Digital Caliper Tweezers

Design Special Topic (ENG5026) Report

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Chapter 1

Introduction

1.1 Project Overview

The Design Special Topic 5 (DST5) course offers final year students an opportunity to demonstrate the skills they have developed across their time at university through com of a short design project. Our team chose to undertake the proposed *”Caliper Tweezers”* project, outlining a handheld, small-scale measurement device capable of picking up and manipulating small objects whilst facilitating measurement capabilities. This task would involve devising a method of generating accurate and reliable measurements, whilst de a usable device, easily handled, with display capabilities. The proposed project presented an intersection between mechanical and electrical design, where both aspects of desig clear implications on the quality of the final product. With this in mind, a rigorous design phase was undertaken.

1.2 Design Specification

A detailed design specification which would act as a set of milestones and end-goals for the design project was key to the tweezers design. In an early group meeting, the design team agreed upon a set of mechanical and electrical goals which would constitute a design specification. This design specification is detailed below.

1.2.1 Mechanical Design Specification

1. *Maximum measurement length* $\geq 15mm$.
2. *Operable with one hand.*
3. *Tweezer jaws open by default.*
4. *Constructed from rigid body to minimise flex.*

1.2.2 Electrical Design Specification

1. *Must possess an electrical or optical method of distance measurement.*
2. *Must accurately display measurement to user.*
3. *Must be battery powered and last 1 month of 30 mins use per day (15 hours total)*
4. *Must have measurement resolution* $\leq 0.1mm$*, and measurement accuracy* $\leq 0.2m$

Chapter 2

Metrology

After the careful consideration of numerous options, capacitive encoding was selected as the method of distance measurement. Capacitive encoding employs a variance in capacitance between multiple metal plates to determine relative displacement, whether angular or translational. A cross section of a simple 3-phase capacitive encoder is shown in figur 2.1. Figure 2.1 shows the three input signals V_1, V_2 and V_3, each connected to successive electrodes. Individual electrodes form a variable capacitor with the output electrode labe V_{OUT}. The relative capacitance of each variable capacitor displays a linear relationship w the displacement between the input and output electrodes. It is this variance in capacitance which allows the displacement to be measured. The details of this will be explained further in section 2.1.

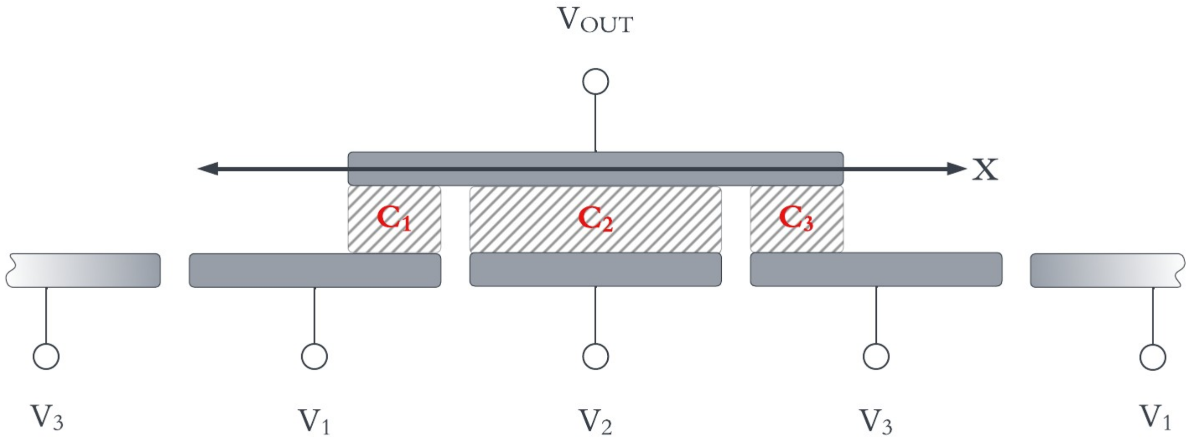


Figure 2.1: Capacitive encoder cross section recreated from [1]

Chapter 3

User Experience

When designing a set of tweezers an emphasis had to be placed on the users experienc This included factors such as: the weight and feel of the device, the resistance when squeezing the tips, the placement of the display and the placement and the usability of buttons. This chapter will cover these areas and explain the decisions that were made to improve th user experience.

