Design, Development and Testing of Microcontroller Systems Simulator using PIC Microcontroller

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Date received: November 7, 2020
Revision accepted: September 27, 2023

Abstract

The inadequacy or absence of training equipment negatively impacts student performance, achievement and employability. Attempting to address this problem, the study was conducted to design, develop, fabricate and test a microcontroller systems simulator (MSS). The MSS was composed of the mainboard and development board comprising the PIC microcontroller, microcontroller circuits and input and output devices. The MSS was designed using AutoCAD, schematic design and circuit simulation software, and printed circuit board auto-routing software. A computerized cutting machine, laser laminator and ink printer were also used in the fabrication of the MSS boards. Test results showed that 12 and 24 VDC voltage readings were normal, sensors were working with the indicated specifications, and the MSS could perform automatic switching simulations. It was concluded that the MSS can effectively demonstrate microcontroller experiments and switching applications and it conformed to the required voltage and current ratings, electronics and electrical safety standards. It was also found that it is technically feasible to develop a microcontroller simulator utilizing commercially and locally available materials and spare parts.

Keywords: design, fabrication, microcontroller, simulator, testing

1. Introduction

Relevant equipment and devices are vital in ensuring quality training and developing technical skills. Teaching resources play a vital role in education. One of the goals of education is to produce students who have skills and mastery of technology for the needs of the labor market and the world of industry, especially in the field of robotics related to the mastery of microcontrollers (Jamaluddin *et al.*, 2019). Further, in the era of the Industrial Revolution 4.0, changes and industrial transition worldwide have led to technological gaps between the industrial and academic environments, particularly in the field of vocational education (Dede *et al*., 2020).

State universities and colleges (SUCs) in the Philippines have problems, particularly the inadequacy or absence of training devices. Many of the SUCs expressed interest in improving their current facilities and equipment. Out of 52 SUC respondents, 41 or 79% have stated their strategic plans and conveyed their interest in establishing and upgrading their facilities and equipment (Japan International Cooperation Agency, 2015). Lack of educational facilities was proven to pose serious consequences on student performance and achievement. There is a growing need for alternative equipment to augment training facilities. Further, several pieces of research have found that school facilities can have an intense impact on both teacher and student outcomes. The Commission on Higher Education (CHED) in all its memoranda on policies, standards and guidelines in the offering of various courses stressed that specialized laboratories shall be maintained for major fields. In particular, CHED Memorandum Order (CMO) no. 79 s. 2017 under section 16 or laboratory and physical facilities required specialized laboratory facilities and the technical facilities and requirements shall be based on the training regulation set by the Technical Education and Skills Development Authority (TESDA) (CHED, 2017). In the same CMO, one of the performance indicators (section 7) is to design and develop curriculum, courses and instructional materials. Recognizing the need for instructional materials, in 2014, CHED ordered the purchase of equipment and other instructional materials under CMO no. 12, s. 2014 (CHED, 2014). One of the program components is the purchase of equipment and other instructional materials.

Faculty members generally suggest that simulators and trainers are indispensable in teaching technical courses. Teachers use methods of teaching that rely more on the involvement of students such as demonstrations, project work and group discussions as effective methods for realistic teaching (Nasir *et al*., 2020). They also believed that they should make their own devices because they know the gap and what is lacking in a particular subject.

The simulator can be used as a means of practice for the students which directly improves their skills with microcontrollers (Amelia *et al.,* 2017). The students are the prime beneficiaries and end-users of the microcontroller systems simulator (MSS). This project used microcontrollers as inputs in the design of the system. Microcontrollers are used in automatically controlled products and devices like automobile engine control systems, implantable medical devices, remote controls, weaponry (Telen and Guirnaldo, 2017), office machines, appliances, power tools, toys and other embedded systems. It is also widely used in smart agriculture such as an automated fish-feeding mechanism (Deroy *et al.*, 2017). Commercially available microcontroller trainers have limitations because they are mostly developed by industries with limited academic backgrounds and exposure in the academe. Thus, these trainers or simulators are developed with limited features. Commercial trainers have constraints in adapting to the changing needs of skills training. There are a lot of unavailable features in commercial microcontroller trainers that are vital and useful in the training and preparation of students in the world of work.

Most commercial simulators, which are too expensive or otherwise cheaper than the MSS, do not tackle the necessary lessons and activities that the teacher on that particular subject wants to implement to attain the course objectives and produce the subject's needed outcome and output. In most universities, courses in automation, robotics, communication and control use microcontroller-based systems (Güven *et al.*, 2017). Based on many experiences of faculty members, particularly in industrial automation, instrumentation and process control subjects, commercially available trainers and simulators lack important features such as detailed and spare parts assembling and disassembling, troubleshooting, voltage and current testing, and schematic diagram interpretation that are needed in the industry. These are very important actual activities that will provide concrete experiences and hands-on training for the students. Further, there is a scarcity of microcontroller training devices in most SUCs in the Philippines. Faculty members have attended numerous training about microcontrollers; unfortunately, some of the SUCs failed to acquire these devices, and the worst, some SUCs do not have even a single device. This problem would result in a lack of training and preparation for students and can lead to job and skills mismatch. Microcontroller training devices are vital in Region 2 since most of the SUCs offer industrial technology and engineering programs in which microcontroller technology is part of the curriculum. It is advantageous on the part of the institution and the teacher handling the subject because he or she knows every detail of the simulator and in any event of a breakdown, immediate solutions and corrections can be done without causing too much delay in fulfilling the course content. Developing teacher-made simulators can be of great help to the instructional needs and the teacher handling a particular subject for quite some time because he or she knows best for his students and the course in terms of instructional material.

