DESIGN OF A TRACKING GLOVE FOR USE IN VIRTUAL REALITY TRAINING ENVIRONMENTS

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by

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Accepted by the faculty of the College of Business and Technology, Morehead State University, in partial fulfillment of the requirements for the Master of Science.

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Current technology has given us many advancements in virtual reality technology. This acceleration is due to a growing demand for consumer VR products for home entertainment use. This ever-increasing market, increased compatibility, support, and affordability has made it feasible to bring these products into industry. This thesis intends to review the current device offerings on the consumer market for VR control devices that integrate finger tracking as well as tactile feedback to the user. Currently, these offerings are limited and not affordable. A new solution is to be designed and evaluated. This unique design will improve accessibility and introduce additional use cases in industry, such as simulated training environments. Other factors considered include size and weight limitations, simplicity of design and use, and unit cost.

Accepted by: _____________________________, Chair
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CHAPTER ONE: INTRODUCTION

Background

Virtual Reality technology has advanced from requiring an expensive computer system capable of processing and rendering the 3-D environment to stand-alone systems. The demand from the consumer market produced small and affordable systems used for media consumption and entertainment. Current Virtual reality systems sold to consumers consist of a headset that sits over and fully covers the eyes. The headset contains a battery, the computer systems, and a set of Fresnel lenses to give the appearance of distance even though the display sits just inches from the eye. To interact with the virtual environment, handheld controllers are most commonly used. These controllers have standard inputs such as joysticks, triggers, and buttons laid out to be intuitively used.

These advancements open the door for affordable and effective Industrial Training. Systems have already been developed and implemented to do precisely that. These systems provide cost savings, improved safety, and expose employees to scenarios that would be difficult or dangerous to simulate in the traditional real-world training environment.

Morehead State Universities National Science Foundation team has developed one such training program simulating forklift operation using available consumer products, including a virtual steering wheel and modified joysticks for actuation and interaction. Additionally, virtual environments have been set up to interact with devices such as PLCs in the real world as well as simulate job skills such as welding.

Purpose

As the use of these systems increases, it is desirable to have a more natural interaction between the physical and virtual worlds. Advancements in control and input devices are nothing new in the VR world. There are many systems, each unique in their own way, used as input interfacing. This research aims to model and build a system that tracks the hand and finger movements and provides tactile feedback to the user.

This study will evaluate the design, hardware requirements, software requirements, and features needed for a functional hardware unit. The proposed system will read finger position of the hand and feed the data into a virtual environment, eliminating the use of a handheld controller and adding an extra level of immersion and realism to the experience. Using handheld controls for environments such as driving or flying is adequate; these system inputs are meant to imitate what will be present in the real world. For example, the proposed hand tracking system could be used for line and process training in a manufacturing facility.

Research Objectives

Objective 1:

Design a system to track the finger position for use in a VR environment.

Objective 2:

The design will use readily available consumer components

Objective 3:

The device will have a mechanism to provide haptic feedback to the user

Assumptions

The following assumptions are considered as pre-conditions for this research.

The device will be used in a single VR environment provided in Unity for testing. This is assumed because other environments or games will have a unique protocol for controller input. It is possible to customize for each instance, but this is not the prime objective of this research.

It is also assumed that this device is being designed as a unique system that would go through multiple design cycles or revisions if the product was to be brought to market. This project will focus on the initial design phases to get a functional system with inferences to future uses, function, or design.

Limitations

The design and validation testing will be performed using an Oculus Quest system. This system is affordable and is available for testing and use. There is a diverse pool of designs and configurations that could be used. Limiting the use to the Quest systems allows for consistency.

Significance

The proposed system would provide greater immersion in virtual environments. As new employees are hired, this technology can be used to train them virtually, eliminating the need for a separate simulated training line to be set up. A virtual scenario can present variations of faults or common errors that may occur. A virtual simulation can be created for specific processes' in a facility, all delivered through one virtual headset. Studies show that with greater immersion, information retention is significantly increased.

For example, new employees can be trained simultaneously, whether physically present or remote, while being led by an instructor in a controlled environment without the risk of injury.

Brief History of Virtual Reality

The earliest record of an immersive system is from 1838 (Barnard, 2019). Charles Wheatstone developed "binocular vision" that allowed the combination of two images taken at different points, giving the image a sense of simple depth and immersion.

In 1961 Philco created a motion-tracking HMD, but it was not used for virtual reality interaction. The system was developed for the military to analyze the risk in different situations. This led to the further development of military flight simulators. In 1969 the first system that would respond to users was developed.

From the early 60s through to 1990, most of the advancements in VR technology came from military research. VR was the perfect medium for flight simulation. In the 80s, NASA had developed its own VR system with a ceiling-mounted headset and interactive glove controllers. These systems helped train countless astronauts and pilots.

Various projects were released by big-name entertainment brands such as Nintendo. However, these releases were commercial failures due to multiple issues and a lack of features such as color displays, lacking user control, and limited processing power.

VR, as we have come to know it, started to become popular in 2014. Facebook purchased Oculus; Google launched their cardboard environment, Samsung announced the Gear VR system, Etc. These systems allow the user to wear a headset and be transported into an endless number of realistic scenarios with intuitive controls and audio-visual feedback. Current VR systems offer a fully immersive experience, allowing the user to disconnect from the physical environment they may be in entirely and interact with the virtual environment. A massive improvement from binocular vision.

Definition of terms

Arduino Micro-controller– A controller board based on the 8-bit AVR microcontroller that's able to achieve the most single clock cycle execution of 131 effective instructions thanks to its advanced RISC architecture (Shaun, 2020).

Augmented Reality (AR) – A technology that superimposes a computer-generated image on the user's view of the natural world, thus providing a composite view (Oxford, 2022). Examples include products like the Google glass, these glasses display real-time information while still giving the user an unobstructed view of the environment around them.

Computer-Aided Design – CAD (computer-aided design) is the use of computer-based software to aid in design processes. CAD software is frequently used by different types of engineers and designers. CAD software can be used to create two-dimensional (2-D) drawings or three-dimensional (3-D) models and assemblies (Chai, 2020).

CPU – "Central Processing Unit." The CPU is the primary component of a computer that processes instructions. It runs the operating system and applications, constantly receiving input from the user or active software programs. It processes the data and produces output, which may be stored by an application or displayed on the screen. The CPU contains at least one processor, which is the actual chip inside the CPU that performs calculations (Techterms, 2022)

FOV: (Field of view) – The field of view FOV of an optical system is often expressed as the maximum angular size of the object as seen from the entrance pupil. The maximum image height is also used. For finite conjugate systems, the maximum object height is useful (Greivenkamp, 2004).

Finger tracking – As referred to in this document, the tracking of the position or bending of the fingers as related to the hand as a whole.

Fresnel lenses – Fresnel lenses consist of concentric grooves etched into plastic or glass. Their thin, lightweight construction, availability in small as well as large sizes, and excellent light-gathering ability make them useful in a variety of applications. Fresnel lenses are most often used in light gathering applications, such as condenser systems or emitter/detector setups. They can also be used as magnifiers or projection lenses in illumination systems and images (Edmund, 2022)

GPU – The primary purpose of a GPU is to render 3D graphics, which are comprised of polygons. Since most polygonal transformations involve decimal numbers, GPUs are designed to perform floating-point operations (as opposed to integer calculations). This specialized design enables GPUs to render graphics more efficiently than even the fastest CPUs (Techterms, 2022)

Hand tracking – In this document, hand tracking is referred to as the position in 3D space of the hand as a single object in relation to the user's view. Also referring to the orientation in space.

HMD: (Head Mounted Display) – small displays or projection technology integrated into eyeglasses or mounted on a helmet or hat. Heads-up displays are a type of HMD that does not block the user's vision but superimposes the image on the user's view of the real world. An emerging form of heads-up display is a retinal display that "paints" a picture directly on the sensitive part of the user's retina. Although the image appears to be on a screen at the user's ideal viewing distance, there is no actual screen in front of the user, just special optics (for example, modified eyeglasses) that reflect the image back into the eye. Other heads-up displays that are not worn by the user but are projected on a surface (for example, on a car or plane windshield) are not covered in this discussion. Some HMDs incorporate motion sensors to determine direction and movement (for example, to provide context-sensitive geographic information) or as the interface to an immersive virtual reality application (Gartner, 2022)

Immersion – in the context of virtual reality, Immersive virtual reality (immersive VR) is the presentation of an artificial environment that replaces users' real-world surroundings convincingly enough that they are able to suspend disbelief and fully engage with the created environment. Immersiveness is a critical element of virtual reality applications, such as virtual reality gaming and therapy (Wigmore, 2016)

Industrial training – Industrial Training refers to the practical training in a company or an industrial environment that helps the students in developing the required skills which will help them in becoming a professional of the future (Indigolearn, 2021).

Tactile feedback – Also referred to as haptic feedback, is the feedback that is physically felt in response to an action. Examples include the vibration after pressing a button on a cellphone or the clicking of a knob as it turns.

Virtual Reality (VR) – The illusion of participation in a synthetic environment rather than external observation of such an environment. VR relies on three-dimensional (3D), stereoscopic, head-tracked displays, hand/body tracking, and binaural sound. VR is an immersive, multisensory experience (Gigante, 1993).

Chapter Two: Review of literature

The majority of the research collected was very recently published; this technology is still emerging. The research deals with current VR and AR uses as well as different uses for tactile feedback, methods for hand tracking, review of the software, and review of hardware.

Empirical Studies

Arkenbout (2015) studied the accuracy of a hand tracking vision system combined with an expensive data collection glove. The addition of the glove in the system added 79% in the precision of joint tracking and an extra 31% in overall accuracy (actual joint angle vs. measured). This study shows that the addition of a data glove is beneficial to the overall function of a hand tracking system for use in VR.

