Introduction

In lab 2, our goal was to implement a digital tape measure electronically using an ultrasonic sensor and use a LCD display module to display the measurements. In almost every field, be it consumer or industrial, accurate measurements are always essential. Conventional tape measures require manual operation and physical contact which has limitations like speed and induce human errors. So a digital tape measurement system helps overcome all these issues and limitations. The system is designed using the ATmega328p microcontroller which is paired with the ultrasonic sensor and a lcd display to measure and display measurements in real time.

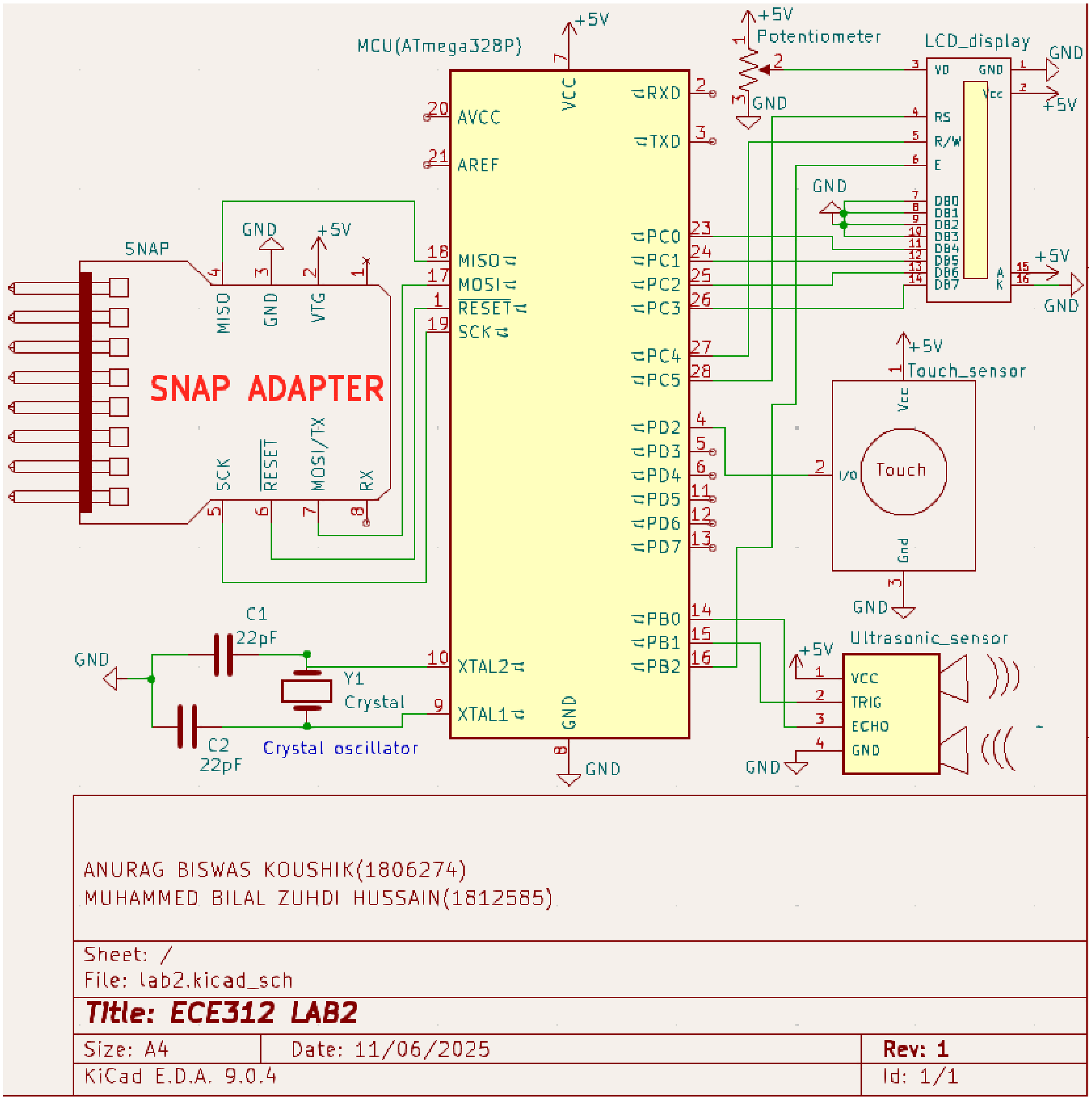
The system works by triggering a short burst of sound waves using the ultrasonic sensor and then recording the time it takes the sound waves to reflect back or echo from the surface that the distance is to be measured. The ultrasonic sensor has one trigger pin and one echo pin. The trigger pin is used to send out the pulse and the echo pin is used to detect the echo. The ultrasonic sensor is designed in such a way that the echo pin stays high until no echo is detected and goes low if an echo is detected. So the distance that the sound wave travels is proportional to the high time of the echo pin on the ultrasonic sensor. This time is recorded using the built-in timer in the ATmega328p microcontroller called the Timer1. Timer1 is a 16-bit hardware timer which can record very precise timestamps as programmed on one of the specific pins on the microcontroller. For this project, we need the Timer1 to record the rising edge and the falling edge of the echo pin on the ultrasonic sensor to measure the time required for the pulse of soundwave to travel and use that with the known speed of sound to measure the distance.