These scenarios need to be addressed to improve the quality of instruction that every institution offers. Developing teacher-made simulators that utilize locally available materials is a step to augmenting the instructional needs of classrooms. Trainers and simulators have been proven to be technically feasible to develop (Pereyras, 2020). The findings also of Amelia *et al.* (2017) revealed that trainer can be used as a means of practice for the students which directly improve their skills with microcontrollers. The technical know-how of graduates is indispensable. Schools should acquire adequate laboratory facilities and instructional materials to make their graduates globally competitive and responsive to industry needs.

This study was carried out to design and develop an MSS. Specifically, it designed the MSS mainboard, experimental and development board (EDB) using a software. It also fabricated the different MSS boards using computerized machines. The assembly of the circuits was also undertaken using commercially and locally available materials and spare parts. Furthermore, this study tested the MSS boards and the MSS's performance, particularly on switching simulations, proximity sensing and automated switching simulations in terms of voltage rating, current rating and sensing distance.

2. Methodology

2.1 Design and Block Diagram of the MSS

The development and fabrication of the MSS comprise the following: planning and layout based on needs, features, and applications; selection and acquisition of materials; fabrication and assembly of the structural support, mainboard, and development board; and fabrication of the workbench. Fabrication of other features such as sequential light simulator, proximity sensing simulator and automatic switching simulator was also conducted. For every part of assembling and fabrication, initial resistance and voltage testing were done, and revisions were undertaken to correct faults. A laser printer and laser cutter were used in the fabrication of the MSS mainboard and development board.

Figure 1 shows the block diagram of the MSS system in which the principal parts and functions are represented by the blocks connected by lines that show the relationships of the blocks. The MSS was composed of 12 blocks or sections, and the major section was the MSS mainboard which is composed of the microcontroller circuits. Proximity sensing, sequential light and automatic switching applications were the major features of the simulator which was controlled by the MSS mainboard. The simulator was composed of input and output devices and essential electronic parts to perform simulations and other activities such as assembling, disassembling, troubleshooting, injecting troubles and interpreting diagrams using breadboards and electronic spare parts usually used for microcontrollers. The design of the MSS was first manually prepared by the researcher through manual drawing before it was processed using AutoCAD® (Autodesk, n.d.).

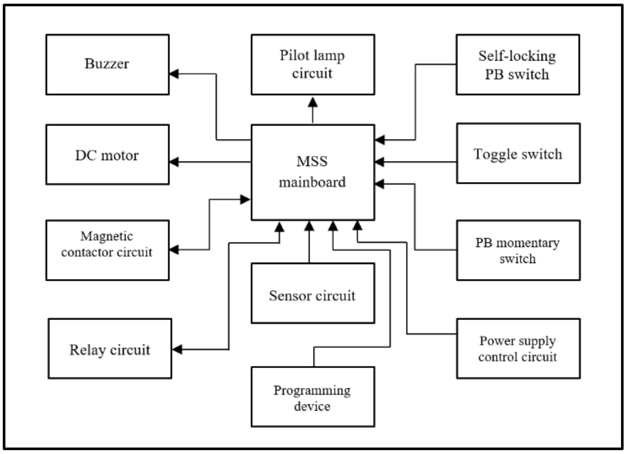


Figure 1. Block Diagram of the MSS

2.1.1 Devices used in the Development and Fabrication of the MSS

Supplies, materials, tools and equipment are vital resources used in the development of the MSS, especially in the fabrication, construction, assembling and testing. The materials and devices, particularly the sensors, were carefully selected and acquired in legitimate stores and online shops. Testing instruments such as digital and analog multimeters were utilized during performance testing. Table 1 presents the voltage and current ratings of various devices and components used in the construction and assembly of the MSS. These electrical parameters reflect the universally accepted standards of electrical devices such as the ULC Standards (2022) which ensure their safety and functionality. These parameters also indicate the limits of the electrical and electronic components which mean that the user should not go beyond these parameters for his or her protection and the device itself.

Furthermore, it also serves as a guide for the specific voltages and current ratings of the devices required for their normal operation.

