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Design a Portable Sensing Platform with a Lidar and TI ARM M4 Controller

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Abstract

The Microcontrollers/microelectronics have been used in variety of engineering applications on complex and efficient operations. One of the challenges in applying existing microelectronic technologies to these engineering systems lies in the need of modular portability, scalability, customizability, and compatibility. This paper focuses on addressing such challenges by designing a portable sensing platform that integrates a Lidar with USB interface and TI ARM M4 microcontroller. This developed sensing system will serve as an effective teaching platform to create new or enhance existing microelectronic courses that allow students to gain hands-on experiences in mobile embedded system designs. Moreover, the customizability and portability of the embedded sensing platform can also be used for the unmanned aerial vehicles in the GPS-denied environments.

Introduction

In the past decades, microcontrollers/microelectronics have been played central roles in ensuring safe and efficient operations of many modern large-scale infrastructures, such as intelligent transportation systems, smart power grids, and smart manufacturing systems [1]. One of the critical issues in applying existing microelectronic technologies to these modern engineering systems is their lack of modular portability, scalability, customizability, and compatibility. There are needs of an intelligent device that can be flexible enough to be integrated into any type of engineering systems. It is particularly demanding in the scale of complexity of those large-scale engineering systems. This is also true in many engineering issues occurring in different Navy systems. This proposal is aimed to address these issues by developing an intelligent mobile sensing platform that integrates intelligent sensors (e.g., Lidar in this project) with necessary peripherals and makes it portable and customizable for different applications.

Lidar is a range measuring sensor that uses laser signals to detect and measure the distances and angles to the surrounding objects. Lidar has been used in variety of mobile applications, such as control and navigation of autonomous vehicles or robots. However, the interfaces between Lidar and the host (which in general is a laptop) require USB connections. This makes the portability - in remote conditions difficult. This proposal aims to design and develop a portable, customizable and scalable embedded platform that integrates Lidars with embedded microcontrollers such as PIC (8 or 16 bits) or TI ARM M4 (32 bits) depending on the complexities of the needed data outputs [2]. The choices of the data format and forms of the communications is flexible in either wire or wireless formats. The designed platform is mobile, portable and customizable to different controllers or modules with industry standard synchronous communication protocols such as SPI (Serial Peripheral Interface) and I^2C (Inter Integrated Circuit). These designs will be evaluated with the "*uC Training System*" that is a product developed from previous funded projects, which is capable of running PIC and/or TI ARM M4 microcontrollers for convenient and interchangeable interface, communication protocols, and hardware/software development [3]. The developed sensing platform will have sufficient intelligence to determine the surrounding objects/obstacles and pass onto other system for further processing or decision making that is applicable to autonomous vehicle and unmanned system for safety detection, particular under GPS-denied environments.

Motivations & Objectives

The purpose of developing such a portable sensing platform is to try to bridge the gap between the existing mechatronic courses and their potential benefits in industrial applications. From the course development standpoint, the portable sensing platform designed in this project is to provide new lecture and lab materials that are closely related to the modern mechatronic areas. The integration of the microcontroller units with other intelligent sensors focuses on the application aspects of the courses will help students gain more hands-on experiences and beneficial to their career choices. From the research perspective, the developed portable sensing platform can be viewed as a prototype of testbed that can be used for verification of research ideas and algorithm developments.

It is also the hope of the authors, this proposed portable Lidar platform can be used for applied engineering projects of microelectronics for faculty in better teaching and learning or further research project that will be interested in the academic community. Currently, there are 15 different institutions that have fully adopted the previous design: "*uC Training System*" where there are strong interests in adding this prototype design to their engineering projects [3, 4]. (Please see www.ucdistancetraining.org).

In the long term objectives, the developed sensing platform will be used to solve a variety of engineering problems. To name a few, one can see the potential application of the device for the congestion problems in city, highway, and tunnel during the traffic hours or emergent conditions. There will be a systematic approach in using multiple intelligent Lidar platforms to form a real-time network with customized protocols to inform, suggest, or even control the vehicle speed without fully stopping the vehicle. By doing so, the traffic congestion become manageable to achieve both time and fuel efficiency. The other possible application is to target the locomotive safety controls that use this real-time network data with proper repeaters in extended distance condition and intelligent communication protocols to avoid collision and eventually save life and properties. Other applications may include the use of the sensing platform in Unmanned Aerial Systems (UAS) to assist the tasks of navigation, autonomous landing and taking off in various demanding situations.