$$2d = vt$$

The pulse travels to and forth to the object which is why the distance is doubled. An external crystal oscillator is used along the microcontroller to improve accuracy. The crystal oscillator helps provide a stable and accurate clock reference which minimizes the uncertainty in the distance measured. [1] The crystal oscillator used for this lab is specified to oscillate at a frequency of 14.7456MHz.

The specification for the digital tape measure project is a range of 2 cm to 200 cm to be measured reliably with the sensor. The device is set to operate continuously, updating the measurements every second on the LCD. The LCD module is driven by the HD44780 controller which uses a 4-bit data bus to transfer the data to be displayed from the microcontroller. The LCD is configured to display the current measurement on the top line and the maximum and minimum to be displayed on the second as well as an "Out of range" message to be displayed when trying to measure anything less than 2 cm and more than 200 cm. This design enables the users to have the instantaneous measurement as well as the historic maximum and minimum displayed on the same screen. Furthermore, the system also includes a reset button to be used to clear the historic maximum and minimum values and also to reset when the measurement goes out of range. The system is also designed to display "NaN" in the maximum and minimum field upon first powerup to indicate no values in memory making the feedback more intuitive and increasing usability and reliability.

Circuit Schematic



Prototype Circuit

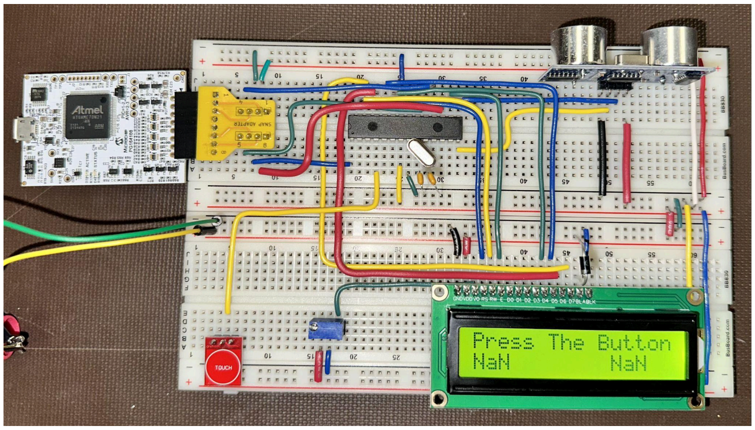


Figure 1.1: The initialization of the circuit at power up shows the instruction to start measuring and the maximum and minimum values show “NaN” as there are no previous measurements in memory.

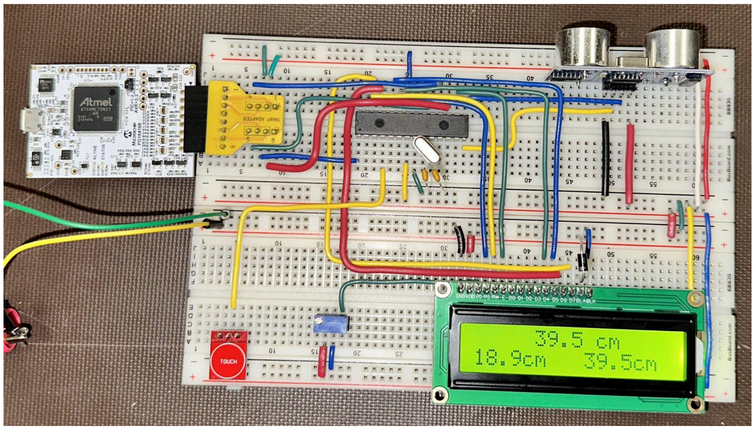


Figure 1.2: The system in its normal operating state, showing the real time measure on the top and then the minimum measurement on the left and the maximum measurement on the right.