Buckingham (2021) presents current hand tracking technology, its significance, and the obstacles we must overcome. He explains how the use of hand tracking without the use of a controller can fully immerse a user. Some benefits sighted include object interaction; the experience is heightened if the user is able to grab an object and interact with it in VR instead of pressing a button on a controller to interact. Some challenges sighted are Tracking location, inclusivity and adoption, and the Uncanny phenomenon. This is the phenomenon referring to the lack of affinity or feeling of unease when looking at or interacting with an object. The experience while using this technology must be satisfying, or it will fail.

Fahmi (2020) studies the use of a sensor glove in large crane simulations. This glove tracks movement and also provides vibration. He found that employees could remember how to use the gloves, but the learning curve was relatively high, and users had difficulty learning to use the sensing gloves. In a second paper by Fahmi, traditional controllers were tested against the sensor gloves, and the controllers were rated higher in every tested category except for haptic feedback. This shows that the technology is usable but not preferred as of yet.

Kim (2020) created a glove that coveys thermal feeling in VR. Traditional systems used to give the sense of temperature change were bulky and had slow response times. This system uses small flexible thermoelectric devices (TEDs) to deliver sensation quickly and efficiently to the users. This technology would allow virtual training to include hazards such as hot items after welding or extreme cold hazards. In a VR scenario, the object can be programmed to give off a thermal reading and give feedback to the user they previously could only get while performing the job and putting themselves at potential risk.

Li (2021) studied the feasibility of a finger tracking glove using fiberoptic sensing. A light source and sensing unit are used to measure the movement of the finger. Two fiberoptic strands are used, one for sensing and the other for reference. The sensing strand is damaged to allow light leakage from the system when it is bent. Relating the sensing strand and the reference, Li was able to detect the change in the angle of the finger at a sensitivity of pi/12.

Markopoilos (2020) conducted a study on a maritime safety VR training scenario. The VR training was used with hand-tracking technology, and the results examined relate to fields from neuroscience back to design. Markopoilos showed that hand tracking was much more natural than using a traditional controller. Users who had no experience with VR or traditional controllers had a hard time using them. With hand tracking, user satisfaction increased, and the users retained and learned more from the training. The shipping industry is another primary industry where VR training can present a variety of scenes without putting the trainee at risk.

Minh (2019) takes a different approach to finger tracking. This paper describes the design and testing of a hepatic finger-sensing glove—the system using its own internal measurement units (IMUs) to track finger position. The system also has a vibration motor on each joint to provide haptic feedback. The paper explains the gyroscopic calculations used to report the movement of the hand and arm.

Nikita (2019) wrote with Minh in a separately published paper on the system makeup, components used, and layout. It goes into detail on the filtering of the raw input data and the calculations that relate to joint movement. The paper shows that the filtering algorithm was adequate and that the results are more accurate than external gyroscopic measurements.

Park (2020) examined the relationship between the dominant and nondominated hands. This was done in VR; the research explores the different control characteristics of the hands. A virtual target was displayed, and the participants used their hands to follow the target at multiple speeds, diameters, and orientations to test visuomotor cues. This research can be used when designing scenarios to ensure objects can be interacted with. It can also be used to evaluate clinical criteria in the medical field for use in therapy or rehab.

Russ (2021) and the MSU NSF team created a virtual reality training simulation for industrial forklift training. This system shows it is possible to create a virtual environment sufficient for training with readily available consumer products.

Sacks (2013) tests the hypothesis that VR safety training would be feasible and more effective than traditional classroom methods. Test participants were split into groups, half trained in the classroom and half trained using virtual scenarios. The results were compared using the before and after test scores and the categories of identification, prevention, and risk assessment levels. Those who went through the virtual training had an increased score in identification and prevention both directly after training and after being tested again one month later.

Song (2019) introduces a pneumatic system that would simulate touch in a virtual setting. In the virtual world, when an object is interacted with, the pneumatic system would activate to halt finger movement and simulate the object in the hand. This system also benefits from operation with no external air system. The developed system performed well and showed that it is possible to simulate feeling in the VR world.

Zhu (2020) looks into building a haptic feedback and hand tracking glove but uses a different method to achieve the result. Zhu has 3D printed rings that fit around each knuckle with a string sensor fitted through them to track finger position. Flexible sensors were also used in the palm for sensing. This system was tested and had an accuracy above 90% at identifying the shape of an object that is interacted with.

Existing products

There are products on the consumer market that offer basic functional finger tracking in VR; these products are in the \$300-\$500 range per hand. The addition of physical interactive tactile feedback can increase the cost up to \$9000. The current production system has a complicated exoskeleton design. The system is also delicate, and the cost is a significant barrier to entry. Until the production costs can be reduced, advancements will be slow going.

Software Review

Arduino IDE:

The Arduino Integrated Development Environment or (IDE) contains a text editor for writing code, a message area, a text console, a toolbar with buttons for standard functions, and a series of menus. It connects to the Arduino hardware to upload programs and communicate with them.

Programs written using Arduino Software (IDE) are called sketches. These sketches are written in the text editor and are saved with the file extension .ino. The editor has features for cutting/pasting and for searching/replacing text. The message area gives feedback while saving and exporting and also displays errors. The console displays text output by the Arduino Software (IDE), including complete error messages and other information. The bottom righthand corner of the window displays the configured board and serial port. The toolbar buttons allow the user to verify and upload programs, create, open, save sketches, and open the serial monitor (Arduino Team, 2022).

Unity:

Unity is the game engine or environment used to create and code a VR simulation. Unity has tools and assets that can be added and manipulated as needed. Unity is one of the most widely used game engines for mobile and tablet gaming. It has cross-platform support, so it can be played on many different platforms once an environment or game has been made. Unity also has integrated Visual Studio support for writing additional C# code for control and integration.

Steam:

Steam is an online platform for buying and playing video games. Steam also has a VR environment used with the company's own VR headset. The software has a community for game support and development.

Solidworks:

Solidworks is a 3D computer-aided design (CAD) program capable of creating 3D models. These models can be imported into VR or exported and sliced for additive manufacturing processes such as 3D printing.

Hardware Review

Arduino nano:

An Arduino nano clone was used because of its small form factor and the inclusion of Bluetooth communication. The Arduino is a consumer-grade option that is highly community-supported.

Figure 1. Arduino Nano

Flex resistors:

This type of resistor strip will change its resistive value as it is bent. The value can range from 10K -to 40k ohms.

Figure 2. Flexible Resistor

Potentiometer:

The specific potentiometers used were sourced specifically for the extended shaft. The potentiometer used will return a range from 0-10k ohms.

Figure 3. 10K potentiometer

Servo motor:

The 9g servos are strong enough for the locking mechanism, but if any malfunctions occur, it is not strong enough to cause any injury to the hand.

Figure 4. Servo Motor

Key retractor:

The key retractor was used because it was compact and inexpensive. The internal components were integrated into the design. The simple model shown below was selected because they are easily disassembled, unlike a more expensive model.

Figure 5. Badge reel

Supplemental materials:

Other materials used include a standard mechanic's work glove, multicolor ribbon cable, soldering iron, 3D printer, glue, and sewing materials.

From the research presented above, there are many options for designing this system. There are also many additional systems that can be integrated. A final commercial product could be made modular to allow the customer to add additional features related to the specific situation they are training for. This project has the potential not only for industrial use; virtual reality can be applied to medical rehabilitation and education and is also very well suited for consumer entertainment use. The integration of hand tracking into

Chapter Three: Method of design

Problem statement

The primary requirement of this research is to create a functional prototype that will report hand and finger movement into a VR environment. The following have been identified as the significant steps to accomplish this task.

- Design a mechanism to track and report finger position using materials that are accessible, affordable, and will fit to the form factor of the hand or arm.
- Design a mechanism to provide tactile feedback to the user to provide better immersion into the simulated environment.
- Communicate with the VR environment to report hand and finger position, as well as receive data for tactile feedback.
- The system is to be able to be integrated into a virtual environment that will use this system as an input device and display it in real-time using a Virtual reality headset.

Initial design

The Initial system design consists of flexible resistors, 5 10K resistors, ribbon wire, and a standard work glove. The flexible resistors were sewn into the fingers of the glove and wired in series to a 10K resistor with a sensing line running out of each connection.

Parts list		
Item		Price
Flexible resistors		$ 15.00
10K resistor		$ 0.06
Ribbon Cable		$1.00 / Ft
Arduino with bluetooth		$ 25.00
Heatshrik tubing		$ 0.05
Outer Glove		$ 15.00
Inner Glove		$ 5.00
Sewing materials		$ 10.00

Table 1. Prototype Parts List

The basic idea for the prototype consisted of the flexible resistors being secured to an inner glove with an outer glove protecting the internal components. Flexible resistive

Sensors were used to provide a low-profile design that would be as close to wearing a standard glove as possible when worn. The Arduino was chosen because of its low power requirements. The unit selected has built-in Bluetooth connectivity for wireless communication with the virtual environment. The prototype costs under $80, which is significantly less than any other competitor.

The sensing circuit consists of a simple voltage divider with a common supply and ground. The circuit is pictured below.