There are other available modules such as Arduino or Raspberry Pi can be used in a similar format as this proposed platform designs. But the disadvantages are: (1) those modules use pre-made functions that are available for download, where they lack flexibility in customized design in teaching and training students for necessary skills in the microelectronics jobs market, (2) the security issues where everyone can gain access of the functions to interfere in the communications, and (3) the deficiency of power consumption and management abilities compromising the portability of the intended applications.

System Framework of Lidar-based Sensing Platform

Figure 1 shows a system framework for the proposed portable embedded sensing platform which consist of the modules of microcontroller unit, portable interface, Lidar sensors, and information storage & display. The information flow goes between microcontroller, portable interface, and Lidar sensors. The communication between the micro-controller and Lidar sensors is conducted through a portable interface that is designed in this project. The microcontroller unit will initialize the communication by setting up the appropriate configurations of the Lidar sensors (e.g., the data rate). After the initialization, the microcontroller unit will request the data of distance and angles from the Lidar sensors and those data will be sent through the portable interface. After receiving the data information, the microcontroller unit will determine whether the information from the Lidar should be displayed on LCD or stored in a memory stick. The decision will be based on certain applications. For example, if the application is aimed at obstacle detection and avoidance. Then the microcontroller unit will process the information of the distance and angles to determine whether the distance is below a specified safe threshold. If the safety threshold is violated, then the microcontroller will disclose the message of safety warning or obstacle detected on LCD. If the safety threshold is not violated, the data of distance and angles will be kept in the memory stick that is also connected to the microcontroller through the portable interface.

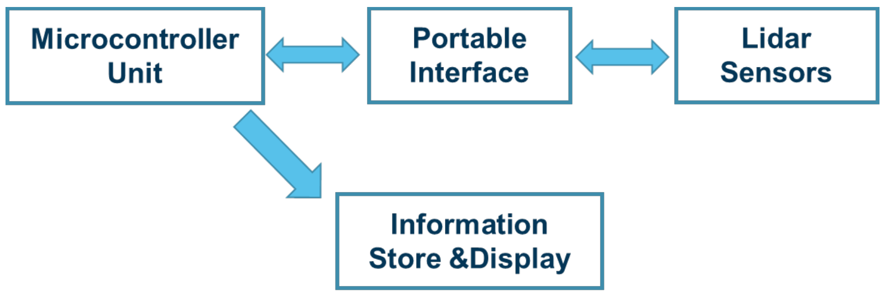

Figure 1. Portable Embedded Sensing Platform

In the subsequence, each module will be described in details by discussing its physical feature and functionality in the sensing platform. The design, evaluation and test of the portable embedded sensing platform are completed based on the undergraduate senior project supervised by the faculty.

Microcontroller Unit and USB Host Controller

The microcontroller unit used in this project is the TI Tiva C Series LaunchPad which has been widely used in different applications. The platform is selected based on its flexibility, and availability of free development software and portability to program without special hardware. Figure 2 demonstrates the launchpad board with the TM4C123GH6PMI microcontroller. The TI microcontroller is a 32-bit ARM Cortex M4-core that uses less memory and has faster speed than pure 32-bit [3]. It is an inexpensive microcontroller with comparable performance in terms of signal processing ability. In this project, we will leverage the capability of such microcontroller unit to design portable interface for smart sensing applications. In particular, the hardware and software interface will be designed based on the communication functionality and features provided by the TI launchpad. The TI launchpad has a variety of hardware interfaces for external device connections. The commonly used ones are USB, Synchronous Series Interface (SSI), SPI and UART. The launchpad comes with well-established software supporting those interfaces design. For instance, the TivaWare for C Series software provides the USB library and the peripheral driver library that enables programming and debugging in different levels. In this project, we will adopt the UART and SPI for communication between devices.