Table 1. Actual voltage and current ratings of the MSS devices

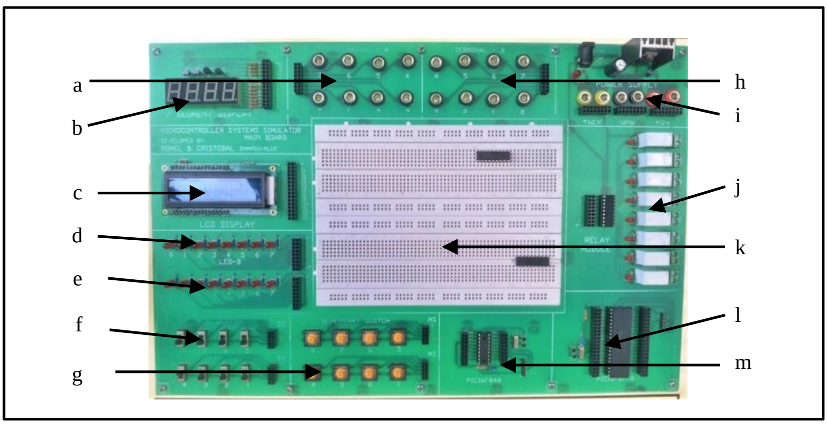
Device	Brand, model, manufacturer and country of origin	Voltage rating	Current rating
Momentary PB switch	Sanjin, LAY7(Y090LAY37), Shaanxi Sanjin Elevator Fittings Co. Ltd., China	660 VAC	6 A
Magnetic contactor	LS Metasol, MC-9a, LS Electric Co. Ltd., China	240-690 VAC	9 A
Relay	Tayco, OJ-SH-112 LMH, Tayco Electronics, United States	28 VDC/240 VAC	10 A
Buzzer	Siemen APT, AD16-22SM, r25, Siemens Group, China	24 V AC/DC	20 mA (LED)
Motor	Aokin, Aokin AG, Germany	12 VDC	2 A
Pilot lamp	RS PRO, IPO40 24V, RS Components Corporation, Philippines	12 VDC	1 A
Self-locking PB switch	WNRE, PB-305A, Yueqing Weinuoer Electronic Technology Co., Ltd.	250 V	3 A
Toggle switch	Altronics, S1044, Altronic Distributors Pty. Ltd., Australia	250 V	15 A
Capacitive proximity sensor	OEM, LJC18A3-H-Z, BY, OEM Electrical Co., Ltd., Thailand	5-36 VDC	300 mA
Inductive proximity sensor	OEM, LJ18A3-8-Z, BX NPN, OEM Electrical Co., Ltd., Thailand	5-36 VDC	200 mA
Photoelectric sensor module proximity switch	OEM, E18-D80NK, OEM Electrical Co., Ltd., Thailand	5-36 VDC	100 mA
Photo interrupter sensor	FUT, FUT-3278, FUT Electronic Technology Co., Ltd., China	5 VDC	50 mA
IR LED/infrared sensor	FUT, FDS053-B-A, FUT Electronic Technology Co., Ltd., China	5 VDC	100 mA
Relay (main board)	Songle, SRD T-73, Ningbo Songle Relay Co., Ltd., China	12 VDC/250 VAC	8 A
PIC16F84A microcontroller	RS PRO, PIC16F84A, RS Components Corporation, Philippines	2-5.5 VDC	25 mA

Table 1 continued.

PIC16F877A microcontroller	RS PRO, PIC16F877A, RS Components Corporation, Philippines	2-5.5 VDC	25 mA
5-mm LED	RS PRO, 5mmT-1 3/4, RS Components Corporation, Philippines	2.2 VDC	20 mA
Seven segment display	RS PRO, CA56-21, RS Components Corporation, Philippines	3.2 VDC	25 mA per LED
LCD display	RS PRO, RS PRO 185-0193, RS Components Corporation, Philippines	5 VDC	20 mA
Tactile switch	RS PRO, DTS 24NV, RS Components Corporation, Philippines	24 VDC	50 mA
Slide switch	RS PRO, MFP113D, RS Components Corporation, Philippines	30 VDC	100 mA

2.1.2 Design of the MSS Main Board

The MSS mainboard in Figure 2 was considered the heart of the system. The MSS used two important circuits, namely the PIC16F84A (Figure 3) and PIC16F877A (Figure 4) microcontrollers (Gridling and Weiss, 2007).



Terminal A (a); seven-segment display (b); LCD display circuit (c); LED-A (d); LED-B (e); slide switch (f); momentary switch (g); terminal B (h); power supply circuit (i); relay module (j); bread boards (k); PIC16F877A circuit (l); PIC16F84A circuit (m)