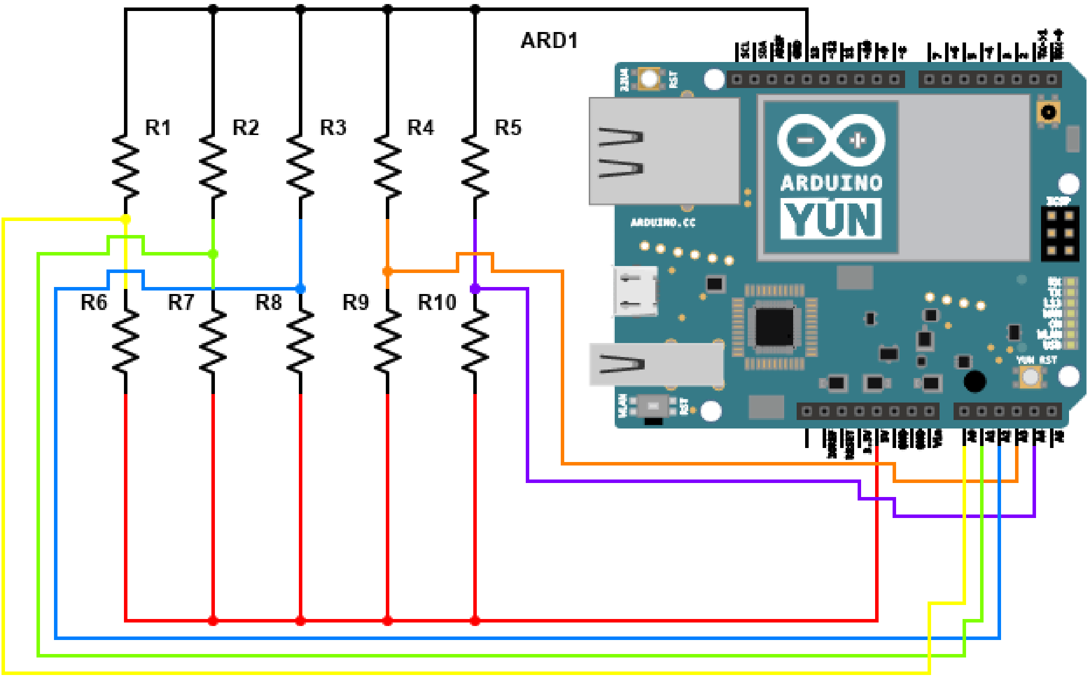

Figure 6. Basic Circuit Layout [1]

R 1-5 in the image above represent the flexible resistors. As seen above, the flex sensors are wired in parallel with a signal wire running to an individual analog pin on the Arduino board. The flexible resistive sensors are rated at 10KΩ flat ±30% and, when flexed, range from 60 KΩ – 110 KΩ. While testing the sensors in the glove prototype, it was determined that the flat resistance ranged from 15 KΩ - 18 KΩ with a maximum bent resistance from 38 KΩ- 45 KΩ. Below is a basic breakdown of the sensing circuit; an online resource (everycircuit.com) was used to simulate resistive reading to verify final readings.

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[1] Electrical schematic made on www.digikey.com/schemeit/project/

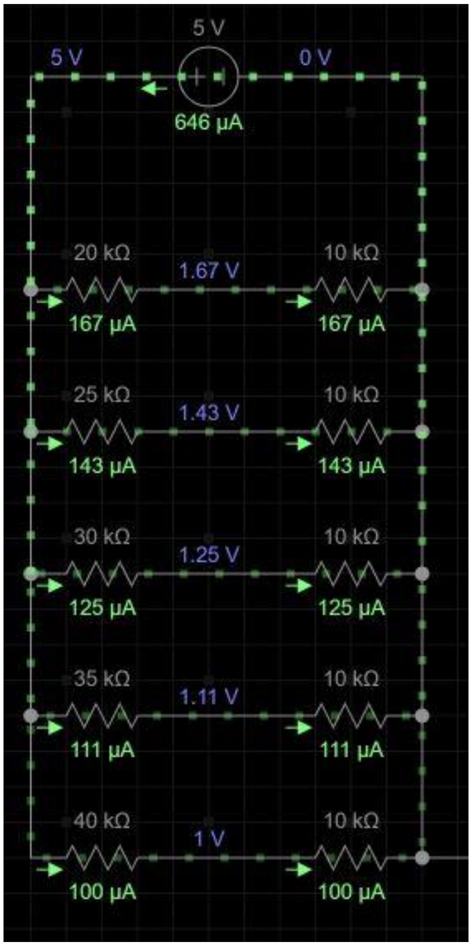


Figure 7. Voltage Divider Example[2]

The prototype was assembled and tested. During initial testing, readings were erroneous and not consistent with the expected values. Testing consisted of trials lasting approximately 1 minute each. During this time, the glove was closed into a fist, and each finger was bent. During each of these tests, the readings were logged. After testing, the readings did not correlate with the movement. This led to total disassembly and examination. The voltage divider was separated and desoldered, the flex sensors were desoldered, and the ribbon cable was checked for continuity. It was discovered that the cable in one section had no connection, as well as the voltage divider on

[2] *Diagram made on Everycircuit.com*

A separate section. All leads were cleaned, fluxed, and resoldered. Heat shrink tubing was placed around the pins of the flex sensors to ensure no shorts could develop; this also acts as a strain relief.

During the reassembly process, measurements were taken after every step to ensure there were no errors similar to the previous disconnections. The wiring harness is displayed below, showing the leads from the glove coming to a resistor as well as the individual signal wires placed in heat shrink tubing. The common power line seen on the left in red was connected to all 5 of the inputs of the finger sensors. The output leads were connected directly to a standard resistor in addition to the signal wire leading to the Arduino. All of the resistors were then connected together and grounded to the test board.

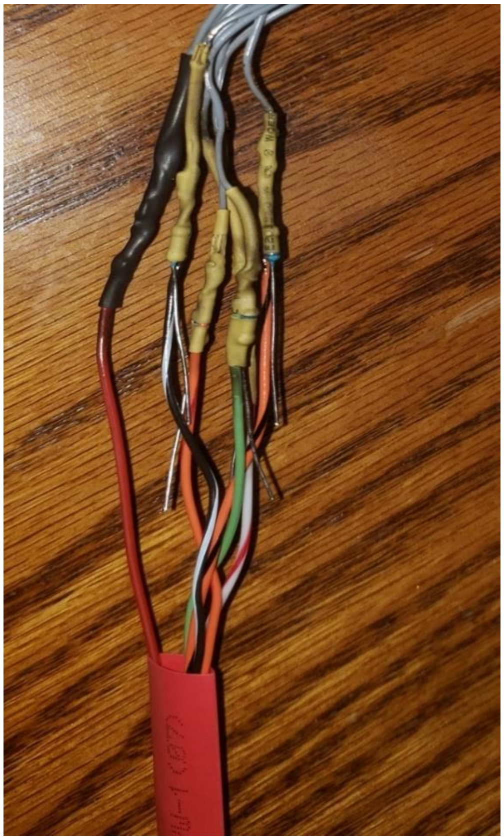


Figure 8. Wiring Harness

After the prototype was reassembled and connections verified, the Arduino code was refined. The following is a synopsis of the code. The code defines the fingers as variable int Thumb= A0; int Pointer= A1; int Middle= A2; int Ring= A3; int Pinky= A4; as well as assigning them to the connected analog input. A sensor wire is run from the 5V pin back into the Arduino to monitor the output voltage used to calculate the resistance of the flex sensor.

Reversing the voltage divider formula give us R1 (flex sensor) = R2 (10K) ((Vin / Vout) – 1). We also must understand that the voltage value returned by the Arduino is scaled from 0-1023 (0-5V). With this information, we can calculate the resistance and, therefore, the position or bend of the fingers. Vin = output from the Arduino board Vout is the output from the voltage divider R2 = 10K. During testing, the output values of the variables were also displayed for troubleshooting and accuracy purposes. After calculations are performed, the values are then relayed out to the virtual environment.

The Arduino returns the resistance or "flex" of the resistors. In the redesign, the driver has an included calibration function; this allows the system to know the starting values with the hand flat and then fully bent. This allows for scale values to be fed to the virtual environment. Currently, the resistance has a wide variation making the data fed into VR erratic, and this does not return a satisfactory result.

The images on the following page show the internals with the channels that hold the resistors in place, as well as an exposed resistor to show the product. There are images of the device on and off the hand showing the wired system. The Arduino is shown in a testing jig; once a fully working system is tested, the leads would be directly soldered to the pins, and a small case would be 3D printed. This will significantly reduce the size. The length of wires will also be reduced; the initial design included more than double the length needed if splicing, resoldering, or general maintenance was required.

After reassembly, testing was once again carried out. Results were much improved, but the flex resistors did not return a reading consistent enough for use. The resistance reading changing positions and returning produced reading differing by as much as 4KΩ. These results are not consistent enough to be used.

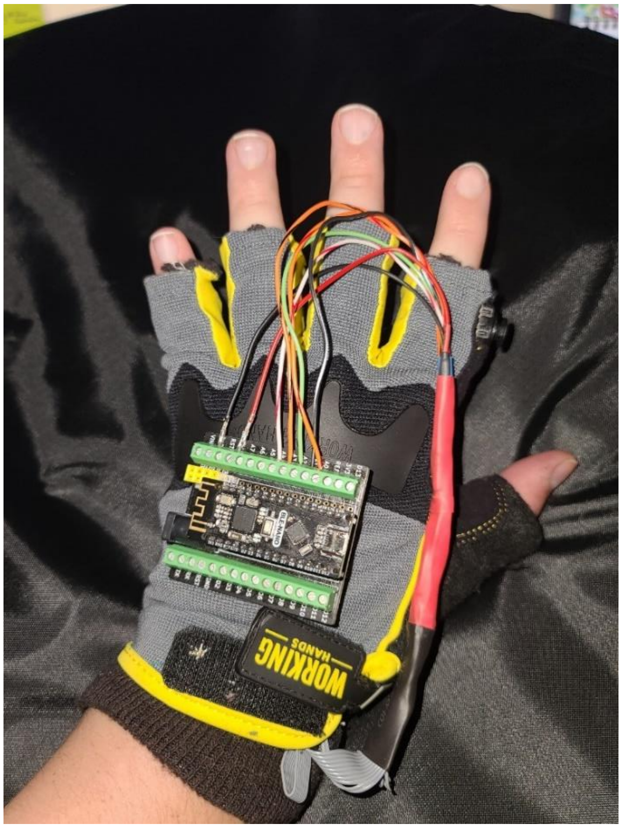


Figure 9. Internals of Glove

Figure 10. Glove system on hand

Alternate tracking solutions

If advanced further, an alternate tracking system would be desirable. The current method of attaching the handheld controller is sufficient, but an external tracker would provide an extra level of convenience.