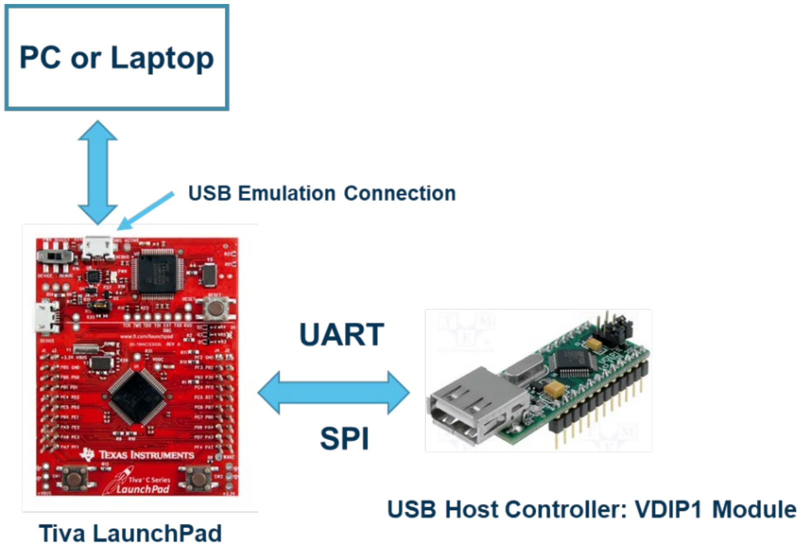

Figure 2. TI Tiva C Series LaunchPad

As discussed in previous section, the first objective of this project is to establish the communication between the microcontroller in the Tiva LaunchPad and the Lidar sensors. Unfortunately, the TM4C123GH6PMI microcontroller in the Tiva LaunchPad does not have the ability to serve as an independent USB host, but only possible to function as an USB device. Indeed, the TivaWare software provides the USB library that supports various classes of USB Device functionality including the HID mouse device class, HID keyboard device class and the Mass Storage device class. However, none of these existing software support the USB host functions, which is critical for the communication between microcontroller and Lidar sensors. Due to the lack of functionality support in the Tiva software, this project selects a USB host controller named VDIP1 module, to address the USB interface supporting issues. The VDIP1 Vinculum VNC1L is a USB host controller module developed by Future Technology Devices International (FTDI) Ltd and it was the first FTDI's Vinculum family designed for providing functions of USB host interface and data transferring as well as the USB device classes [7]. The VDIP1 module handles the data structure by communicating through UART, SPI or parallel FIFO interfaces via simple command set. The flexibility and simplicity features of this module provides an effective and efficient means for those devices that do not have USB host capability. Moreover, the VDIP1 module is able to support up to two USB devices simultaneously. As shown in Figure 2, one of the USB ports is physically constructed and can be directly connected to the devices while the other one can be constructed by adding external circuits. The external circuit configuration of a second USB port can be found at Figure 6.1 in the data sheet of the VDIP1 module [7]. In this project, only one of the USB ports will be used to connect to the Lidar sensor.

VDIP1 module: Figure 3 illustrations the schematic connection between the VDIP1 module and the microcontroller unit in the Tiva Launchpad. Specifically, the VDIP1 module has 24 pin outputs consisting of 13 regular I/O pins (AD and AC) and 11 function pins. The module provides on-board jumper pin that takes the AC5 and AC6 as inputs selecting different communication modes. There are three modes that can be selected for the communication between the module and external USB devices. The serial UART mode is selected if both the input pins AC5 and AC6 are either high or low. The SPI mode is selected if the input AC5 is set to be low and AC6 is set to be high. The parallel FIFO mode is activated if the input AC5 is high and the input AC6 is low. After setting the appropriate communication mode, it can be interfaced the appropriate I/O pins to the MCU for different applications. In this paper, we focus on the use of UART mode for communication and other modes can be set up similarly. Once the serial UART mode is selected, the pins of AD0 and AD1 serve as the ports for receiving and transmitting data, respectively.

TI Tiva Launchpad: the MCU in the Tiva Launchpad provides serial connectivity of eight UART units, six I^{2}C units and four SPI units. From the MCU side, the UART unit can be activated by configuring the appropriate General Purpose Input/Output (GPIO) pins. For instance, in the Tiva Launchpad, the GPIO pins PD6 and PD7 can be configured as the receive and transmit sides of the UART module 2. The mappings of GPIO pins to the other seven UART modules can be found at Table 14-1 in the Tiva MCU datasheet [3].