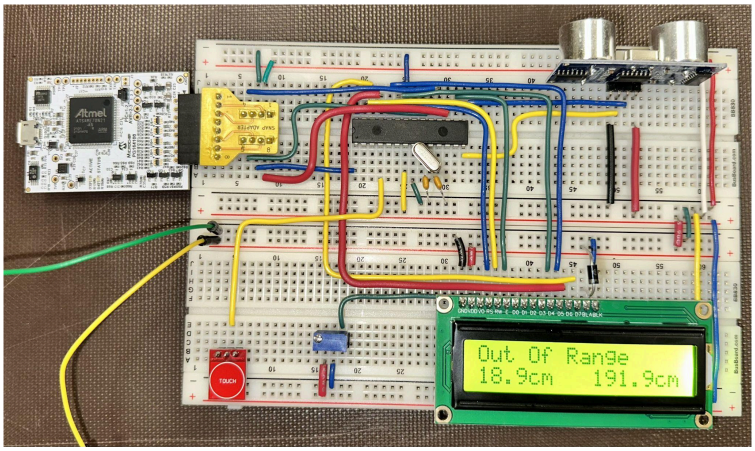


Figure 1.3: The system showing “Out of range” when it exceeds its range of measurement.

Conclusion

This lab successfully demonstrated the design and implementation of a digital tape measure system utilizing the ATmega328p microcontroller, an ultrasonic sensor, and an LCD display. The system operates by emitting ultrasonic sound pulses to measure distances based on the time it takes for the sound to reflect back from an object. The distance is displayed in real-time on the LCD, with the device continuously updating measurements every second. Additionally, the system tracks the minimum and maximum distances measured since startup, providing a useful history to the user. The ultrasonic sensor's echo pulse timing, captured through Timer1 of the microcontroller, allows for accurate distance calculation. The inclusion of an external crystal oscillator further improves the accuracy of the timing, ensuring precise measurements. The device also features an "Out of Range" message for distances outside the 2 cm to 200 cm range, and "NaN" is displayed for the minimum and maximum fields at power-up, indicating no previous measurements.

During the design and implementation process, several challenges were encountered. One of the primary difficulties was ensuring accurate timing using the Timer1 module. The ultrasonic sensor's echo signal required careful handling to detect rising and falling edges precisely, as even slight timing errors could result in incorrect measurements. Additionally, the interaction between the ultrasonic sensor and the ATmega328p microcontroller required careful consideration of input-output timing and the fragile nature of the timer. There were also challenges related to the fuse bits of the ATmega328P, which had to be flashed multiple times in order to program it to run. Moreover, ensuring the reset button worked to clear the history when needed was another hurdle, due to issues relating to touch detection on the touch sensor. Also, unexpected behaviors such as false readings from the ultrasonic sensor due to environmental factors were difficult to fix.

The accuracy of the system could be enhanced further by implementing advanced calibration algorithms that adjust for potential measurement errors caused by the sensor's alignment or environmental factors, given the sensitivity of the sensor. The wire on the breadboard from the echo pin to the microcontroller can be shortened such that the sensor's rising and falling edges can be detected quicker and more accurately. Furthermore, a separate interrupt dedicated to the trigger line for the rising edge, so as to note the timer1 value when the sonic pulse is sent out, rather than purely relying on the echo pin may aid in the accuracy of the system. These implementations may improve the accuracy and effectiveness of the system significantly.

<u>Reference</u>

[1] *ECE 312 – Lab 2: Digital Tape Measure*, Canvas, University of Alberta. [Online]. Available: https://canvas.ualberta.ca/courses/29018/files/6045571?module_item_id=3286294. [ACCESSED: 06/11/2025].

[2] "Lab 2: Digital Tape Measure," *Canvas, University of Alberta*. [Online]. Available: https://canvas.ualberta.ca/courses/29018/pages/lab2-digital-tape-measure?module_item_id=3256285. [ACCESSED: 06/11/2025].