Wang (2021) developed a model to track finger position using a single RGB camera in real-time. An AI system was trained using an extensive data set of images. This data set had key points marked on each hand to indicate the true finger position. Once the AI was trained, the system was able to provide an accurate hand model in 3D space. Wang's system showed exponential improvement over previous models, operation with minimal error.

Figure 11. Traditional tracking Wang (2021)

Figure 12. Model by Wang (2021)

Facebook, the owners of Oculus, announced support for hand tracking using the dual IR cameras already positioned on the headset. Recently this method of tracking has been integrated into the Unity engine. This method uses the cameras to triangulate the hand location. Unfortunately, it is still in the early stages of support and offers limited uses. This technology can estimate the orientation and position of the hand along with finger position if in view. It will display a generic model that can be used to interact with buttons and selections in a menu or similar setting.

Microsoft implemented A full IR camera in its Connect system. This camera emits IR points and is able to accurately track movement for use in the Xbox game console. The community has developed this technology to act as a 3D scanner for use in CAD modeling. An object can be placed in front of the system and slowly turned, allowing it to collect millions of points that are logged into software that can then be interpreted and compiled. These measurements have been shown to be highly accurate.

Kalnoskas (2019) describes the HTC vives tracking system using ultra-low-power ultrasonic transceivers to track the user. "The position tracking system utilizes sonar by transmitting ultrasonic pulses between CH-101 sensors inside the VR system's head-mounted display (HMD) and the handheld controllers, providing 3D position information of the controllers relative to the HMD."

A system such as that proposed by Li (2021) would provide extreme accuracy, but the system components are not compact and not easily integrated. The fiberoptic system required a belt pack to house the equipment and a computer connection for data processing. It is desired that the tracking method be able to fit on the hand. Additionally, the data must be able to be processed by a small microprocessor such as an Arduino-type system.

It was decided for this project to use the handheld controller mounted somewhere near the hand. This solution offers functionality and allows development without the need for any additional equipment.

The most significant issue that prevents a vision-based model from further use is the interference when the hands are interlocked. When the fingers or hand is behind another object, the camera cannot gather any additional data. A hybrid of Wang's visual model with a simple physical tracking solution would appear to be the best solution with further development.

A hybrid of these two technologies would allow the visual system to relate the occluded movement of the hand. AI could be trained to look at the exposed portions and infer the position based on the additional physical sensor data. This also would allow the physical sensor to be less advanced because the AI model would handle the bulk of the processing.

Alternate haptic systems

When considering how to handle haptic feedback, multiple solutions were considered. The system described by Song (2019) using a mini pneumatic system was heavily considered. Unfortunately, the manufacturing process for this type of system was not a viable option using the equipment available. An initial design used a small syringe and a linear actuator to inflate a series of tubing that sat under each finger, but a solution to pressurize each section individually was not found.

The use of a linear potentiometer was considered in a system similar to the redesign below. A linear potentiometer would lay on the hand, and a spring retained system would be attached to strings running along with each finger. When the haptic system was activated, the linear movement would be blocked. It was found that a form factor small enough to fit on the hand was not feasible, and the servo position to limit movement along the full travel of the linear potentiometer was not possible.

A unique design from Meta uses lines of pneumatic pockets on the palm to accomplish the preferred haptic feedback.

Figure 13. Meta haptic prototype (Robertson, 2021)

This solution presents an additional level of feeling in the palm. When the sections are inflated, finger movement Is restricted. Another advancement of this system is that depending on the pressure; it would be possible to simulate more in-depth feelings of texture, such as the deflection when squeezing on a ball or no movement if the user was touching a hard object like a table. This is an early design; the complete unit is powered externally with a separate compressed air supply.

An external support skeleton was thought to be a viable option for use. An experimental system released by Dexta Robotics Inc shows long extensions leading from the base of the system out to the fingertips. It appears the system's electronics are housed above each knuckle and use a similar servo actuation to prevent movement when triggered.

Figure 14. Dexmo from Dot R

Ultimately this type of design was not utilized because the strength of available materials was not sufficient. The form factor was also not possible to achieve using the components on hand.

Redesign

During the initial redesign, the focus centered on a finger tracking solution. The costs of the redesigned parts are presented below.

Parts list	
Item	Price
Work glove	$10
Potentiometer a15011600ux0235	$0.45
Key retractor N-0001	$1.00
BLE Nano B08PC32DM9	$26
PLA 3D printing material - 1Kg	$20
Servo motor B07RQWV8SJ	$3.33
Ribbon Cable 16ft B07V4LF866	$8.86

Table 2. Prototype redesign Parts List

The first tracking design used the spring-loaded spool from a standard retractable badge holder. The spool was removed from its casing and inserted into a 3D printed body that also held a potentiometer in place. The spring was set, and the line from the spool was secured around the post of the potentiometer.

This spring-loaded potentiometer can be mounted on a glove, and the line guided and secured to the end of the finger to track movement. Below are the pieces of assembly split to show the inner detail. The body was held together with press-fit pins. The small posts in the center of the larger inner circle held the spring tension in the system; the spool fits securely in the indention. The smaller through-hole is the passthrough for the potentiometer and the space for the line attached to it. Finally, the horizontal channel in the center acts as a guide for the line as it is actuated.

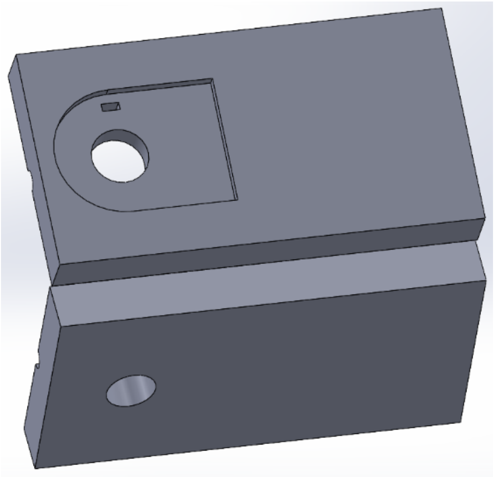


Figure 15. Rear view of open assembly

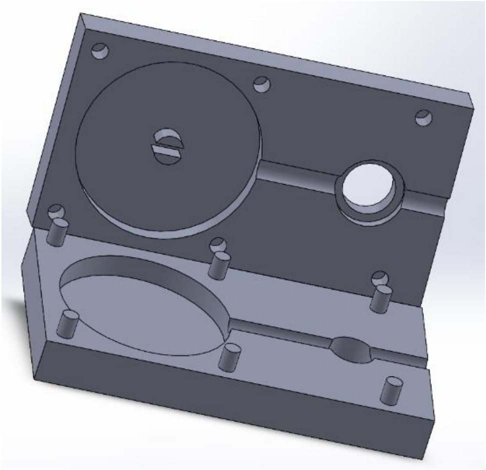


Figure 16. Front view of open assembly

After testing this configuration, it was found that there was no viable option for mounting the haptic feedback mechanism. This body design was also a bit too long to fit comfortably on the back of the hand.

The second body design went through 3 phases of redesign until an optimal layout was found. The entire body was shortened to fit on the hand. The haptics mechanism is a one-way ratchet gear that restricts the user's finger movement when a 9g servo motor mounted on the top of the body is moved into position. This design allows restriction of the fingers to simulate the feeling of an object in the hand but also allows the mechanism to retract when the virtual object is released and allows the system to reset the servo motor to a neutral position.

During design, special care was taken to ensure the orientation of the spring retention slot and potentiometer were correct, as well as the final position of the potentiometer. Shown below is the primary body mount; the body is presented at an angle to show features accurately.

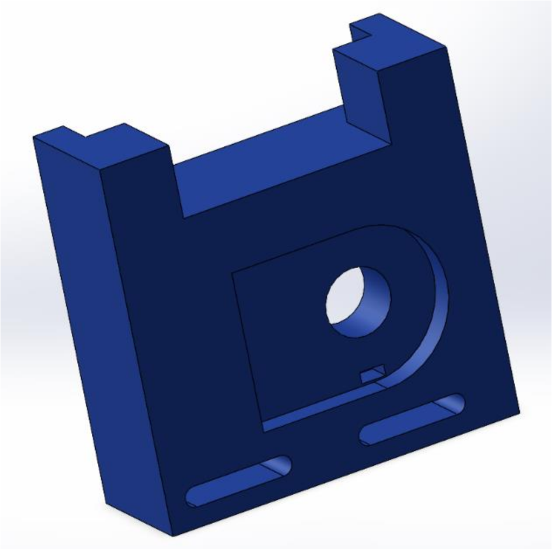


Figure 17. Rear view of sensor body

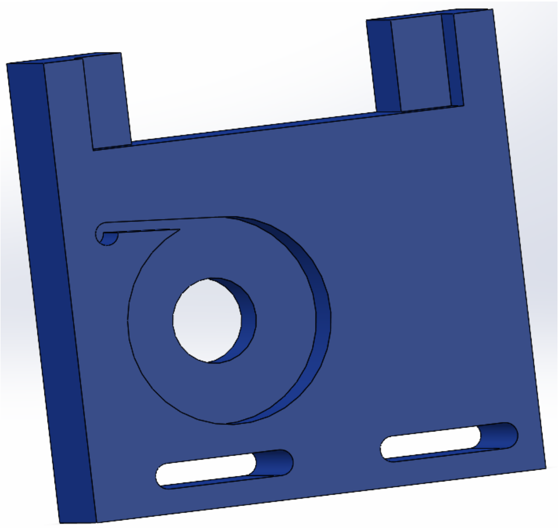


Figure 18. Front view of the sensor body

The next step in the redesign process was string management. The original spool was too large to mount on the side of the body as desired, so a low-profile spool was designed to fit on the potentiometer.