In this project, the UART module 2 of the MCU is used for the connection to the UART of VDIP1 module. In particular, as shown in Figure 3, the pin PD6 of the UART2 receiver is connected to the pin AD0 of the UART transmitter in the VDIP1 module. The transmitter pin PD7 of the MCU is connected to the receiver pin AD1 of the VDIP1 module. After powering both of the modules with +5 V power supply and grounding both modules, the hardware connection between the TI MCU and USB host controller VDIP1 module is established [7]. The data exchange between MCU and VDIP1 model can be done in two different modes through the UART interface. The first mode is called the “command monitor mode” which provides an interface for the MCU to read and send the data. When the VDIP1 module works under the command monitor mode, a prompt of “D:\>” will be sent back to the MCU indicating that the VDIP1 module is ready to execute any commands being sent [8]. The second communication code is called “data mode” under which the data is directly passed between the devices without checking the status. As described in the firmware manual of VDIP1, user can choose the command mode or data mode by setting the pin AD4 to be either high (command mode) or low (data mode). Then, the AD5 severs as an output for the mode status with its high logic state representing the command mode and low logic state representing the data mode.

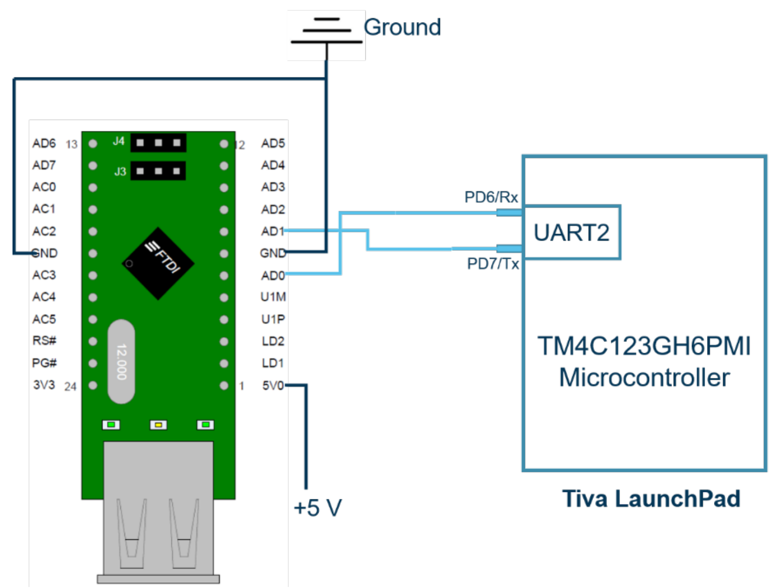

Figure 3. Hardware Connection Between TI Tiva C Series LaunchPad and VDIP1 Module

Once the communication channel between VDIP1 module and MCU is established, we are ready to connect the Lidar sensor to the USB port of the VDIP1.

Lidar Sensors

The Lidar sensor that we are using in this project is Hokuyo URG-04LX-UG01 scanning Laser Rangefinder with the USB interface. This Lidar sensor is suitable for indoor applications with short distance range (maximum of 5 meters). The market price for this type of Lidar is around $1,040.00 and the detailed specifications can be found in the official website https://www.hokuyo-aut.jp/search/single.php?serial=166. The URG-04LX-UG01 Lidar is able to provide the measurement of distance with accuracy of $\pm$ 30 mm and angles with respect to its 270 degrees view angles [9]. It has been used as intelligent sensors for a variety of applications, to name a few, the navigation of mobile robots and flying quadrotors, due to its light weight and low-power consumption. However, many of these applications rely on the USB connection to the PC or laptop. For the applications of quadrotors, the Lidar is often integrated with costly and advanced MCUs that comes with USB host controller. These MCUs often have well-developed modules that are not easy to be customized into different needs. Thus, from research's standpoint, it is important to develop a portable and customizable sensing platform for applications with limited budgets. This project takes the first step to design the portable and customizable interface between the MCU and URG-04LX-UG01 Lidar. From the course development's perspective, the developed sensing embedded system provides a platform that benefits the development of new multidisciplinary courses in the mechatronic areas.

The Lidar sensor sends the data of distance and angles to the MCU through the USB host controller. The data transmission protocol must satisfy the communication specifications that are defined to comply with URG sensor command system in SCIP ver2.0 or SCIP ver1.1 [10]. The communication protocol specifies commands and data format that need to follow to ensure successful data transmission. The commonly used commands include "MD/MS" and "GD/GS" where the "MD/MS" is a sensor data acquisition command sent from host (MCU) to the sensor requesting three character (MD) or two character data (MS) and the command "GD/GS" represents the request of the latest data to the host. Upon receiving the commands, the sensor encodes the data by adding the hex number 30H to each 6-bits binary raw data and sends the encoded data to the host. Each data is associated with a time stamp with 1 millisecond resolution. The time stamp represents the starting point of the scanning.

