VERSION 1.0

CRITICAL DESIGN DOCUMENT

ULTRASONIC DISTANCE MEASUREMENT

MEMBERS : ALAA MOHAMED (W0411797)
ANDREW KIM (W0414568)

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1. CONCEPT OF OPERATIONS

The objective of this project is to build a portable Ultrasonic Distance Measurement device with minimal operation interaction. The core functionality of the device will be perimeter detection of objects in four directions (Front, Back, Left and Right). Four ultrasonic sensors will be utilized to continuously detect objects and measure the distance from the device. Of the object detected by the device, the closest object will take precedence and will be displayed on an LCD module indicating the direction and distance of the object. The distance displayed shall be measured in both metric and imperial units which can be selected using a switch on the device. Additionally, distance displayed will also have automatic unit conversion for distances greater than 100 cm or 12 inches to meters and feet respectively depending on the selected distance unit for optimal user usability. In addition to the LCD display, LED will also light up in the direction of the closest object for immediate visual verification. An audible alarm (buzzer sound) will also be implemented to notify the user when any object gets closer than 15 cm or 6 inches. In accordance to the main functionality of the device stated above, user will also be able to enhance device accuracy by selecting the calibration mode to reduce and adjust the margin of error that may be present for each sensor.

2. REQUIREMENTS BREAKDOWN

1. CAPABILITY

1.1 Device shall be portable (Battery powered)
1.2 Device shall be operated in an indoor environment
1.3 Device shall utilize microcontroller chip(*Derived*) to execute core functionality
1.4 Device shall have the ability to detect object/s in 4 directions (Front, Back, Right, Left) in reference to the enclosure
1.5 Device shall have the ability to identify the direction of the closest object
1.6 Device shall have the ability to identify the distance of the closest object
1.7 Device shall display the direction and distance of the closes object via LCD Display(*Supplied*)
1.8 Device shall utilize 4 ultrasonic sensors(*Supplied*) to detect object/s
1.9 Device shall utilize 4 ultrasonic sensors(*Supplied*) to measure distance of the object/s
1.10 Device shall utilize 4 ultrasonic sensors(*Supplied*) to determine object direction
1.11 Device shall have the ability to display distance in inches (Imperial)
1.12 Device shall have the ability to display distance in feet (Imperial)
1.13 Device shall have automatic unit conversion from inches to feet for distances greater than or equal to 12 inches
1.14 Device shall have the ability to display distance in centimeters (Metric)
1.15 Device shall have the ability to display distance in meters (Metric)
1.16 Device shall have automatic unit conversion from cm to meters for distances greater than or equal to 100 cm
1.17 Device shall provide selection option of preferred distance unit (Imperial or Metric)
1.18 Device shall be calibrated on each use to increase distance measurement reliability
1.19 Device shall notify with audible alarm if any object is closer than 6 inches or 15.24 cm
1.20 Device should have the ability to detect object/s up to a distance of 254 inches or 6.45 meters max

2. CONSTRAINTS

2.1 Detected object should be aligned with sensor's line of sight for measurement reliability
2.2 Detected object should have min width of 0.25 inches or 6.35 mm for measurement reliability
2.3 Detected object should have min height of 2.5 inches or 6.35 cm for measurement reliability
2.4 Measurement reliability for objects closer than 6 inches or 15.24 cm is not guaranteed

3. POWER

3.1 Device shall be fully powered by a commercial standard 9-volt battery(*Supplied*)
3.2 Device shall utilize 5V regulator(*Supplied*) to adjust power for necessary components
3.3 Device shall utilize 3.3V regulator(*Supplied*) to adjust power for necessary components
3.4 Device should use a LED(*Derived*) as indicator for power-on state

4. CIRCUITS

4.1 Device shall have 1 main circuit and 4 sub circuits
4.2 Main circuit shall consist of power and microcontroller circuitry
4.3 Main circuit shall connect to components placed on top-side of enclosure
4.4 Sub circuit shall consist of sensor circuitry and related components place on top-side of enclosure

5. SENSORS

5.1 Ultrasonic sensors shall be powered by the 5V regulator output
5.2 Ultrasonic sensors will use high frequency sound to detect objects within range
5.3 Ultrasonic sensors shall have a distance resolution of 1 inch max
5.4 Device should utilize analog voltage output format of the ultrasonic sensor