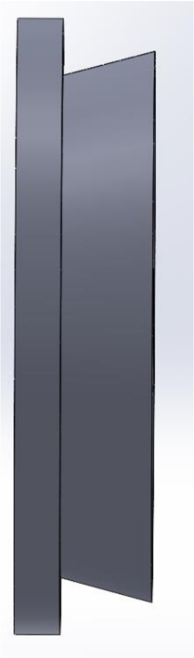


Figure 19. Side view of spool

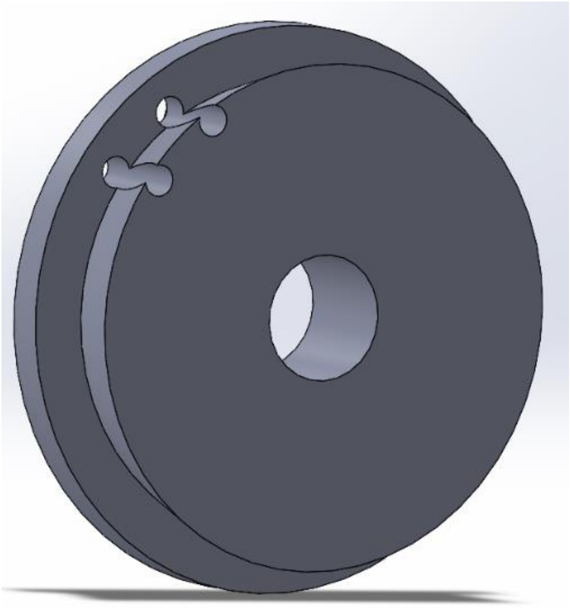


Figure 20. Front view of the spool

The new spool has a slight slope so that the string will sit at the lowest point, this is helpful during retraction, so it does not tangle. The two small holes are to secure the string to the spool; the larger hole in the middle press fits onto the potentiometer. A small spacer plate is placed between the body and the spool and secured to the potentiometer.

The ratchet gear pictured below is glued onto the open face of the spool; the gear itself also helps to keep the string in place.

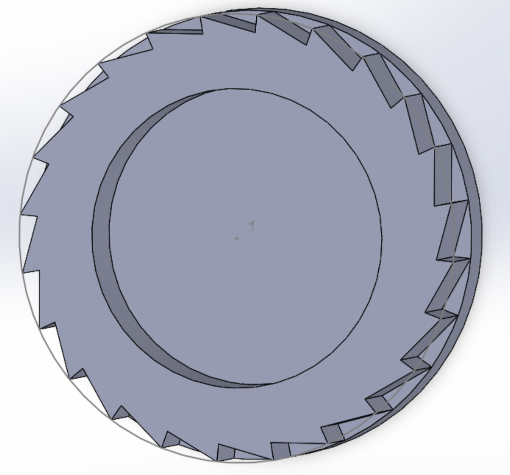


Figure 21. front view of the ratchet gear

The ratchet mechanism is comprised of a 9g servo motor and a section of wire. After testing different materials to attach to the servo to lock the mechanism, it was found that a section cut from a paperclip was easily adjustable and attached directly to the hardware arm that came with the servo motors. The holes to attach the servo to the body were predrilled with a small drill bit, and the 3D printed body was sturdy enough and had no issues with loose fitting or attachment failure.

The final parts for the systems are the anchors that attach to the tips of the finger, the string guides that sit on the length of the finger, and a small protective case for the Arduino board. The fingertip anchors were designed, and the average finger width of the glove was used. The string guides were designed with a slight curve to comfortably sit on top of the finger. The

Arduino shell has multiple passthrough points on the side and bottom and access to the reset button on top.

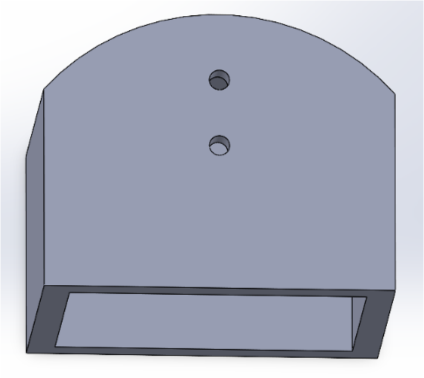


Figure 22. Top view of fingertip cover

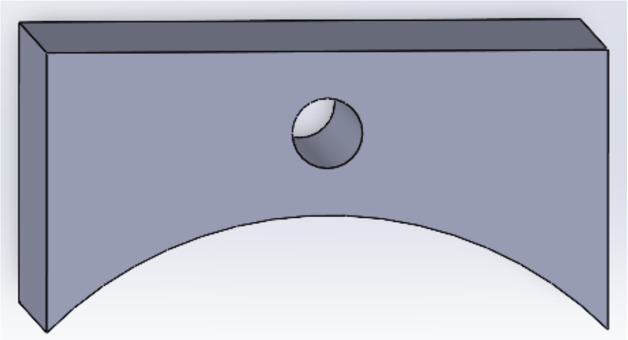


Figure 23. Front view of joint string guide

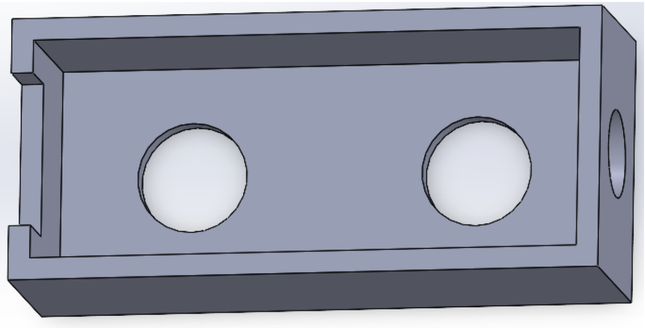


Figure 24. Top view of Arduino case

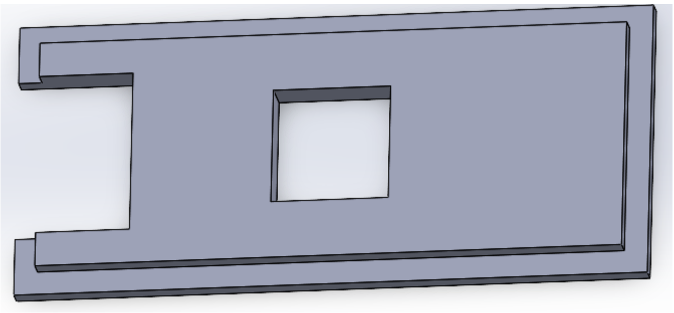


Figure 25. Top view of Arduino case lid

Chapter 4: Assembly and Testing

System assembly

The parts took approximately 15 hours in total to 3D print, not including design time. Once all system components were on hand, the main body was assembled. The main body was cleared of any extra support material, and the potentiometer was fit into the body. The spring was then harvested from the internals of the badge retractor and fit into the retention mount on the opposite face of the body and fit into the potentiometer. The tongue of the spring was bent in a way to keep it captive in the body, and as an extra precaution, a small amount of superglue was applied in the remaining retention space.

Once the glue had dried, the spring was manually wound by freeing the potentiometer and tensioning it until it was approximately half the starting size. The potentiometer was then tested to ensure it would return to its starting position after being turned. The fit of the potentiometer in the body was a firm press fit, but it was also glued in place and allowed to set.

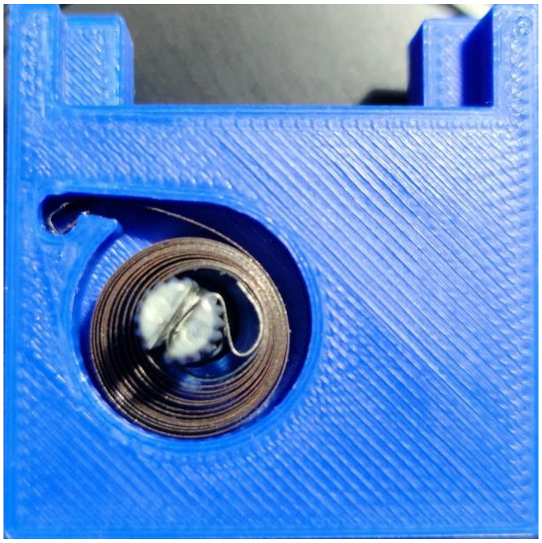


Figure 26. Assembled spring mechanism

The spacer is then placed over the spring to ensure it will not press against or get caught on the moving spool assembly. The string is attached to the base of the spool and then pressed over the remaining exposed shaft. The base spool is again glued to the shaft to ensure it is secure and will not slip. The ratchet gear is then centered and glued to the base spool. The teeth of the gear act as a centering guide and keep the string in place on the spool as it is wound out and back in during use.

Once 5 of these assemblies were finished, wires were soldered onto each potentiometer. A small piece of heat shrink tubing was fit around each pin to act as both a strain relief and to ensure no shorts or cross-connections would occur. All positive leads were then connected together on a common wire; the same is true for all ground pins. Each sensing pin was wired with a unique color for easy identification.

Each servo motor had standard connections already on the leads, these were removed, and the wires were stripped and tinned. Each positive and ground lead was again joined together to a common wire and shielded with heat shrink tubing.

The system was temporarily hooked to the Arduino to set each servo motor to its 0 position (home). Once the motors were all in the home position, the arms were placed horizontally in reference to the body. Once screwed into the motor, a small piece of metal was secured to the actuating arm and bent into shape. Multiple lengths and positions were tested and remain in the system to show the difference in actuation. The arms were individually tuned to lock the gear after moving a set distance. More information on this process will be provided in the coming text. Featured on the next page is an example of one of the haptic mechanisms.