3.1 Weight and Feel

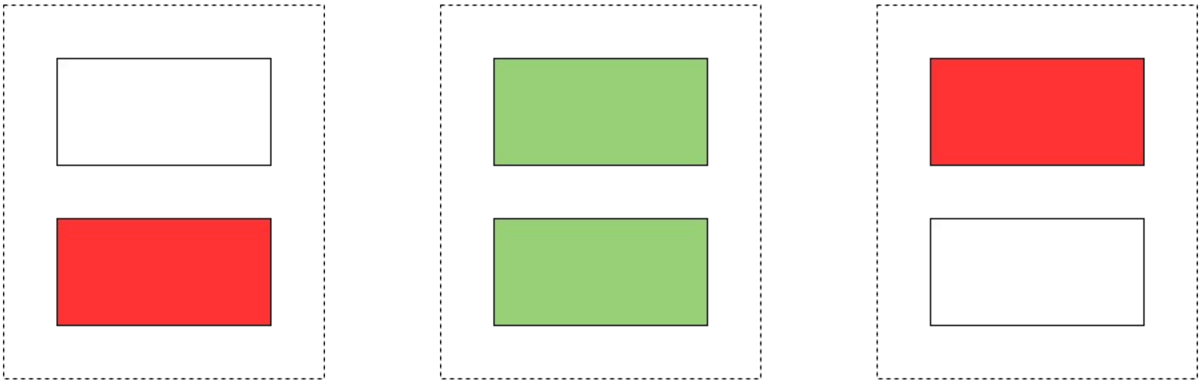
A major priority of the design was to keep the weight to a minimum. This is a factor which was not easy to control and had to be achieved through intelligent design at every stage, including choice of materials and electronic bill of materials (BOM). After researching a deciding upon capacitive encoding for the distance measurement mechanism and reali that this type of sensor could be integrated into a printed circuit board (PCB), a decision was made to make the PCB the main mechanical structure of the device. The device would be constructed from two PCBs which pivot relative to each other. This decision massively decreased the complexity of manufacturing a custom design by making use of the prec 2D cutting facilities that modern PCB manufacturers can provide. One area which took advantage of this was the ribbed grips which would be cut into the legs of the device to improve the grip in the users hand. This is a feature which would have been difficult to achieve using other manufacturing methods. The FR-4 material that PCBs are constructed from is also light weight, stiff, and could be comfortably held in the users hand for long periods of time.

3.2 Mechanical Resistance

One important feature of tweezers is the mechanical resistance they provide. By gently resisting when squeezed, they provide the user with the ability to have more control over the fine movements which are necessary when manipulating small objects. A simple way to achieve this was to add a tension point to the butt of each PCB. The tension could then adjusted by selecting a different size of O-ring or rubber band to be fitted to this point.

3.3 Display Placement

A requirement which was set at the start of the project was that the device must featur display to convey the measurement to the user. To avoid the user having to look away from the object they were manipulating in order to read the measurement, the display would be placed as close as possible to the object being manipulated. This proved difficult as the display in question was too wide to be mounted on the tangs of the device. A compromise was decided upon which would place 2 red/green bi-color LEDs close to the tips of the tweezers. These LEDs would show if the current distance measurement was less than, m than, or within $\pm 0.2\,mm$ of the zero position. This is shown in figure 3.1.



(a) Current distance < -0.2 (b) $-0.2 \le$ Current distance ≤ 0.2 (c) $0.2 <$ Current distance

Figure 3.1: LED lighting configurations (measurements are in mm).

3.4 Zeroing Button

Thanks to the main structure of the device being constructed from the PCB, the zeroing button can be placed at the users finger tips without the need to run wires to the butto A side-actuated button was selected to allow the zeroing button to be pressed during nor device operation. After picking up an object, the user could zero on this measurement by simply pressing slightly firmer and actuating the button.

3.5 Ergonomic Prototype

After considering all of the issues discussed above and having made a decision on the c of the tweezers, an ergonomic prototype was designed in CAD and 3D printed. The final assembly including electrode layout can be seen in appendix G. This allowed the design decisions to be evaluated before committing to a final PCB design. This prototype is shown in figure 3.2.