6. MICROCONTROLLER CHIP

6.1 Microcontroller shall be powered by the 3.3V regulator output
6.2 Microcontroller should utilize AtoD function to convert sensor's analog voltage to digital format
6.3 Microcontroller should process the converted digital format to determine object distance
6.4 Microcontroller should process the converted digital format for distance unit conversion
6.5 Microcontroller should process the converted digital format to determine the closest object
6.6 Microcontroller shall use serial communication to interface with LCD

7. ENCLOSURE

7.1 Device enclosure should be a box with dimension of 8" width x 8" length x 5" height min
7.2 Device enclosure's top-side should be openable to access internal circuitry
7.3 Device enclosure should made of sturdy material (i.e. wood, plastic)

8. LAYOUT

8.1 Main circuit shall be constructed on large breadboard
8.2 Sub circuit shall be constructed on small breadboard
8.3 Enclosure shall be marked to display corresponding direction (Front, Back, Left and Right)
8.4 Ultrasonic sensors shall be centrally positioned on each side of the enclosure

8.5 All switches shall be positioned on the top-side of the enclosure
8.6 All LED shall be positioned on the top-side of the enclosure
8.7 LCD display shall be positioned on the top-side of the enclosure
8.8 Buzzer shall be positioned on the top-side of the enclosure
8.9 All switches positioned on the top-side of the enclosure should be labeled

9. INTERFACE

[Switches]

9.1 Device will use a toggle switch(*Derived*) to power on/off the device
9.2 Device shall use a toggle switch(*Derived*) to select measuring units (Imperial and Metric)
9.3 Device shall use a toggle switch(*Derived*) to select measure or calibrate mode
9.4 Device shall use two momentary push-button switches(*Derived*) for calibration increment/decrement input
9.5 Device shall use four toggle switches(*Derived*) to select the sensor/direction to be calibrated

[Display & Alarm Output]

9.6 Device shall be able to write 8-bit data result to the LCD display
9.7 LCD display shall be powered by the 5V regulator output
9.8 Device should utilize 4 LEDs(*Derived*) to visually indicate the direction of the closest object
9.9 Device shall interface with buzzer(*Supplied*) for audible alarm to object closer than 6 inches or 15 cm

10. DISPLAYED OUTPUT

10.1 LCD shall utilize max 2 rows and 16 characters to display direction and distance (Numeric and Measuring Unit)
10.2 LCD shall display the direction as one of the following (Front, Back, Left and Right)
10.3 LCD shall display the distance numerically in max 5 digits including decimal point
10.4 LCD shall display the distance measuring unit in 2 digits max

11. CALIBRATION

11.1 Device shall be calibrated for increased accuracy for distance measurement
11.2 Device shall use measure/calibrate switch to select calibrate mode
11.3 Device shall be calibrated by selecting one corresponding sensor at a time
11.4 Each sensor/direction shall be calibrated by using the increment or decrement button to make adjustments accordingly to the actual and displayed distance
11.5 User shall switch back to measure mode before measuring direction and distance

3. PROJECT BREAKDOWN

Task #	Task Description	Start Date (Estimate)	Completion Date (Estimate)
1.0	Module 1 - Core Functionality	10/29/2019	12/03/2019
1.1	Code - ADC	10/29/2019	11/22/2019
1.2	Code - Measurement	11/04/2019	11/22/2019
1.3	Code - Unit Conversion	11/05/2019	11/22/2019
1.4	Code - Direction	11/07/2019	11/22/2019
1.5	Test/Debug Module 1	11/01/2019	12/03/2019
2.0	Module 2 - Calibration	11/11/2019	12/16/2019
2.1	Code - Calibration	11/11/2019	12/16/2019
2.2	Adjust Calibration	11/12/2019	12/16/2019
2.3	Test/Debug Module 2	11/12/2019	12/16/2019
3.0	Module 3 - Output	11/18/2019	11/20/2019
3.1	Code - UARTRx (LCD)	11/18/2019	11/19/2019
3.2	Code - LED Direction/Distance Indicator	11/19/2019	11/20/2019
3.3	Code - Buzzer	11/19/2019	11/20/2019
3.4	Test/Debug Module 3	11/20/2019	11/20/2019
4.0	Software Integration	11/21/2019	12/16/2019
4.1	Software Integration	11/21/2019	12/16/2019
4.2	Software Test	11/25/2019	12/16/2019
4.3	Debug and Optimize	11/25/2019	12/16/2019
5.0	Hardware Integration	11/01/2019	12/03/2019
5.1	Place order for derived components	11/01/2019	11/15/2019
5.2	Build Enclosure	11/15/2019	11/29/2019
5.3	Assemble Voltage Regulators Circuitry	11/04/2019	11/06/2019
5.4	Assemble PIC Circuitry	11/18/2019	11/21/2019
5.5	Install all circuitry & components to enclosure (Sensors, LCD, LEDs, Switches & Buzzer)	11/22/2019	11/27/2019
5.6	Circuit Test/Modification	11/27/2019	11/29/2019
6.0	Project Completion	12/02/2019	12/16/2019
6.1	Finalize Documents	12/02/2019	12/16/2019
6.2	Project Delivery	12/05/2019	12/16/2019