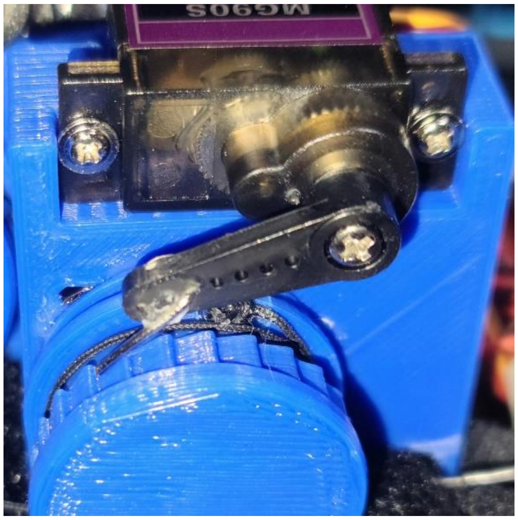


Figure 27. Locking mechanism

The assemblies were secured to the glove before the system could be fully wired to the Arduino board. Velcro straps were used to hold the sensing bodies in place and also allow for adjustment. The first strap was cut down the middle to allow it to slide through the slots on the bottom of the body. A second strap was also cut to allow the sensors to be staggered to fit the hand's profile better. The straps were attached to the glove using safety pins.

Once the main sensing bodies were secured, the string was measured to ensure enough length was available and the spool had two turns of excess length. The strings were then placed through two guides per finger, and the string was tied to the end finger anchor. During final fitment, it was ensured that the strings were taught when the hand was fully open and each finger could fully bend. The fingertip anchors and the string guides were then glued to the glove.

System Wiring

Once the glove was assembled, the glove could be fully wired to the Arduino. It was decided to solder directly to the pins to minimize the overall footprint. Below is the wiring diagram for the glove.

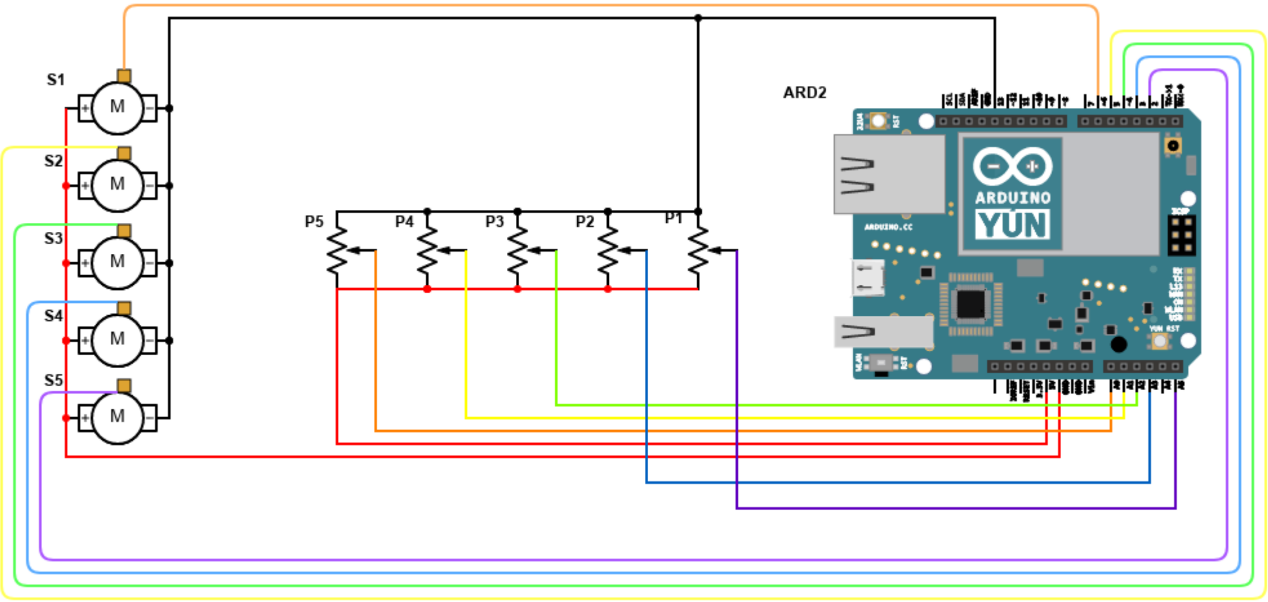


Figure 28. Circuit Layout after redesign [3]

The common grounds were connected to the board ground, but the positive connections used different pins for voltage. The servo motors run on 5VDC, and the voltage can fluctuate under load. If these positive collections were shared with the potentiometers, this would change the finger position reading and cause a negative feedback loop. The servo positive was connected to the 5v pin, and the positive common for the potentiometers was connected to the 3.3V pin.

[3] Electrical schematic made on www.digikey.com/schemeit/project/

Each of the sensing lines from the potentiometers was connected to A0-A4. Each connection was noted and correlated to a finger. Each control wire from the servo motors was connected to D2-D6, noting the finger position.

Each connected pin was then shielded with heat shrink tube to ensure isolation when placed in the case. After the system was wired, any excess wire was managed with zip ties, and the case was secured to the remaining open space on the glove. Below is the assembled glove, ready for testing.

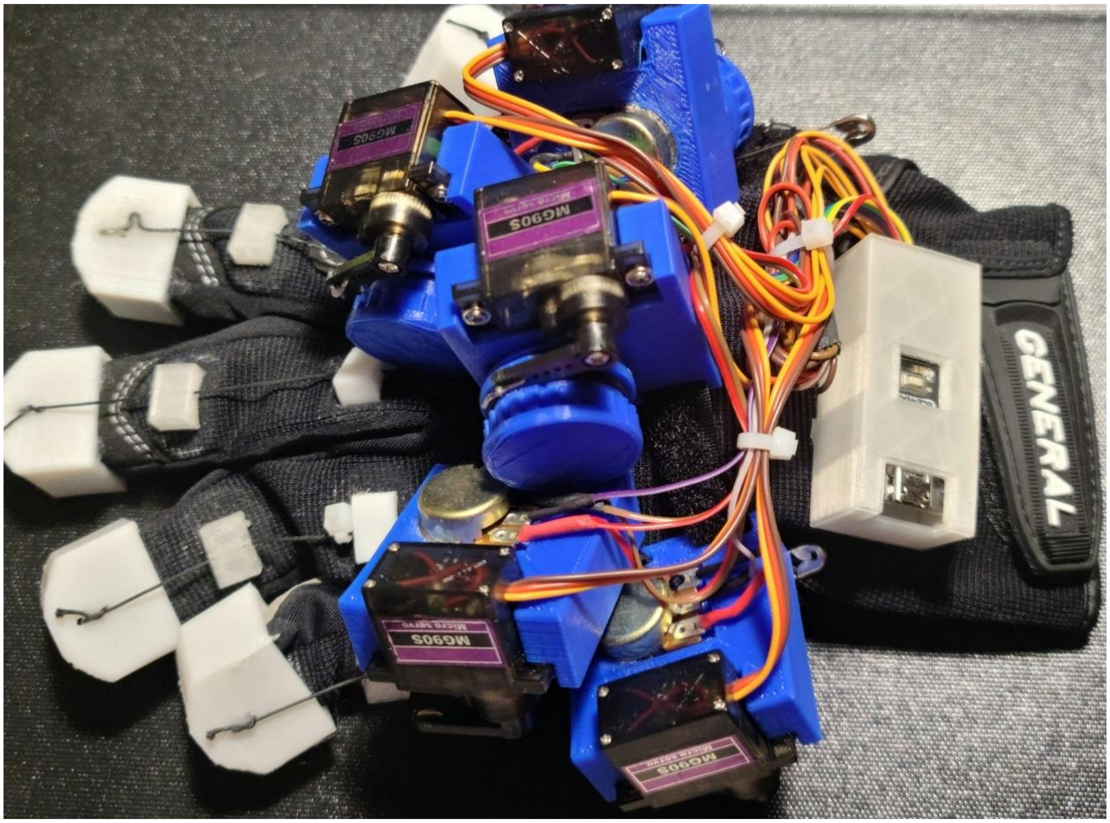


Figure 29. Full system assembly

System Testing

After the unit was assembled, a basic Arduino program was written to test and validate each component. This program took the analog value read from the potentiometer and displayed it in a readable string labeled for each finger. The glove was worn, and each finger was bent. Each potentiometer returned a value of less than 10 when the hand was fully open, and as each finger was bent, each value did increase. This shows that the mechanism for sensing finger position was functioning as intended.

The next components validated were the servo motors. An Arduino program was written to set the servo motors to the home position of 0. After a short delay, the program instructed the servo motors to turn 10 degrees. This positioned the locking arm close to the gear. The metal ends of the arms were then bent to get a rough calibration. After getting the locking arms positioned close, each individual motor was then actuated 1 degree at a time until the metal came into contact with the locking gear.

With the locking mechanism calibrated, the Arduino was programmed to set the servo motors to 0 degrees, wait 5 seconds and then move the arms to the specific locking angles. After another 5 seconds, the program would loop and return to 0 degrees. Each arm was adjusted as needed. After 20 cycles of actuation, the servo motors could accurately and consistently return to the set positions with no noticeable drift.

It is vital to position the gears during assembly, so they are parallel to the body. This is to avoid any substantial variation in the position or relative height from the servo. To ensure that this is achieved, the spacer on the back of the spool was introduced during the design process. The spacer allows the spool to be press-fit with no interference from the spring being held underneath. The spool can then be adjusted with a small gap to allow for free turning. A second design element included to avoid any issues is the width of the gear itself. In case there is any axial tilt, the width of the gear allows the locking arm to catch.