Figure 2. MSS main board

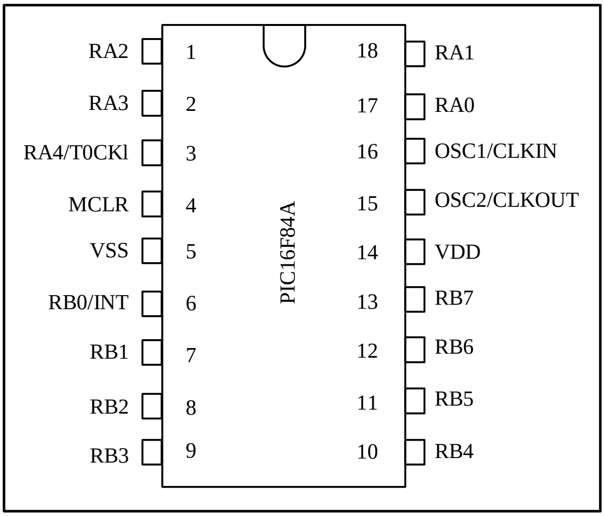


Figure 3. Pin diagram of PIC16F84A

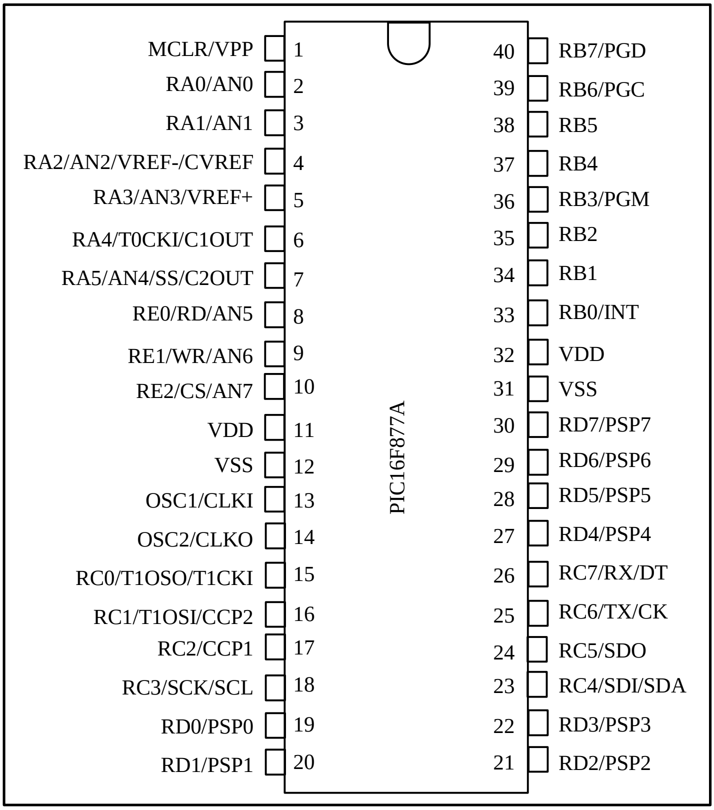


Figure 4. Pin diagram of PIC16F877A

2.2 Materials and Production Cost

Table 2 presents the quantity, unit, description, unit price and total price of supplies and materials needed for the development of the MSS.

Table 2. Bill of materials

Quantity	Unit	Description	Brand, model, manufacturer, country of origin	Unit price (Php)	Total price (Php)
1	unit	Acrylic plastic assembly with sticker and laser-cut holes	HSQY/HSQY Plastic Group, China (acrylic plastic only)	4,500	4,500
1	unit	Microcontroller mainboard assembly	Customized and assembled by the researcher; parts were acquired locally.	10,000	10,000
1	unit	Workbench assembly	Customized and assembled by the researcher; parts were acquired locally.	3,000	3,000
1	set	Desktop computer (surplus)	Surplus, assembled/clone	5,000	5,000
1	unit	PICKIT 2 programmer	Microchip, DV164122, RS Components Corporation, Philippines	679	679
4	pcs.	Momentary push button (PB) switch	Sanjin, LAY7 (Y090LAY37), Shaanxi Sanjin Elevator Fittings Co. Ltd., China	150	600
2	pcs.	Magnetic contactor	LS Metasol, MC-9a, LS Electric Co. Ltd., China	440	880
2	pcs.	Breadboard	RS PRO/102-9147/RS Components Corporation, Philippines	150	450
1	pcs.	Buzzer	Siemen APT, AD16-22SM, r25, Siemens Group, China	250	250
1	pc.	DC motor	Aokin, Aokin AG, Germany	90	90
2	packs	Breadboard jumpers	Mikroelektronika, MIKROE-512, RS Components Corporation, Philippines	200	400
15	m	Connecting wires (stranded # 22)	RS PRO, 873-9970, RS Components Corporation, Philippines	8	120

Table 2 continued.

12	pcs.	Pilot lamp (heavy duty)	RS PRO, IPO40 24V, RS Components Corporation, Philippines	48	576
3	pcs.	Pilot lamp (light duty)	Xindali, AD22-22B, Xindali Industries Co., Ltd., China	25	75
3	pcs	PIC16F84A (programmable IC)	RS PRO, PIC16F84A, RS Components Corporation, Philippines	200	600
1	pc.	PIC16F877A (programmable IC)	RS PRO, PIC16F877A, RS Components Corporation, Philippines	287	287
2	pcs	Light dependent resistor	Luna Optoelectronics, NSL-19M51, Luna Optoelectronics, Philippines	25	50
1	pc.	Voltage and current indicator	NIN, AC 22-mm LED, Zhejiang Ninuo Electrical Co., Ltd., China	226	226
5	pcs.	Universal PCB prototyping board	Fengfu, 6*8CM, Shenzhen Fengfu Electronic Technology Co., Ltd., China	35	175
30	pcs.	Resistors (assorted, 1-100 ohms)	Fengfu/, 1/4W resistor metal film 1%, Shenzhen Fengfu Electronic Technology Co., Ltd., China	2	60
30	pcs.	Jumbo LED (assorted color)	RS PRO, 5mmT-1 ¾, RS Components Corporation, Philippines	5	150
2	pcs.	DC relay (28 V, 10 A)	Songle, SRD T-73, Ningbo Songle Relay Co., Ltd., China	105	210
10	pcs.	IR switch transducer infrared motion reflective optical photoelectric sensor TCRT5000	FUT, FDS053-B-A, TCRT5000, Fut Electronic Technology Co., Ltd., China	100	100
2	pcs.	3-pin KY-018 optical sensitive resistance light detection photosensitive sensor	Tuozhan / TZ-ALS5I850 /Tuozhan Optoelectronics Company/China	178	356
1	pc.	Reed sensor	NIN/ LJ5A3-1-Z/BX / Zhejiang Ninuo Electrical Co., Ltd./China	140	140
1	pc.	Float sensor	NIN/ XK-156 / Zhejiang Ninuo Electrical Co., Ltd./China	50	100

Table 2 continued.