4. PSEUDO CODE

1. Function: Main

Main Function calls all the functions required to perform the calibrated AtoD Conversion for 4 different analogue inputs, Call Calibration function and store their data in 4-element array, call "Closest" function, call SetOutput

- Define a variable (mdir[]) to hold the calibrated value AtoD conversion
- Define a variable (delta[]) to hold delta values from calibration function
- Call Initialization function
- Set indefinite while loop for continuous operation
- Call GetAnalogVoltage function 4 times for the 4 inputs (for loop)
- Call GetCalibrated function while calibration switch is ON
- Add delta value to non-calibrated digital values to get calibrated distances
- Call GetClosest function to determine the smallest value representing distance of the closest object
- Call SetOutput function
- Arguments: None
- Returns: None

2. Function: Initialize

Function to initialize the PIC Controller for all pre-configured settings, such as AtoD conversion, USART and digital I/O.

- Initializes the USART peripheral to be ready to transmit and receive 8-bit data to LCD.
- The PIC USART is set up for a 9600 baud rate, 8-bit data, asynchronous mode of operation using interrupts.
- Function Initialize () definition: set conversion clock speed to 8 MHz
- Select 4 analogue inputs (RA0, RA1, RA2, RA3)
- Select 8 digital inputs (RB0, RB1, RB2, RB3, RB4, RB5, RC2, RC3)
- Select 5 digital outputs (RD0, RD1, RD2, RD3, RD4)
- Set the voltage reference to Vdd/Vss
- Set the justification for the ADRESH registers
- Arguments: None
- Returns: None

3. Function: GetAnalogVoltage

Acquire and ADC sample of the four analog voltages present on 'input'. The function will store the ADC 16-bit value which will then be passed back to main for further processing.

- Defines a variable that holds converted digital value
- Receives an argument in the form of a char to tell the function what input will be used
- Four If condition statements depending on received argument to determine which analog input will be converted (determine ADCON register)
- Performs the operation of acquiring the 16-bit sample of the input analog voltage (ADON 1)
- Turn on the ADC (GO-DONE1)
- Initiate an ADC Conversion
- Pass back the converted value

4. Function: GetCalibrated

This function is to increment or decrement the returned digital value from ADC function for the purpose of calibration. Increment or decrement will be done by two momentary pushbuttons which then the calibrated value will be returned to the main function. Four digital inputs (switches) will determine which direction will be calibrated then pass the "delta" value back to main function and call SetOutput function to display the distance during the calibration process. Additionally, LED of the direction being calibrated will be on for visual confirmation.

- Call AtoD function
- Based on the direction of the closest object, do the adjustment by increment or decrement digits to the AtoD digital value
- Store the 4 calibrated digital values in an array
- Return array to function 'main' to be called by SetOutput function

5. Function: GetClosest

This function is to determine the smallest digital value out of the converted four signals which represents the distance of the closest object and turn on the LED of the associated to direction.

- This function receives four different digital values representing calibrated distance of objects from the four sides
- Perform four conditional statements to determine direction of the closest object
- The four conditional statements will also determine digital value representing the distance of the closest object
- Turn on LED associated to the direction of the closest object
- Return digital value representing the distance of the closest object

6. Function: SetOutput

This function is to receive digital value of the distance of closest object and convert it to distance in inches/feet or centimeter/meters based on the unit selection switch. It will also enable buzzer to alarm if distance becomes less or equal to 6 inches (or 15cm). This function will call another three functions to display direction of the closest object, distance and measurement unit to the LCD display.

- Define a function with char argument (ADPortval) that will receive the calibrated AtoD value
- Define a float variable (distance) to hold the measured distance in inches
- Use the resolution value to determine distance in inches (i.e. 9.8mV/in. * ADPortCal=distance)
- Conditional statement if distance is less than 0.0588 (which represents 6 inches)
- Then, RD4=1 (buzzer alarms)
- Unit conversion code
- If unit selector switch is OFF (RB0=0), then units will be in imperial (default)
- So, if distance >12, then distance = distance/12 (to show distance in feet)
- If unit selector switch is ON (RB0 is 1), then units will be in metrics
- Distance = distance * 2.54
- If distance >100, then distance = distance/100 (to show distance in meters)
- Call function LCD_direction to display direction on LCD
- Call function LCD_distance to display distance and unit on LCD
- Call function Lcd_Cmd to clear screen and another to place cursor on Row 2, bit 1

7. Function: LCD_direction

This function enables the UART transmitter and transmits a string of characters one at a time to LCD to display direction of the closest object based on turned on LED in measuring mode or turned on switch in calibration mode.