Software

While researching communication methods between Arduino and the unity game engine, an open-source driver was found. This driver was called Opengloves (Lucas, 2021), and it allowed for direct passthrough of the sensing information needed, along with an Arduino code example. This driver also had a Unity demonstration that could be used with minimal changes. The creator of Opengloves is also in the process of developing support for a haptic feedback system using a different method than the one presented in this project. The proposed system uses similar sensing methods with potentiometers but different implementations and an entirely unique tactile feedback mechanism and trigger.

This driver was created to support SteamVR, but Using the Oculus link service, it was possible to use the non-steam-supported headset available on hand. To use this software, the sensing data being sent back to the Arduino had to be interpreted in a different manner. The original string sent back to the Arduino included a scaled integer based on the finger curl in the virtual environment. This scale included the finger position and the servo motors' maximum and minimum movement positions. Based on the sensor reading and feedback from the virtual environment, the servo motor's position can be calculated. Once the virtual object is not interacted with, the servo returns to a neutral position for a full range of motion.

This return to neutral feature allowed this new mechanism to be integrated without any significant changes to the driver or Arduino program. The best description of the software change is to say a binary sensing method was introduced. Because the driver originally sends the servo back to a neutral home position, this allowed the locking logic to use If statements.

The original encoding method was preserved; the only relevant values are the neutral or 0 position and any value above neutral. The Arduino program was changed to recognize the neutral command, and if any value greater was read, the servo is set to move into the locked position. The original scaling factors were left in the program. This is because this scaling factor was already integrated with the finger calibration of the software, and its inclusion provides a more reliable trigger.

When an object is encountered in the virtual environment, the string for each individual finger will be triggered. With this different mechanism, no matter what value is returned, the lock will activate if it is greater than the neutral value. Once the object is not being interacted with, the string value drops back to the neutral value, and the servo resets to its home position and is ready to actuate again when triggered.

When triggered, the servo moves to a predefined position to lock the spool and resist the finger movement, creating a sense of touch or tactile feedback. When the trigger is released, the ratchet slips under the lock and allows the sensor to signal reset.

The Arduino software takes the minimum and maximum read values during use to calibrate the glove. The user only needs to open and close the hand before use. This calibration is used to better relay information to the hand model to ensure an accurate representation of the hand is being displayed during use. These values are sent to the SteamVR hand model.

A VR handset needs to be attached around the wrist to use the glove. The handset is not used but is required by the Oculus for hand position. In the driver settings, there is a function to align the hand and the controller. This allows the controller to be mounted in any orientation and ensures the user's hand is shown in the same position as it is in the physical world. The unity demonstration environment can be opened after configuring the Opengloves driver and communication settings. Each object in this environment that is able to be interacted with has a specific trigger boundary associated with the surface.

The hand model used also has a specific trigger boundary associated with it. When these boundaries meet, the unity engine attaches the objects and allows the hand model to manipulate objects without using a standard controller. Once triggered, the object moves with the hand model. Once the model senses the object has been released, the hand and the object are detached. The unity physics engine then takes over, and the object will fall.

For simple demonstrations, Arduino code was written to trigger the locking mechanism at set finger positions; this allows the glove to be used with only an external battery pack to verify mechanical function for the proof of concept without a VR system.

Chapter Five: Conclusions

Potential improvements

With further design improvements to the sensing body design, the size of the system as a whole could be reduced. This initial design provided functionality, but there are opportunities for improvement. The design of the caps at eh ends of the fingers would be further refined. The current design has had edges that can interfere with the other fingers when moving. A rounded and thinner design would provide a better feel and function. With these improvements, lengthening the section that sits on the pad of the finger would improve the tactile feel. A design similar to what is shown by Zhu (2020).

The current guiding mounts for the strings work well. It would be beneficial to design a system that would allow for adjustment around the finger. The attachment points of the string to the fingertip should also be redesigned for better adjustment. It would be possible to insert a small channel to allow for the system to be pre-tensioned. When the string is slid forwards, it is free to be adjusted, and when slid back to the original position, it would be securely held by the clamping section.

After extensive testing of this prototype, the small 28ga wire used started to fail in multiple locations. A loose ground, as well as sensing pins from the potentiometers, broke free from the solder. One of the potentiometers failed; this could be the cause, but most likely, it is just an issue with the internal wiper or electrical connection. A major design flaw was found when these components needed to be replaced and reconnected. The potentiometers are a nonreplaceable part because they were glued in. While not necessary, this was done because it was unknown how the system would react to initial use and testing.

While correcting the wiring failures, it was noted that the Arduino case should have been designed so that the wire passthrough point is not fully enclosed. This became an issue during repairs because the system could not be entirely removed from the case. The rewiring process could have been completed much faster if the processor was not captive.

The spool should be fully covered in future design iterations to ensure the string could not inadvertently slip off. This issue did not occur during testing, but it is a possibility. The addition of an enclosure and a single opening would ensure reliability. An additional change to the spool would be a reduction in size. During testing, it was possible for the locking gear mechanism to rub on the adjacent sensing body. No noticeable impact was observed; the internal spring was able to overcome any additional friction forces it experienced. The addition of a joystick for added control is needed, as well as a button for added support in multiple environments.

The current hand model that displays the flex of the finger from the Opengloves and SteamVR driver is a representation of the standard curve of flex. It would be beneficial to add support for the sensing of the bending of individual joints, but it would not be feasible for a system such as this. This would also cause the need for a complete redesign of the finger retention mechanism.

The thumb sensor requires a separate mounting system. During the initial design, the thumb sensor was placed in a non-optimal position. The original placement used the mounting straps for the other finger sensors for convenience. With the initial placement, the user had to move the thumb toward the center of the hand; it would not read the movement of the first joint of the thumb individually. The optimal placement of this sensor is lower on the hand in line with the thumb to allow for proper tensioning. Dedicated straps were positioned to accomplish this. The repositioning of the thumb sensor had the added benefit of allowing the four other finger sensors to be better centered on each finger.

The method of using a Velcro strap and staggering the sensing bodies worked well. The current retention system allows for adjustment around the palm of the hand to provide additional stability. It allows for easy adjustment to avoid contact between the sensors as well. A more robust mount

The use of potentiometers provides an accurate and affordable method to collect finger movement data. The spring-loaded self-retracting design is a simple and effective way to ensure little variability because the sensor only moves if the finger moves. The readings are resistant to external movement because there is no slack available in the system. This is key in an interactive device that will be moved in all directions, such as this one.

Final Thoughts

While developing this system, it was shown that it is possible to create an affordable and functional glove to provide both haptic feedback as well as the tracking of finger movement.

From research gathered, VR training is more effective than traditional classroom training. This serves as a cost-benefit to employers. Better training implies less retraining, fewer accidents, and higher production knowledge. Thermal sensing, like that used by Kim (2020), could be used for welding training, another VR training exercise being developed at Morehead

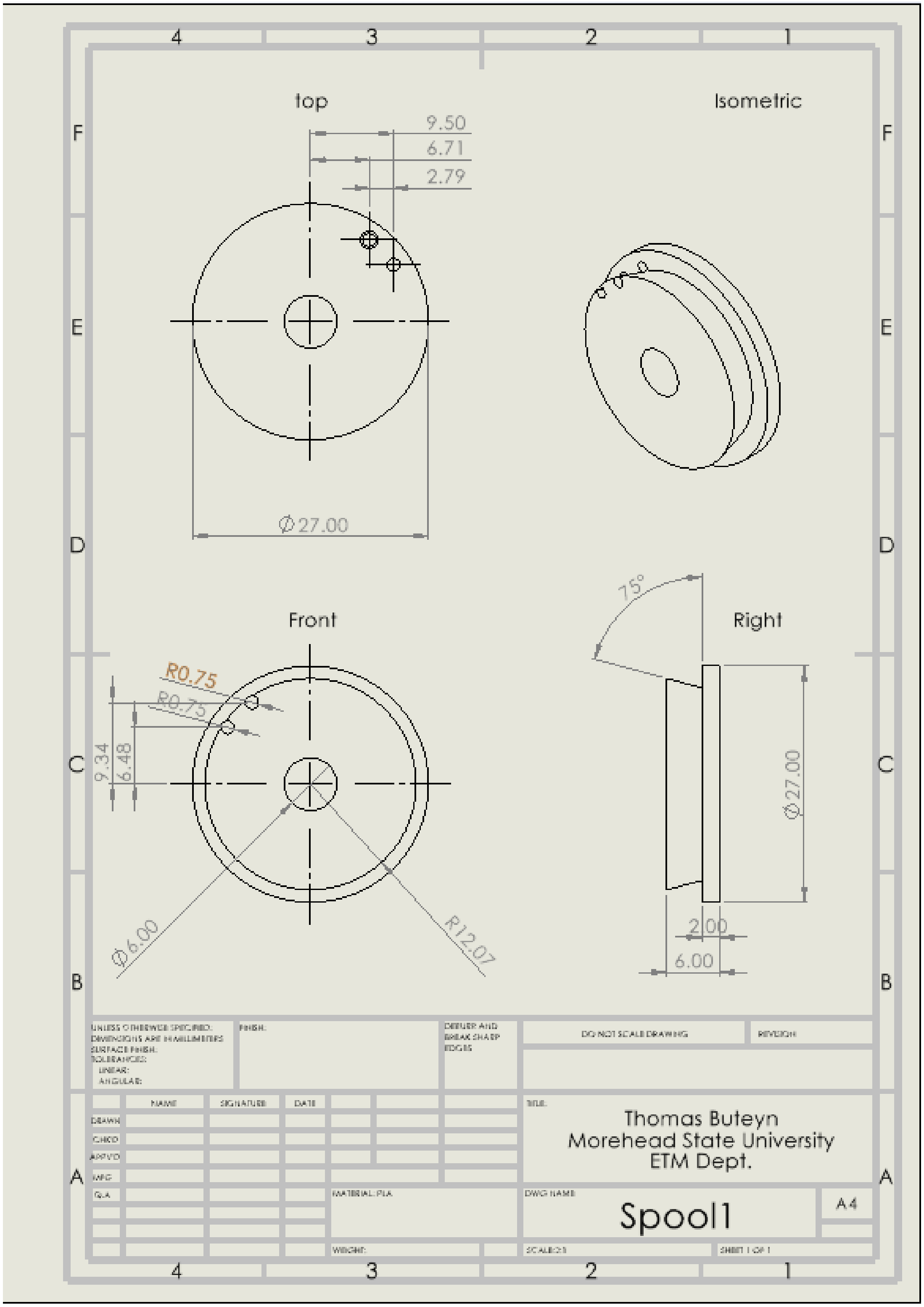
State University and the National Science Foundation research team. After welding, if the parts are picked up prematurely, the glove would heat up to have a practical example of the proper cooldown time of parts. If an employee is working in food processing, the gloves could be cooled to simulate conditions in the cold storage area and signify a hazardous exposure. For those who work in extreme conditions, simulations could be created for fire training, working in snow and Icey conditions, Security training, first aid, and many other industries.