Based on the communication protocol specifications, one of the major developments in this project is the design of software interface between MCU and Lidar sensor. The software interface consists of a group of APIs that serve for different functionalities. These functionalities include the initialization of the UART, function configuration of the GPIOs, error handling and response function, read/write data, distance acquisition function, angle acquisition function and the obstacle detection function. Details of these APIs will be discussed in the next section.

Portable Interface Design

The objective of design a portable interface is to ensure that the developed sensing platform can transferrable in different applications. The key idea for the portable design lies in defining and implementing modularized APIs that perform different functionalities of the system in a hierarchical structure. Figure 4 displays a hierarchical structure of the portable interface design which is comprised of three different layers. The first layer called “initialization/data acquisition” directly communicates with the hardware interface of the MCU, VDIP1 and Lidar sensors. The first group of the APIs in the first layer involve initialization functions that are defined to setup the appropriate parameters for all the three modules to be ready for use. Within the initialization functions, the configuration of the hardware parameters, such as GPIO pins, UART module, the clock frequency, baud rate, command mode as well as enabled interrupts. The second group of APIs in the first layer is the Read/Write functions which read the data coming from the FIFO buffer of the MCU as well as write commands to the FIFO buffer. The read/write functions handle the data stream through the UART ports, which are embodied in the interrupt functions. The last group of APIs in the first layer is the error handling functions which responds and displays specific messages explaining the presence of certain errors, such as “the device not connected” or “Invalid Commands” which are commonly encountered but difficult to detect in the debugging process. On one hand, the APIs in the first layer are called by the second layer to handle complex requests and commands, such as “take the measurements of distance and angles every 100 ms”. On the other, the second layer receives the data from the read function in the first layer and packets them for the use of third layer. Thus, there are data stream exchanged between the first layer and the second layer.

The second layer of the smart sensing APIs implements the functionality of information extraction. Here the information extraction means that the information of distance and angle is extracted out of the data received from the UART FIFO buffer. As discussed in the previous section, the packet sent from Lidar sensor is comprised of distance information as well as the control information. The distance information is encoded by adding the hex number 30H. To extract the distance and angle information, the APIs in the second layer need to do the following two steps. The first step is to extract the distance information from the packet by removing the control information. The second step is the decoding of the distance information by subtracting the encoded data. The extracted information is requested by the third layer for applications. In this project, the application focuses on the obstacle detection which determines the presence of obstacles by checking whether the distance measurement is below a pre-defined threshold. Thus, the third layer involves the APIs that implement the obstacle detection and mapping algorithms.