1	pc.	Photo interrupter	FUT/FUT-3278/Fut Electronic Technology Co., Ltd./China	55	55
1	pc.	DC 6-36V NPN NO 3-wire 4-mm noncontact inductive proximity sensor switch	OEM, LJ18A3-8-Z, BX NPN, OEM Electrical Co., Ltd., Thailand	290	290
1	pc.	Proximity sensor	OEM, E18-D80NK, OEM Electrical Co., Ltd., Thailand	279	279
1	pc.	1-10-mm capacitance proximity sensor switch (PNP NO DC 6-36 V 300 mA)	OEM, LJC18A3-H-Z, BY, OEM Electrical Co., Ltd., Thailand	420	420
1	unit	Regulated power supply (12 VDC)	ZJIVNV, S-CT60B-12, Yueqing City Zhijiu Electric Co., Ltd., China	150	150
1	pc.	Step down transformer (12 x 12, 2 A)	YHDC, PE2812-I, Beijing Yaohua Dechang Electronic Co., Ltd., China	300	300
4	pcs.	Rectifier diode (2 A)	ANBONSEMI, 1N4007G, Shenzhen Anbon Semiconductor Co., Ltd., China	10	40
1	pc.	Filter capacitor (3,700 MF/16 V)	JEC, 3700uf, 16v, Dongguan Zhixu Electronic Co., Ltd., China	50	50
5	pcs.	Toggle switch	Altronics, S1044, Altronic Distributors Pty. Ltd., Australia	30	150
126	pcs.	Binding post	OUKE, JS-910B 4 mm, Guangzhou Ouke Electronics Co., Ltd., China	15	1,890
50	pairs	Banana jack	OUKE, JS-910B 4 mm, Guangzhou Ouke Electronics Co., Ltd., China	20	1,000
2	pcs.	Male plug (heavy duty)	Usbo, U2P, Shenzhen Meisbo Technology Co., Ltd., China	30	60
4	pcs.	Self-locking push button switch	WNRE, PB-305A, Yueqing Weinuoer Electronic Technology Co., Ltd., China	25	100

Table 2 continued.

16	pcs.	Stainless allen bolts and wing nuts	Foracing, 14, Xi'an Forlong Technology Co., Ltd., China	35	560
2	sets	Universal convenience outlet (with plate)	Xingpeng, 118B, Yueqing Beibaixiang Xingpeng Electrical Switch Factory, China	145	290
5	m	Duplex wire (stranded, #14)	Tony, 10~24awg, Shenzhen Tony Electronics Co., Ltd., China	25	125
				Total cost	34,833

Table 3 shows the total production cost amounting to Php 47,024.55, inclusive of the 25% labor cost and 10% overhead cost. The structure of labor cost was adopted from the study of the Philippine Statistics Authority (2016) about the structure of labor cost in the Philippines where the manufacturing industry reflected a 25.2% average labor cost for all sizes of industry. Education, on the other hand, reflected an average labor cost of 27.7%. The MSS is intended for the education sector; however, it is a product of manufacturing, particularly electronic products. Thus it has adopted the labor cost for manufacturing of 25%. Meanwhile, the 10% overhead cost was based on the cost of the business in the Philippines as presented by ASEAN Briefing (Ellis *et al.,* 2015).

Table 3. Production cost

Cost element	Cost (Php)
Supplies and materials	34,833
Labor cost (25%)	8,708.25
Overhead cost (10%)	3,483.3
Total production cost	47,024.55

2.3 Fabrication of the Printed Circuit Board (PCB) of the MSS Main Board

The Circuit Maker 6.2 (Altium Limited, n.d.) was used in the schematic design and circuit simulation (Figure 5a, 5c and 5d), and TraxMaker 3.03 Pro (Altium Limited, n.d.) was used in the PCB layout and autorouting of the MSS mainboard (Figure 5e). The design (Figure 5b) was printed in a film using an ink printer (Canon imagePROGRAF PRO-521, Japan) and transferred to the phenolic board. The traditional method of drilling holes in the PCB applied the traditional method using an improvised drilling machine (Figure 5f). To remove the unwanted part of the phenolic board to form the printed circuits, the wet etching method was used (Figure 5h). The surface of the PCB was then laminated using a dry film PCB laminator (Figure 5g).

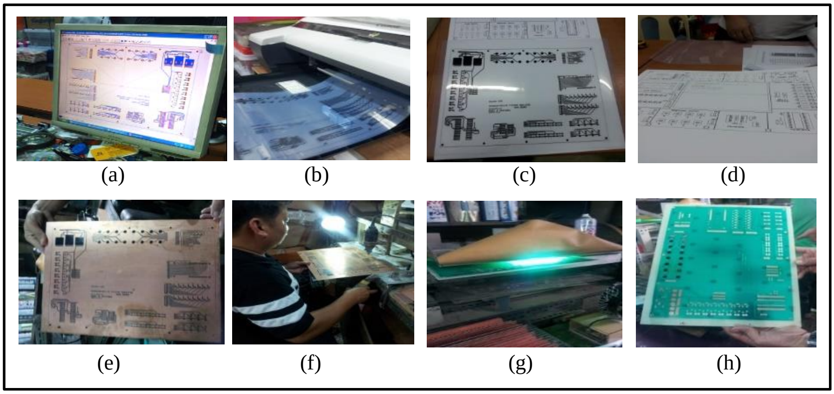


Figure 5. Fabrication of the PCB of the MSS main board

2.4 Assembly of the MSS Main Board

The spare parts and components were placed based on the design and the circuits (Figure 6b and 6d). The assembly was done by circuit or section using a 30-W soldering iron (Figure 6c).

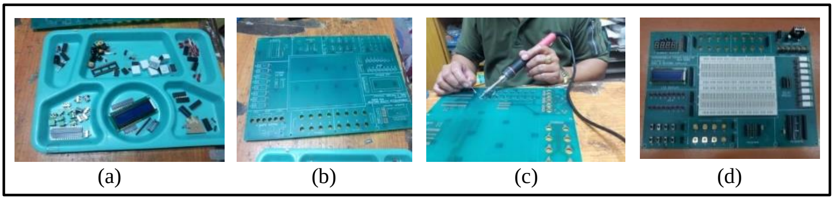


Figure 6. Assembly of the MSS main board

The circuits were composed of electronics components or spare parts such as the integrated circuit (IC), light-emitting diode (LED), resistor, capacitor, tack switch, slide switch, relay, LCD, seven-segment display, breadboard and pin header connector (Figure 6a).

