. You may assume the power remains on and no reset has occurred.

9. Submission Requirements

Each student will be required to demonstrate their final project and answer interview questions. Depending on the lab delivery mode, the demonstration and interview may be in-person or virtual. **Any project that is not accompanied by a complete final report will be assigned a 0 for the entire project.**

If the **lab delivery mode is in-person**, students should expect to demonstrate how well their project meets the specification and clearly answer specific questions about their design choices and implementation of the project. If the student cannot (or does not) answer or defend a design choice then no marks will be awarded for that portion.

Submit the following items to Avenue (separately) by the defined deadline:

(1) Final report - as outlined above. Must be a single file and in PDF format.

(2) 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 after the deadline.

Any student choosing not to demonstrate the project, submit the a complete final report, and/or full set of executable 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 specified due date. 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) Released Feb 16, 2023
(2) Clarified deliverables 1 and 2 as in-person assessment only.
(3) Clarified deliverable 1 as the completion of student assigned specific project modification for milestone 4.
(4) Corrected deliverable 2 deadline.
(5) Removed reference to labs in virtual mode (the University delivery mode is specified as in-person).
(6) Clarified MSAF is for interview only and report+code are expected submitted prior to due date.
(7) Application Example merged with User Guide and clarified the Expected Output should be a comparison of your campus location vs. your 3D model.