- Define array that holds string for the direction
- Four If statements that determines the printed direction based on the state of LEDs in measure mode or turned on switch (sensor select switch) in calibrate mode
- Enable USART transmitter
- Print direction, delay then disable transmitter

8. Function: LCD_distance

This function receives two arguments, distance and measurement unit, then enables the UART transmitter and transmits a string of characters to display measured distance of the closest variable (in case of measure mode) or the distance of the direction being calibrated (in case of calibrate mode) in addition to displaying the measurement unit.

- Define 2 variables to hold distance and unit
- Enable USART transmitter
- Print distance and unit
- Delay then disable transmitter

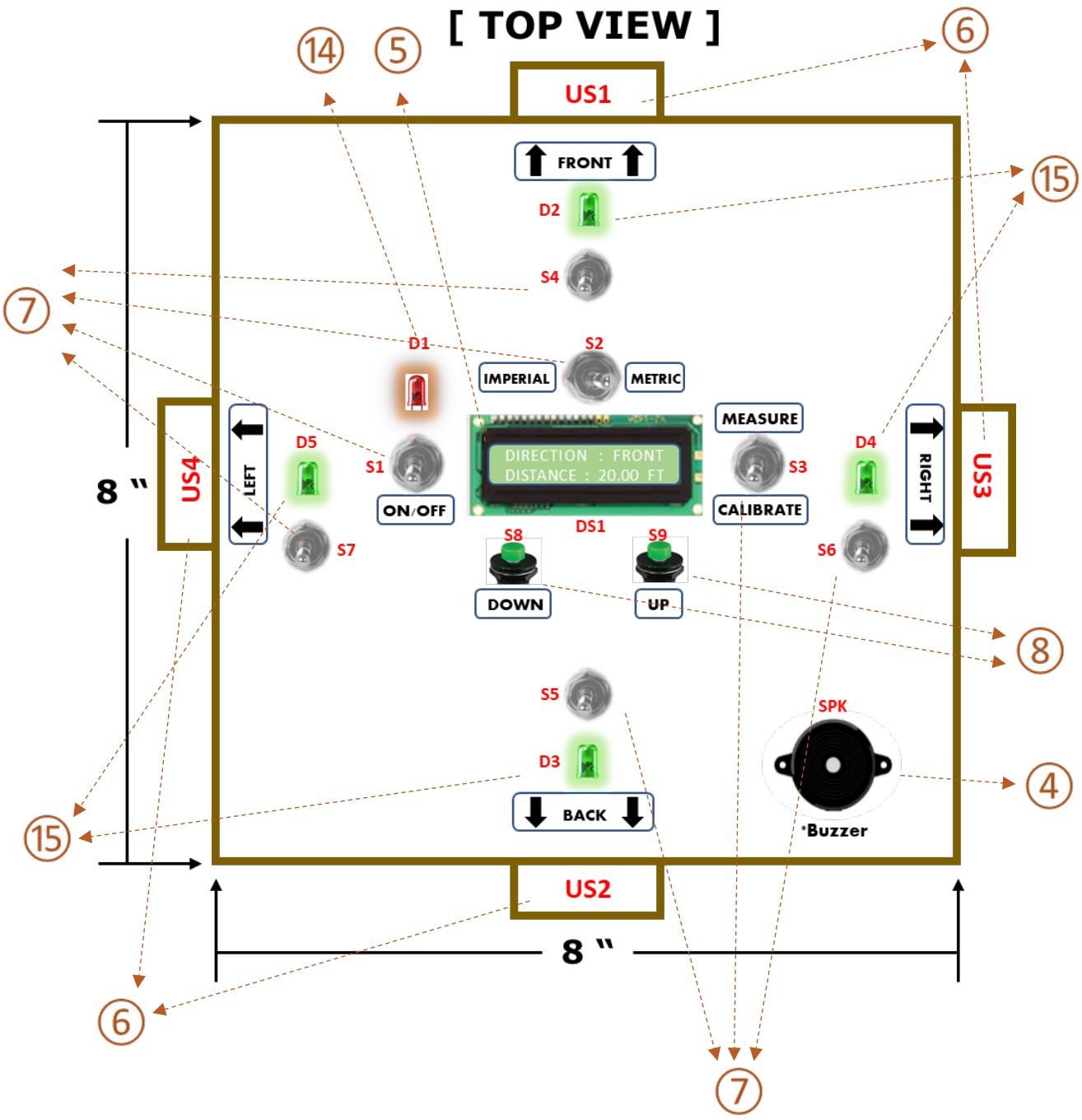
9. Function: Lcd_Cmd

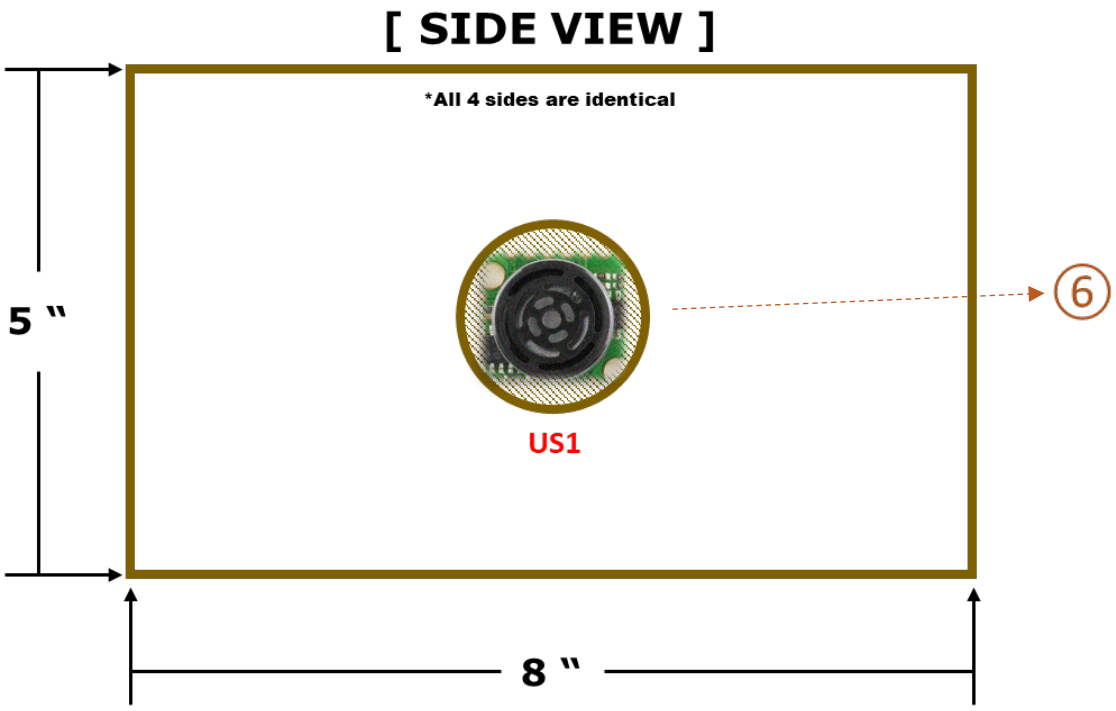
This function is to issue commands to the LCD module to either clear the screen or place cursor in the next line based on received argument.

- Define a variable that holds the data received (argument)
- Enable USART transmitter
- Continue to loop while the TXREG still has data
- Once Transmitter Register has been cleared, load it with new line
- Delay then disable transmitter