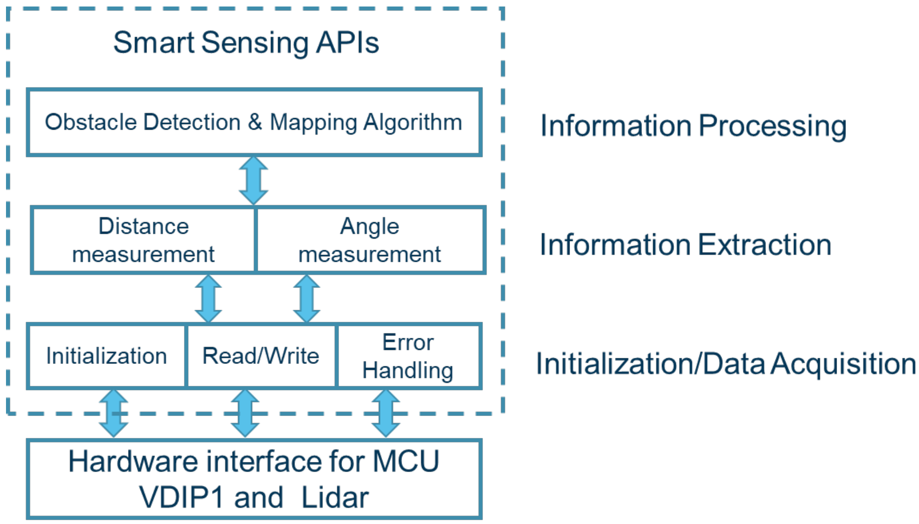

Figure 4. Hierarchical Scheme of the Portable Interface Design

The hierarchical structure of the APIs enables the flexible and portable implementation of the smart sensing platform that can be used in different mobile applications. One of the examples is the navigation task of the mobile robot where the obstacle detection algorithm used in the smart sensing platform can provide safety guarantee when the robot navigates through the indoor environment. Moreover, the same platform can also be used to assist the tasks of landing and taking off for UAV systems. The smart sensing APIs are defined and implemented using the C codes that are based on the libraries provided by TivaWare [2]. The TI Code Composer Studio (CCS) [6] is used to write and debug the designed APIs and the test results are printed in the PC terminal or LCD module.

Information Store & Display

The information coming out of the smarting sensing APIs can be stored in memory sticks or displayed on the LCD. Whether the information should be stored or displayed depends on the specific applications. For instance, the obstacle detection application requires that warning messages must be displayed in LCD whenever an obstacle is detected within a safe region. When the obstacle is absent in a nearby environment, the data of the distance and angle should be stored in a memory stick. The memory stick can be connected to the second USB port of the VDIP1 USB host controller.

Prototype of Portable Sensing Platform

In this project, the portable sensing platform is built on the *uC Training System,* which has been developed by one of the authors under previous funded NSF projects [3]. The platform has been successfully used in the lecture and lab classes at different universities and colleges including Old Dominion University, Farmingdale State College (FSC). All the available course and lab modules are available at www.ucdistancetraing.org.

It is the authors' intention that these developments will be used as future teaching tools. Figure 5 shows a prototype of a portable sensing platform where the selected TI Tiva C Series Launchpad is placed in the socket and the VDIP1 USB host controller is inserted into the breadboard of the *uC Training System.* It has been demonstrated in previous projects that the *uC*

Training System is able to integrate different types of MCU including the PIC as well as the LCD display unit. The Lidar sensor is connected to the main USB port of the VDIP1 module. The jumpers are used to connect the appropriate pins of the MCU and VDIP1 module as discussed in previous sections. The main objective of this project is to demonstrate the customizability and portability of the sensing platform. The ultimate goal is to integrate all the modules (MCU and USB host controller) into one single board that can be applied to different applications. The prototype of the sensing platform demonstrated in Figure 5 is a prototype of the concept.