2.5 Fabrication and Assembly of the MSS EDB

The AutoCAD® (Autodesk, n.d.) was used for designing the MSS EDB (Figure 7a). Using a 3/8-inch clear acrylic plastic (Figure 7d) with predetermined dimensions (Figure 7b), the material was cut and milled according to the design using a computerized sticker-cutting laser and engraving machine (Kaizer LE-0604, China). The same machine was also used in the cutting of sticker labels (Figure 7c). As part of the assembly of the EDB, the input and output (I/O) devices were mounted accordingly (Figure 7e and 7f). The terminals of the I/Os were extended to the board through soldering using 4-mm female banana jacks for easy access when performing a connection and simulation.

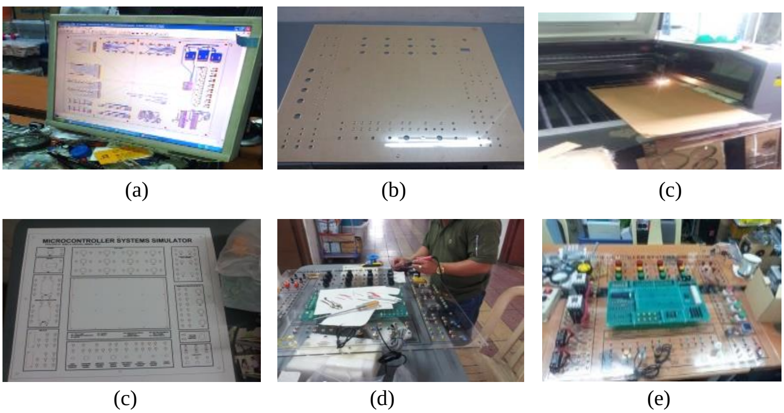


Figure 7. MSS EDB's construction and assembly

2.6. Performance Testing of the MSS

Performance testing included laboratory, technical and classroom testing and demonstration. The MSS underwent performance testing in an integrated automation company in Sta. Cruz, Manila, Philippines. The mainboard and development board were tested at the industry site. From there, revisions were made to make the simulator functional based on the needs, requirements and objectives of the course and end-users. Performance testing comprised of voltage and resistance tests (Homeres, 2020) and the ability of the simulator to perform the required simulations. The tests included simulations of 13 experiments as reflected in the MSS user's manual. These experiments included momentary switching, particularly push-on and release-off simulation. These were followed by toggle switching; start/stop function and up/down switch sequencing. Experiments about proximity sensing and automated switching simulations such as alarm systems using proximity sensor switches, object, and materials detection which tackled the use of capacitive proximity sensors and metal detection using inductive proximity sensors were also included. It was followed by an experiment on float sensor simulation which presented liquid-level automated switching simulation. Proximity sensing experiments that used a photo interrupter sensor, infrared reflective (IR) LED, and the parts that follow in this section deal with a light-dependent resistor for light sensing. Concluding the experiments about sensors was the use of a reed sensor or magnetic sensor for magnetic switching simulation. It should be noted that in each experiment, voltage and current measurement and testing were performed which was composed of three replications for every sensor. Voltage and current measurements were performed using an analog multimeter (Sanwa YX 360TRF, Sanwa Electric Instrument Co., Ltd., Japan), and a digital multimeter (Sanwa CD800a, Sanwa Electric Instrument Co., Ltd., Japan) as a confirmatory and comparative test. The results from the digital multimeter were the ones reflected in the table of actual performance since the device provides a more accurate and precise output as compared to the analog one. Final and rigorous performance testing was done in the workstation of the researcher.

2.6.1 Testing and Simulations of the MSS Main Board

The testing of the MSS main board (Figure 8) involved the testing of the functionality of every circuit of the board including its simulations. Component, resistance and voltage tests were undertaken before performing the connections.

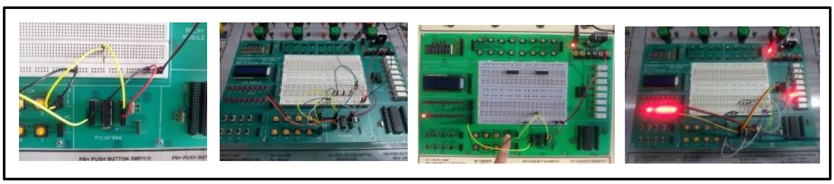


Figure 8. The MSS main board during testing and simulations

Component and resistance tests (Electrical Technology, 2014) were performed to ensure that every circuit and its components were in good condition. Voltage tests (Knap and Stroe, 2021) were also done to check voltage levels and polarity. The microcontroller circuit was the heart of the board, and the I/Os were support components to perform a simulation. The assembling of the microcontroller circuit and connecting of I/O devices was done using breadboard jumper wires as connectors. The MSS mainboard was a stand-alone circuit that could perform simulations using smaller devices.

2.6.2 Testing and Simulations of the MSS EDB

The MSS EDB was tested in the same way as the MSS mainboard, which included testing the functionality of every circuit on the board, as well as its simulations (Figure 9). Before making the connections, component, resistance and voltage tests (Lv *et al*., 2022) were performed.