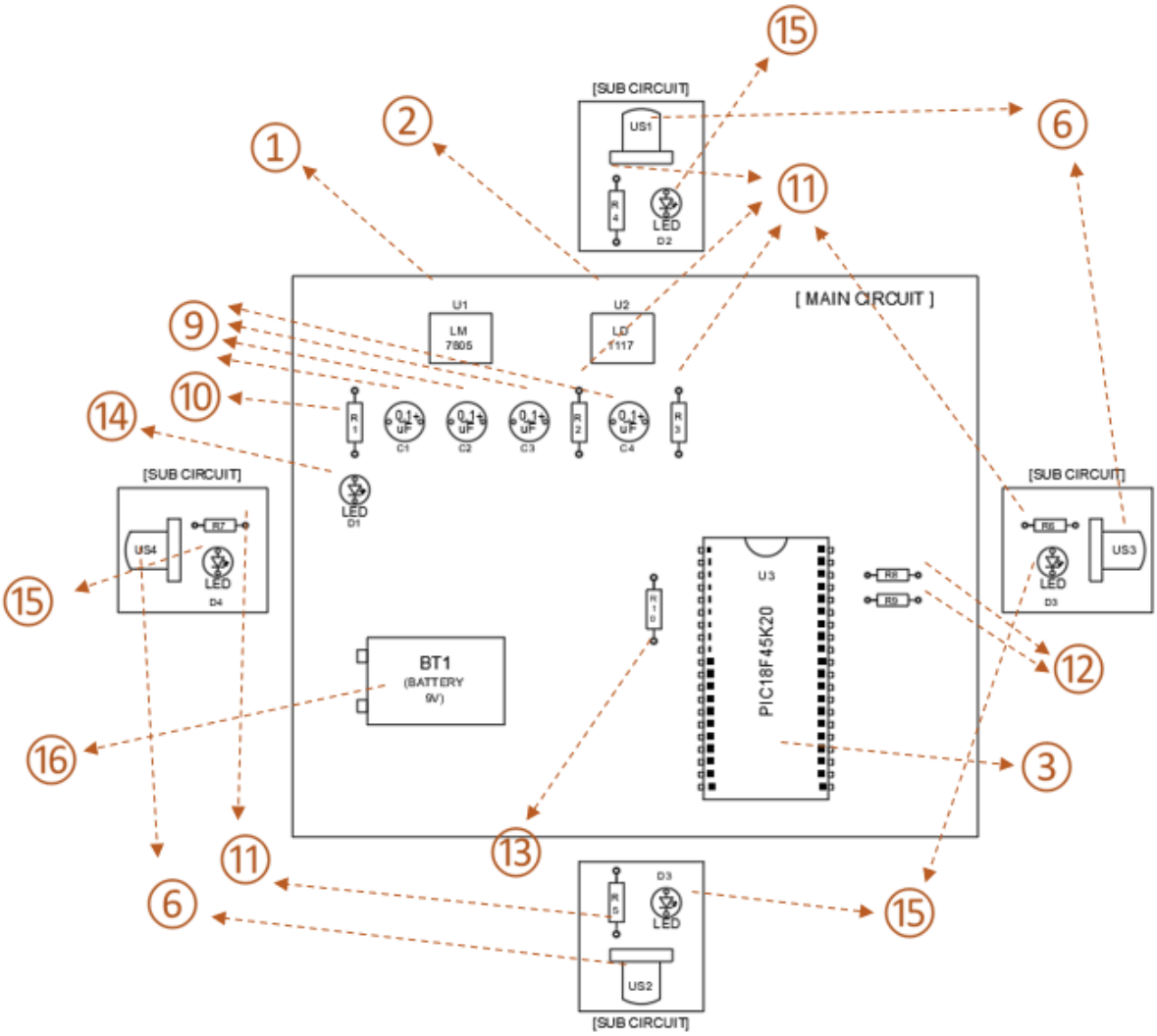
5. HARDWARE DESIGN

▶ ASSEMBLY LAYOUT





CIRCUIT BOARD LAYOUT

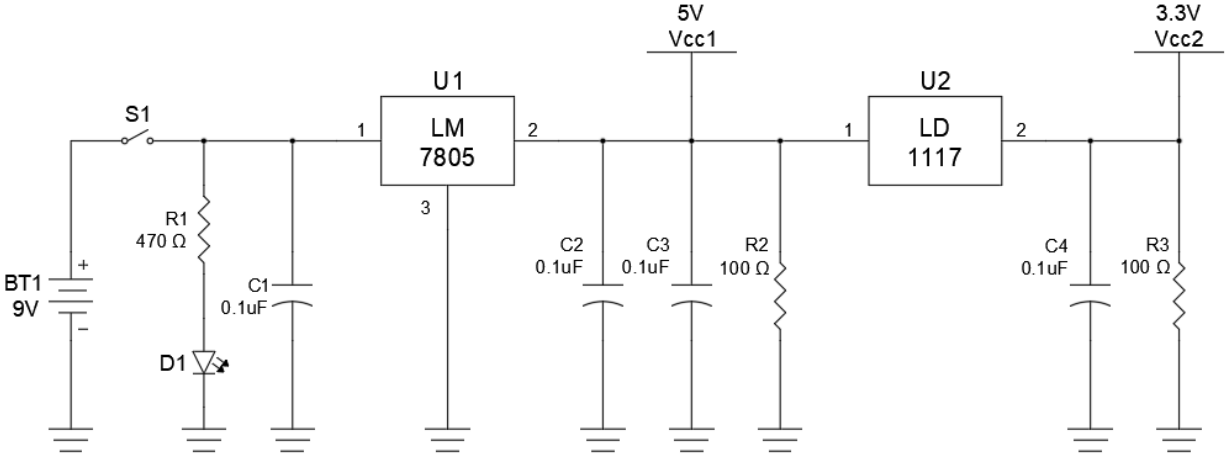


▶ PARTS LIST

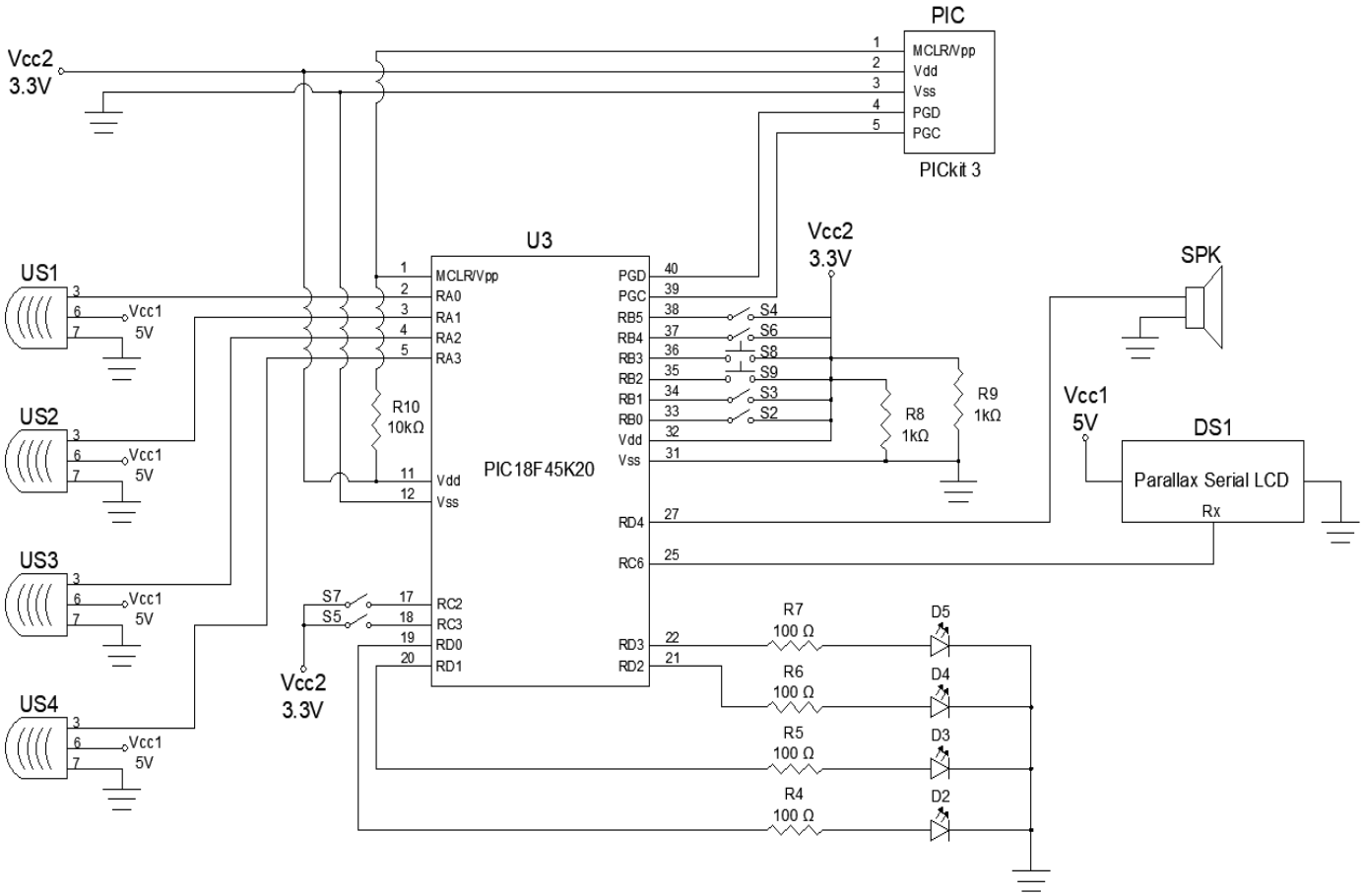
Item	QTY	Part Number	Description	Ref Designator
1	1	LM7805	5 Voltage Regulator	U1
2	1	LD1117	3.3 Voltage Regulator	U2
3	1	PIC18F45K20	PIC Microcontroller	U3
4	1	CEP-2202A	Buzzer	SPK
5	1	EL1602	LCD Display	DS1
6	4	MB1020 LV-MaxSonar-EZ3	Sonar Range Finder	US1, US2, US3, US4
7	3	TBD	Toggle switch	S1, S2, S3, S4, S5, S6, S7
8	2	TBD	Momentary switch	S8, S9
9	4	K104K20X7RH5TH5	Capacitor - 0.1uF	C1, C2, C3, C4
10	1	CBT50J470R	Resistor - 470 Ω	R1
11	6	CBT50J100R	Resistor - 100 Ω	R2, R3, R4, R5, R6, R7
12	2	CBT50J1000R	Resistor – 1k Ω	R8, R9
13	1	CBT50J10000R	Resistor – 10k Ω	R10
14	1	WP7113LID	LED Red (Power)	D1
15	4	WP7113LGD	LED Green (Direction)	D2, D3, D4, D5
16	1	TBD	9-Volt Battery	BT1
17	1	N/A	Battery Holder	
18	1	N/A	Main Breadboard (Large)	
19	4	N/A	Sub Breadboard (Small)	
20	120	N/A	Jumper wires	