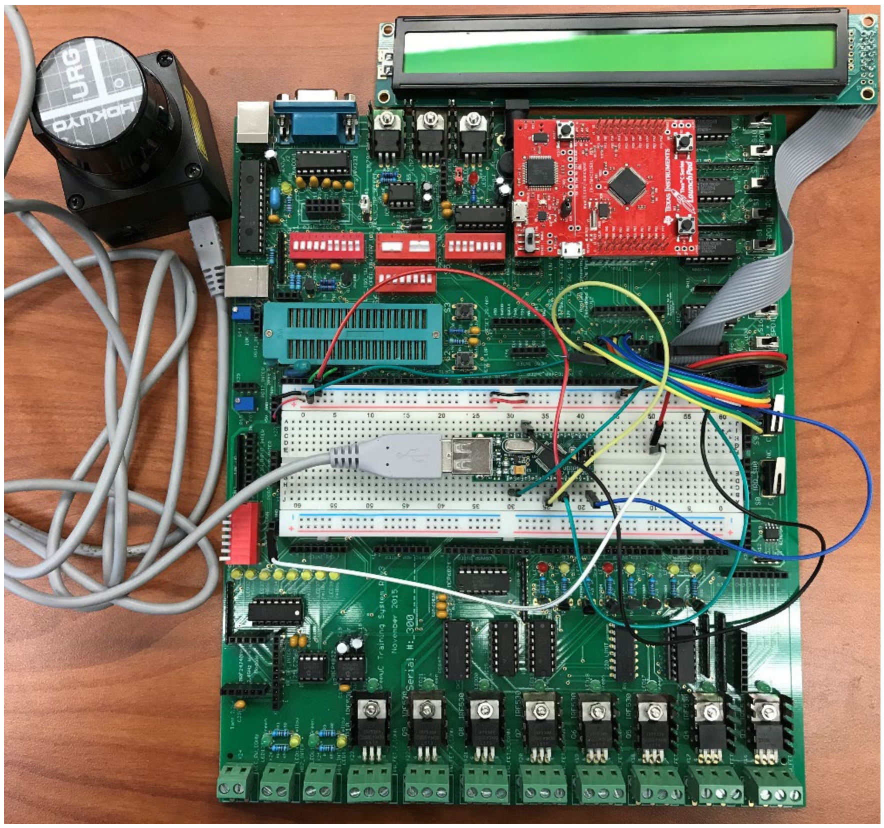

Figure 5. The Portable Sensing Embedded System Using the *uC Training* System

Obstacle Detection Demonstration

Regarding the application of the developed sensing platform, this project focuses on the demonstration of obstacle detection tasks. The portable sensing system shown in Figure 5 will be used for the demonstration and the platform will be further revised for detecting different obstacles. The LCD display unit will disclose the information about the presence of obstacles in terms of the distance and angles. If the distance of the obstacle is too close to the platform, the LCD will display warning message informing the system that there might be a potential collision given the distance measured by the Lidar sensor.

Potential Teaching & Research Development

The purpose of this project is to introduce a portable sensing platform that can be used for potential teaching and research development. From the teaching standpoint, the platform provides a foundation under which new or existing courses can be developed and improved to meet the new challenges in the industry. This is especially important for the mechatronic areas where devices with portable and intelligent capabilities are the most desirable features in various applications. The developed platform can also be used in senior project design or capstone project for undergraduate students who want to obtain hands-on experience of working with microcontroller with intelligent sensors. From research's standpoint, the smart sensing platform can sever as a testbed that is used for verification and experimentation of the proposed research ideas. The potential research directions may include the exploration of the cybersecurity issues in using the Lidar sensor and the algorithm development of 3D mapping using the Lidar sensor.

Conclusion and Future Work

This project is funded by Navy research and development (ONR Award N00014-18-1-2682) that also involved undergraduate students' capstone projects, which lead to meet naval current & future workforce development needs. All the Lidar sensors are in the price range of $1,000 to $5,000 depending on its power, speed, and detecting distance. Without the external supports of this project, it is impossible to bring this portable sensor platform designs into the classroom for teaching and learning.

This paper introduces a portable smart sensing platform where the TI Tiva MCU is able to communication with the URG-04LX-UG01 Lidar through the VDIP1 USB host controller. The focus of this paper is the design of portable interface enabling data exchange between MCU and Lidar sensor. The hierarchical structure of the portable interface allows the implementation of complex tasks and commands in MCU. Moreover, this project shows a prototype of the portable smart sensing platform that is built upon the well-developed *uC training system*. The demonstration of the obstacle detection using the smart sensing platform will provide a proof of concept for our ultimate goal of integrating all modules in one single board. In the future, we will continue to explore the portable interface design for Lidar sensor with other interfaces, such as Ethernet. This can further lead to the development of new microcontroller courses based on the portable sensing platform. From education's perspective, it is important and interesting to see whether the learning performance of the students can be improved by using the platform.

References

1. A. Malinowski and H. Yu, "Comparison of embedded system design for industrial applications," *IEEE Trans. Ind. informatics*, vol. 7, no. 2, pp. 244–254, 2011.
2. Texas Instruments, Tiva™ C Series TM4C123G LaunchPad Evaluation Board, User's Guide, 2013.
3. LMS, January 30, 2018. [Online]. Available: http:// http://www.ucdistancetraining.org/moodle/
4. S. Hsiung, J. Ritz, M, R. Jones, J. Eiland, "Design and Evaluation of a Microcontroller Training System for Hands-on Distance and Campus-Based Classes." Journal of Industrial Technology 2010; 26(3): 2-8.
5. Texas Instruments, Tiva Ware Peripheral Driver Library, User's Guide, 2016.
6 CCS, Texas Instrument Code Composer Studio, January 30, 2018. [Online]. Available: http://www.ti.com/tool/ccstudio
7. Future Technology Devices International Ltd., VDIP1 Vinculum VNC1L Module Datasheet, 2010.
8. Future Technology Devices International Ltd., Vinculum Firmware, User Manual, 2008.
9. HOKUYO, Range-Finder Type Laser Scanner URG-04LX-UG01 Specifications, 2005.
10. HOKUYO, URG Series Communication Protocol Specification SCIP-Version2.0, 2006.