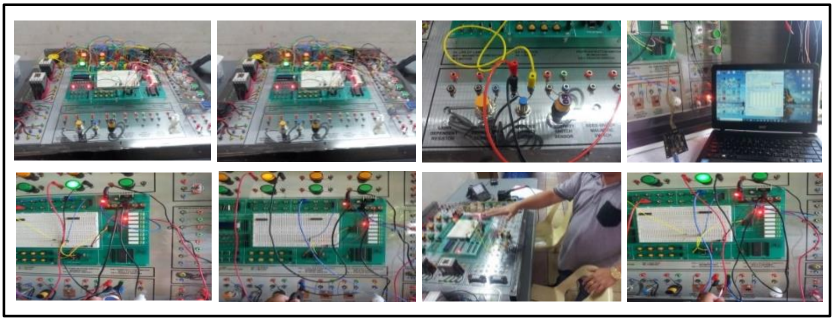


Figure 9. MSS EDB during testing and simulations

The circuits and components of the MSS EDB were also subjected to component and resistance testing to confirm that they were in good working order. Voltage testing, however, was more complex than that of the main board because the I/O devices in the EDB operated on different voltage levels, and some worked on alternating current (AC), and other devices worked using a direct current (DC) source. In the assembly of the circuits and performing simulations, this board used male and female banana jacks aside from breadboard jumper wires. Unlike the mainboard, it was not a stand-alone board and depended on the microcontroller circuit to perform a simulation. The programming of the PICKit 2 (Bates, 2011) was also a part of the process. The simulations relied on the kind of program that is being written on the PIC microcontroller. During the simulation testing, both the mainboard and EDB were able to perform the required simulations.

3. Results and Discussion

3.1 The Actual Design of the MSS EDB

The MSS EDB in Figure 10 was composed of various input/output (I/O) devices that can be connected and interfaced to the MSS main board to perform an experiment and simulate a particular function and application.

Buzzer (a); motor (b); magnetic contactor circuit (c); relay circuit (d); sensor circuit (e); pilot lamps circuit (f); self-locking push button (PB) switch and toggle switch circuit (g); momentary PB switch (h); voltage and current indicator circuit (i); and power supply control circuit (j)

Figure 10. MSS EDB

The MSS EDB had 10 sections or circuits. The circuits or sections were I/O's which can perform a particular function depending on the program and application needed. The EDB can be categorized into three applications or functions. Input devices such as sensors and switches fall under the first category. Along with this function, the experimental board had sensors, a self-locking push button (PB) switch, and toggle switch, and a momentary PB switch. The input devices are the ones responsible for giving a command to the microcontroller such as opening and closing a circuit or on/off, proximity sensing or detecting the presence or absence of an object and detecting a particular state such as sensitivity to light. Input devices are often controlled by the user. Second were output devices such as a buzzer, motor and pilot lamp. The EDB had a buzzer and a motor and several lamps. Output devices are sometimes called actuators because they actuate or perform the command of the microcontroller such as lamp lights, motor rotates and buzzer rings. Output devices perform what the user wants or needs. Interface devices like the magnetic contactor and relay are under the third category. These devices work as an interface for output devices that operate at higher voltage and current ratings. Good examples are the large motor that operates at 220 VAC and lamps that work on 24 VDC. The microcontroller only provides 5 VDC output with a very limited current rating, so actuators that require a greater amount of voltage and current need the required power source. In this case, an interface device is needed. Sometimes, both the relay and magnetic contactors are used as interface devices for the same circuit.

3.2 Simulation Performance of the MSS

Table 4 shows the summary and average performance of the simulator in terms of sensing distance, supply voltage, output voltage and time consumed in performing the simulations or experiments.

Table 4. Summary of simulation tests results

Simulations/ experiments	Sensing distance (mm)	Time consumed in performing the experiment (min)	Supply voltage (V)	Output voltage when target was detected (V)	Output voltage when target was not detected (V)	Output voltage when switch was activated (V)
1. Momentary switching (push-on, release-off)	n/a	3:15	4.97	n/a	n/a	4.48
2. Momentary switching (push-on, release-off) with advance activity	n/a	8:35	4.97	n/a	n/a	4.48
3. Toggle switching using PIC microcontroller	n/a	2:15	11.91	n/a	n/a	11.76
4. Start/stop function using PIC microcontroller	n/a	2:10	11.91	n/a	n/a	11.76
5. Up/down switch sequencing	n/a	1:57	11.91	n/a	n/a	11.76
6. Sequential light and LED controller	n/a	2:29	4.97	n/a	n/a	n/a
7. Alarm system using proximity sensor switch	980	3:18	11.97	11.91	6.25	n/a

Table 4 continued.

8. Object and materials detection using capacitive proximity sensor						
a. Plastic	18	1:51	11.91	11.89	6.24	11.89
b. Paper	6	1:51	11.91	11.89	6.24	11.89
c. Cloth	28	1:51	11.91	11.89	6.24	11.89
d. Plastic bottle with water	30	1:51	11.91	11.89	6.24	11.89
e. Plastic bottle without water	3	1:51	11.91	11.89	6.24	11.89
9. Metal detection using inductive proximity sensor						
a. Stainless steel	3	1:55	11.91	11.89	6.24	11.89
b. Silver	4	1:55	11.91	11.89	6.24	11.89
c. Gold	4	1:55	11.91	11.89	6.24	11.89
d. Copper	2	1:55	11.91	11.89	6.24	11.89
e. Steel	6	1:55	11.91	11.89	6.24	11.89
f. Aluminum	2	1:55	11.91	11.89	6.24	11.89
10. Float sensor simulation	n/a	2:00	11.91	n/a	n/a	n/a