CIRCUIT SCHEMATIC

[Power Circuit]



[Main Circuit]



6. PROJECT TEST/EVALUATION

Test#	Requirements	Test step	Pass/fail
1	1.18	Place an object 20 inches on the front side, power on device, set circuit to calibration mode (turn on calibration switch). Switch front sensor calibration ON and ensure all other sensors calibration switches are OFF. Verify the displayed distance is 1.67 feet (+/-1 inch). If reading is lower, press increment button or if reading is higher, press decrement button till LCD displays 1.67 feet and direction is "Front"	
2	1.18	Place an object 20 inches on the back side, power on device, set circuit to calibration mode (turn on calibration switch). Switch Back sensor calibration ON and ensure all other sensors calibration switches are OFF. Verify the displayed distance is 1.67 feet (+/-1 inch). If reading is lower, press increment button or if reading is higher, press decrement button till LCD displays 1.67 feet and direction is "Back"	
3	1.18	Place an object 20 inches on the right side, power on device, set circuit to calibration mode (turn on calibration switch). Switch Right sensor calibration ON and ensure all other sensors calibration switches are OFF. Verify the displayed distance is 1.67 feet (+/-1 inch). If reading is lower, press increment button or if reading is higher, press decrement button till LCD displays 1.67 feet and direction is "Right"	
4	1.18	Place an object 20 inches on the left side, power on device, set circuit to calibration mode (turn on calibration switch). Switch Left sensor calibration ON and ensure all other sensors calibration switches are OFF. Verify the displayed distance is 1.67 feet (+/-1 inch). If reading is lower, press increment button or if reading is higher, press decrement button till LCD displays 1.67 feet and direction is "Left"	
5	1.4, 1.5, 1.6, 1.7, 1.11, 1.13	Set circuit to measure mode, then place an object 20 inches on the front side. Verify the displayed distance is 1.67 feet (+/-1 inch) and displayed direction is "Front"	
6	1.4, 1.5, 1.6, 1.7, 1.11, 1.13	Maintain state of test (5), then place another object on back side with distance closer than 20 inches (e.g. 10 inches). Verify that the LCD is displaying "Back" and the measured distance of the closer object.	
7	1.15, 1.17	Maintain state of test (5), then select unit switch to 'Metric'. Verify that LCD displays the measured distance correctly in equivalent cm (+/- 2.5 cm)	
8	1.19	Maintain state of test (7), then select unit switch to 'Imperial' then place a 3rd object on the right side of the device at a distance of 5 inches. Verify that buzzer alarms and displayed distance is smaller than 6 inches.	
9	1.4, 1.5, 1.6	Maintain state of test (8), Place an object on the left side at distance of 4 feet. Verify that LCD display remains unchanged.	

10	1.4, 1.5, 1.6, 1.7, 1.11, 1.13	Maintain state of test (9), and then remove all objects except the object on the left side. Verify that LCD display shows closest object direction is "Left" and distance is 4 feet.	
11	1.14, 1.15, 1.16, 1.17	Maintain state of test (10), then select unit switch to 'Metric' and verify that distance is 1.20 m (+/- 0.025 m).	
12	1.14, 1.15, 1.16, 1.17	Maintain state of test (11), move the object on left side closer to the device to 95 cm then verify that displayed distance is 95 cm (+/-2.5 cm).	