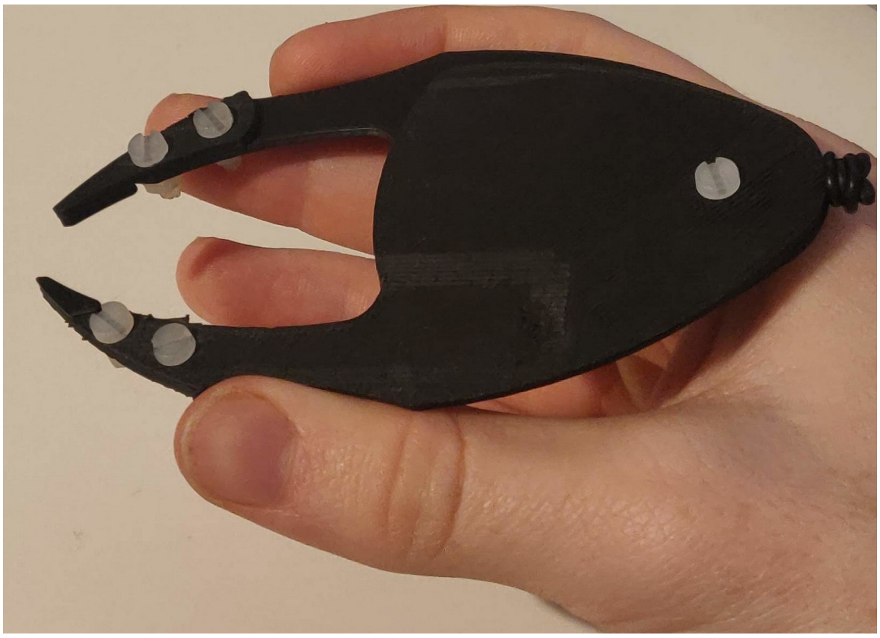


Figure 3.2 3D printed ergonomic prototype of tweezers.

After evaluating the prototype minor changes were adopted to improve the ergonom Development then proceeded on to schematic design, PCB layout and firmware develop

Chapter 7

Conclusion

7.1 Recapitulation

Ultimately, the team was able to deliver a device which met the desired design specific Through detailed study of the operation of capacitive encoders including their non-ideal characteristics, a measurement method which was both accurate, precise and easily integrated into the device was selected. This allowed a totally custom capacitive encoder to be designed into the devices main PCB. To simplify the manufacturing process this PCB als became the main mechanical structure of the device and the user interface elements were built into it including edge buttons for zeroing and resetting the device as well as ribbed grips along the tangs of the tweezers. This allowed the device to be fully operated with one hand. Through intelligent hardware choices, the device BOM was kept to a minimum saving on board space and power consumption. This helped to keep the device small and the battery life long. The MCU which controlled the system was utilised to its full potential using timers and DMA transfers to automate the PWM generation and data acquisition processes. This allowed the main program of the MCU to run a simple measurement loop which performed DFT and trigonometric operations to calculate the phase of the signal a lookup table to determine the distance between the tweezer tips.

During testing a significant repeatable error was observed. Part of this error was predicted by the investigation into capacitive encoders detailed in section 2 and was due t the linear variation of capacitance with distance instead of sinusoidal. However a larger low frequency sinusoidal error remained unexplained. Due to the error being repeatable an array of compensation values was added to the lookup table. This effectively removed the repeatable error and made the measurements significantly more accurate.

7.2 Meeting the Specification

The final design successfully met the design specification.

7.2.1 Mechanical Design Specification

1. **Maximum measurement length $\geq 15mm$.** The maximum measurement length was $25.24mm$.
2. ***Operable with one hand.*** By keeping the BOM minimal and using an edge actua zeroing button at the users fingers, the device is fully operable with one hand.
3. ***Tweezer jaws open by default.*** By designing in a tensioning point at the base of the tweezers and by using a tensioning O-ring, the tweezers remain comfortably o by default.
4. ***Constructed from rigid body to minimise flex.*** By using the the fibreglass PC as the main body of the device a rigid body was achieved, minimising flex.

7.2.2 Electrical Design Specification

1. ***Must possess an electrical or optical method of distance measurement.*** A capacitive encoder integrated into the PCBs was used to measure distance.
2. ***Must accurately display measurement to user.*** A 4 digit segmented LCD display was used to display the measurement to the user.
3. ***Must be battery powered and last 1 month of 30 mins use per day (15 hours total).*** The battery life at an MCU clock frequency of $8MHz$ was approximated to be 60.5 hours.
4. ***Must have measurement resolution $\leq 0.1mm$, and measurement accurac $\leq 0.2mm$.*** The measurement accuracy was $\leq 0.2mm$ and was compliant with a confidence interval of 95% up to a distance measurement of $\sim 8mm$, but was still compliant with a confidence interval of 68% for the remainder of the measurement range.

Appendix G

Tweezer CAD assembly