n/a – not applicable

The settings of the sensors used were factory settings, and no adjustments were made during the simulations. It can be seen that the time consumed in performing the simulations or experiments varies, with “momentary switching with advance activity” having the longest average time of 8:35 min, while “object and material detection using capacitive proximity sensor” having the shortest time of 1:51 min. It was also noticeable that the supply voltage was the same or had a minimal difference from the output voltage when the switch or sensor was activated. On the relevant sensors, the output voltage decreased by more than 50% when the target was not detected. This implied that the output voltage was affected by the detection of a target object. Additionally, it was clear that neither the supply voltage nor the output voltage was affected by the type of material being detected. The table also demonstrated how the sensing distances of the sensors, particularly the capacitive and inductive sensors; differed depending on the type of material. The capacitive proximity sensor recorded the longest sensing distance of 30 mm for plastic bottles containing water and the shortest sensing distance of 3 mm for plastic bottles devoid of water for these simulations. The inductive proximity sensor revealed the shortest sensing distance for copper and aluminum at 2 mm and the longest sensing distance for steel at 6 mm. Finally, compared with the inductive and capacitive proximity sensors, the proximity sensor switch demonstrated the longest sensing distance of 980 mm, which was expected given that it is an optical sensor.

3.3 Performance of the MSS

Table 5 presents the results of replications of the actual performance of the sensors, while Table 6 reveals the average performance of the sensors along with measured voltage, measured current and maximum sensing distance. On average, it showed that the capacitive, inductive and proximity switch sensor functions normally at 5 and 12 VDC supply. However, it was non-responsive to 24 VDC, which was contrary to the given specifications of the sensors. The photo interrupter, IR LED sensor and reed sensor worked only at 5 VDC. Generally, if the supply voltage increases, the current also increases, which is consistent with Ohm's law – meaning, the voltage is directly proportional to the current.

Table 5. Actual performance of the sensors

	Replications	Sensors a	b	c	d	e	f
Measured voltage/12 VDC supply (V)	1	12	12.03	12.04	n/a	n/a	n/a
	2	12	12.03	12.04	n/a	n/a	n/a
	3	12	12.03	12.04	n/a	n/a	n/a
Measured voltage/5 VDC supply (V)	1	5.02	5.02	5.02	1.18	1.88	5
	2	5.02	5.02	5.02	1.18	1.88	5
	3	5.02	5.02	5.02	1.18	1.88	5
Maximum measured current (mA)	1	14.4	4.2	35	10.9	8.2	0.41
	2	14.4	4.2	35	10.9	8.2	0.41
	3	14.4	4.2	35	10.9	8.2	0.41
Maximum sensing distance (mm)	1	12	4.5	42	3	6	23
	2	12	4.5	42	3	6	23
	3	12	4.5	42	3	6	23

a – capacitive proximity sensor; b – inductive proximity sensor; c – proximity sensor switch; d – photo interrupter sensor; e – IR LED/infrared sensor; f – reed sensor

For the capacitive sensor, increasing the supply from 5 to 12 V improved also its sensing distance from 2 to 12 mm, which meant that there was an improvement in the sensitivity of the sensor. Similar observations were also noted from the proximity sensor switch where sensing distance improved at 33 to 42 inches from 20 to 24 inches when increasing the supply voltage from 5 to 12 VDC. Another notable observation of the proximity sensor switch was that it registered the highest current rating with 35 mA at 12 VDC. These results were not consistent with the performance of the inductive proximity sensor where the same sensing distance (4.5 mm) was observed even though the supply voltage was increased from 5 to 12 VDC. The photo interrupter and IR LED sensor operated at a very minimal voltage of 1.18 and 1.88 VDC with 3 and 6 mm sensing distance, respectively. The reed sensor operated at 5 VDC and registered the lowest current rating of 0.41 mA among the sensors. It had also a sensing distance of 23 mm.

Table 6. Average actual performance of the sensors

Device	Supply/source rating			Measured voltage (V)	Measured current (mA)	Maximum sensing distance (mm)
	5V/2A	12V/2A	24V/2A			
1. Capacitive proximity sensor	x			5.02	1.81	2
		x		12	14.4	12
			x		Non-responsive	
2. Inductive proximity sensor	x			5.02	1.26	4.5
		x		12.03	4.2	4.5
			x		Non-responsive	
3. Proximity switch sensor	x			5.02	4.5	609.6
		x		12.04	35	1066.8
			x		Non-responsive	
4. Photo interrupter sensor	x	n/a	n/a	1.18	10.9	3
5. IR LED/ infrared sensor	x	n/a	n/a	1.88	8.2	6
6. Reed/ magnetic sensor	x	n/a	n/a	5.0	0.41	23

n/a – not applicable; x – supply/source rating applied

4. Conclusion and Recommendation

This study demonstrated that it is technically feasible to design, develop and fabricate an MSS utilizing commercially and locally available materials. Test results showed that the voltage readings were normal, sensors were working with the indicated specifications, and the MSS could perform simulations. The series of testing and revisions of the MSS conformed to required technical parameters, electrical, electronics and safety standards and ensured the safety of users and technical performance of the simulator in terms of sequencing applications, switching simulations, proximity sensing and automated switching simulations. It is recommended to simplify the development and fabrication process and apply cost-cutting measures to possibly reduce the cost of production. Also, future research should delve into similar studies considering other and more advanced applications of microcontrollers.

5. Acknowledgement

The author would like to thank Engr. Edmund C. Wong and Dr. Manolito F. Dela Cruz for their guidance, support and technical assistance. He also acknowledges the support of Isabela State University, Angadanan Campus.

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