In the future, incorporation of a similar system to Arkenbout's (2015) study vision system tracking would improve overall function. The system would be successful with integration into a system such as Russ (2021). The key to a system such as this being viable is realism and ease of use, as described by Buckingham (2021). This total emersion is the breaking point between using a VR training system as a novelty and providing an effective training method.

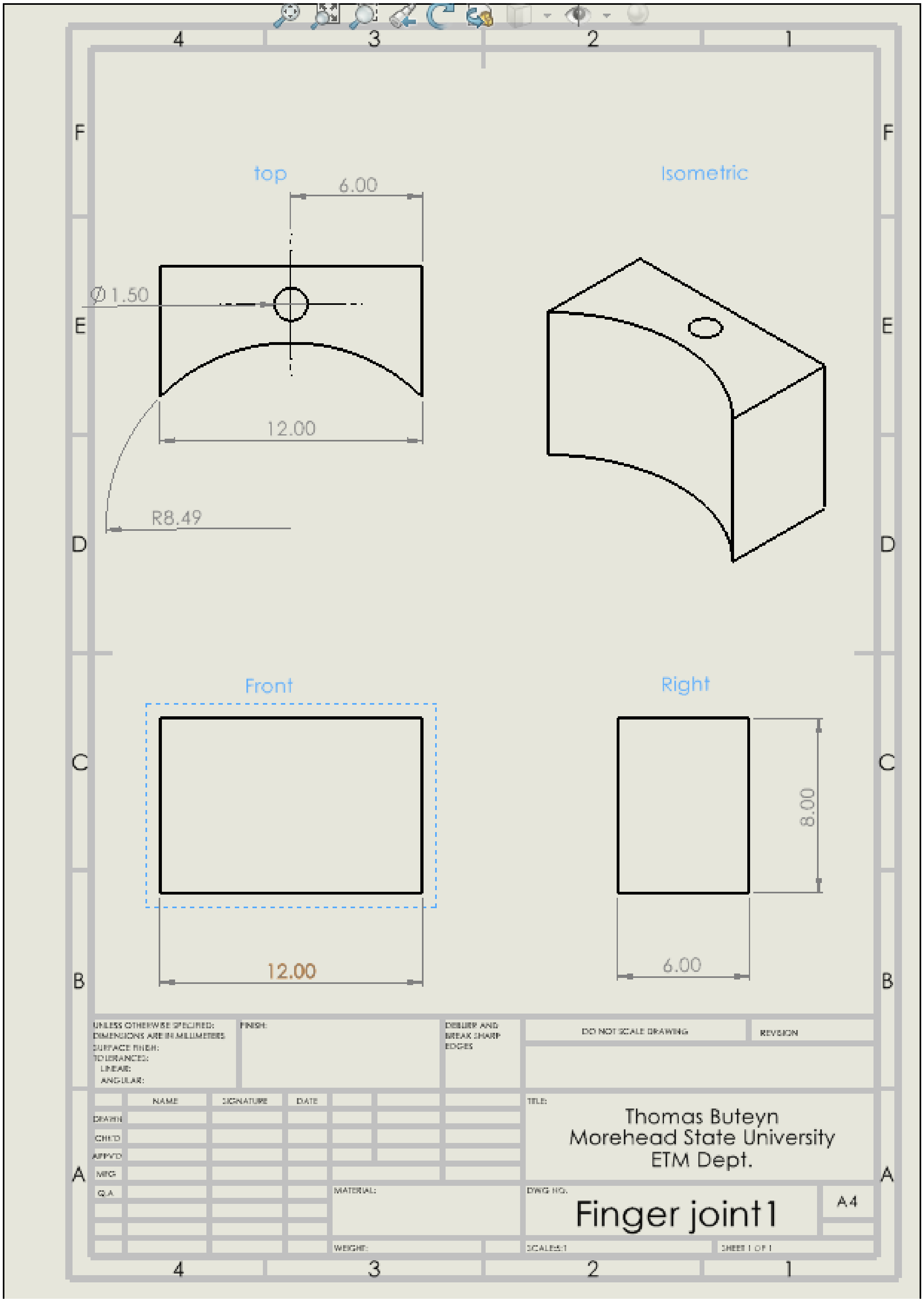
Fahmi (2020), Markopoilos (2020), and Sacks (2013) all concluded that VR systems are a more efficient way to conduct training. The system has limitless potential to expose users to any situation that could arise. This glove system could have a substantial impact on these pieces of training. With total emersion, the user has nothing to learn before entering the environment; it is as simple as putting on the headset and gloves and going to work.

Appendix

Spool Rev.1



Joint Rev.1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Q.A
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Thomas Buteyn
Morehead State University
ETM Dept.
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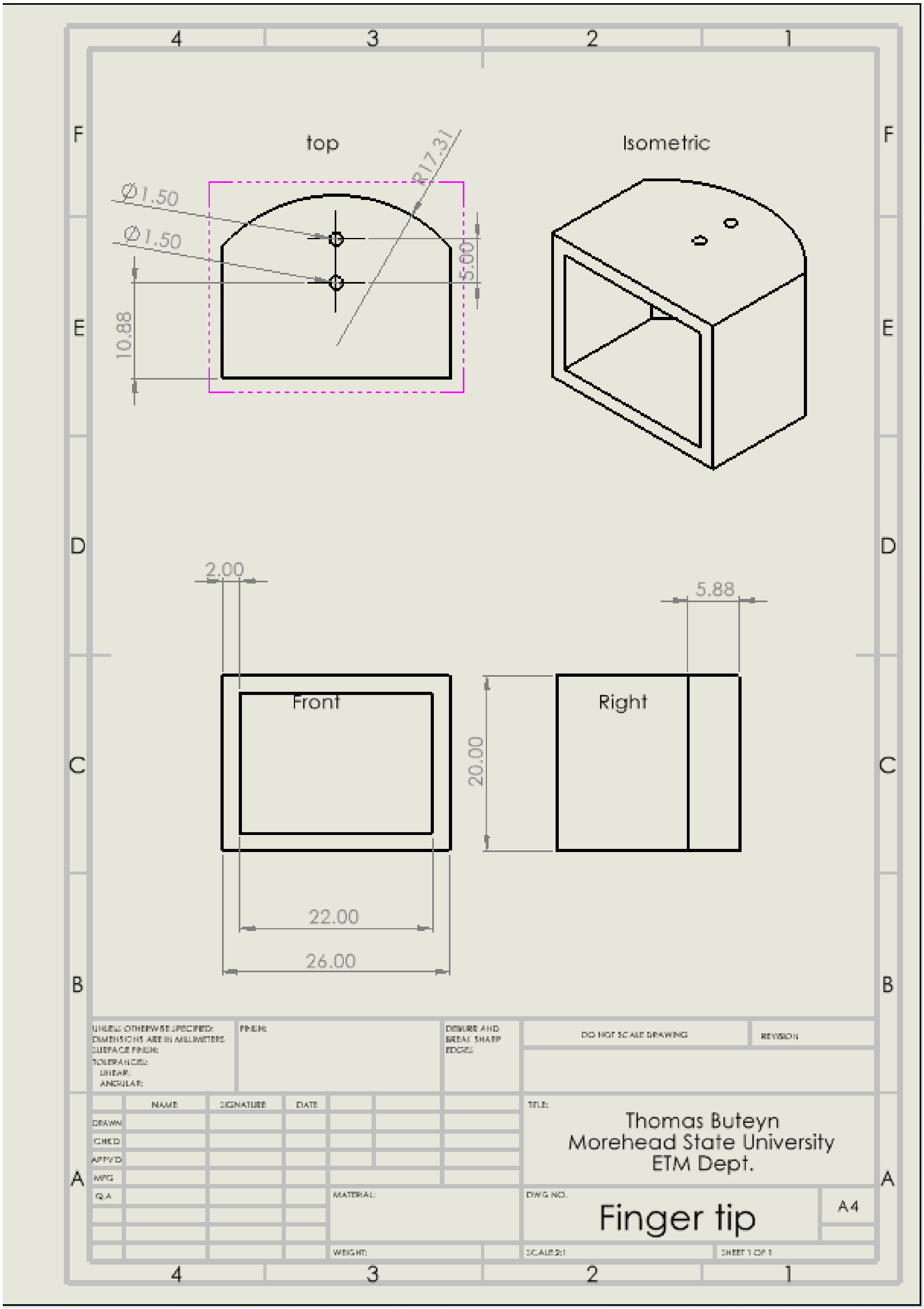
A4
WEIGHT:
SCALE:5:1
SHEET 1 OF 1

<u>Fingertip</u>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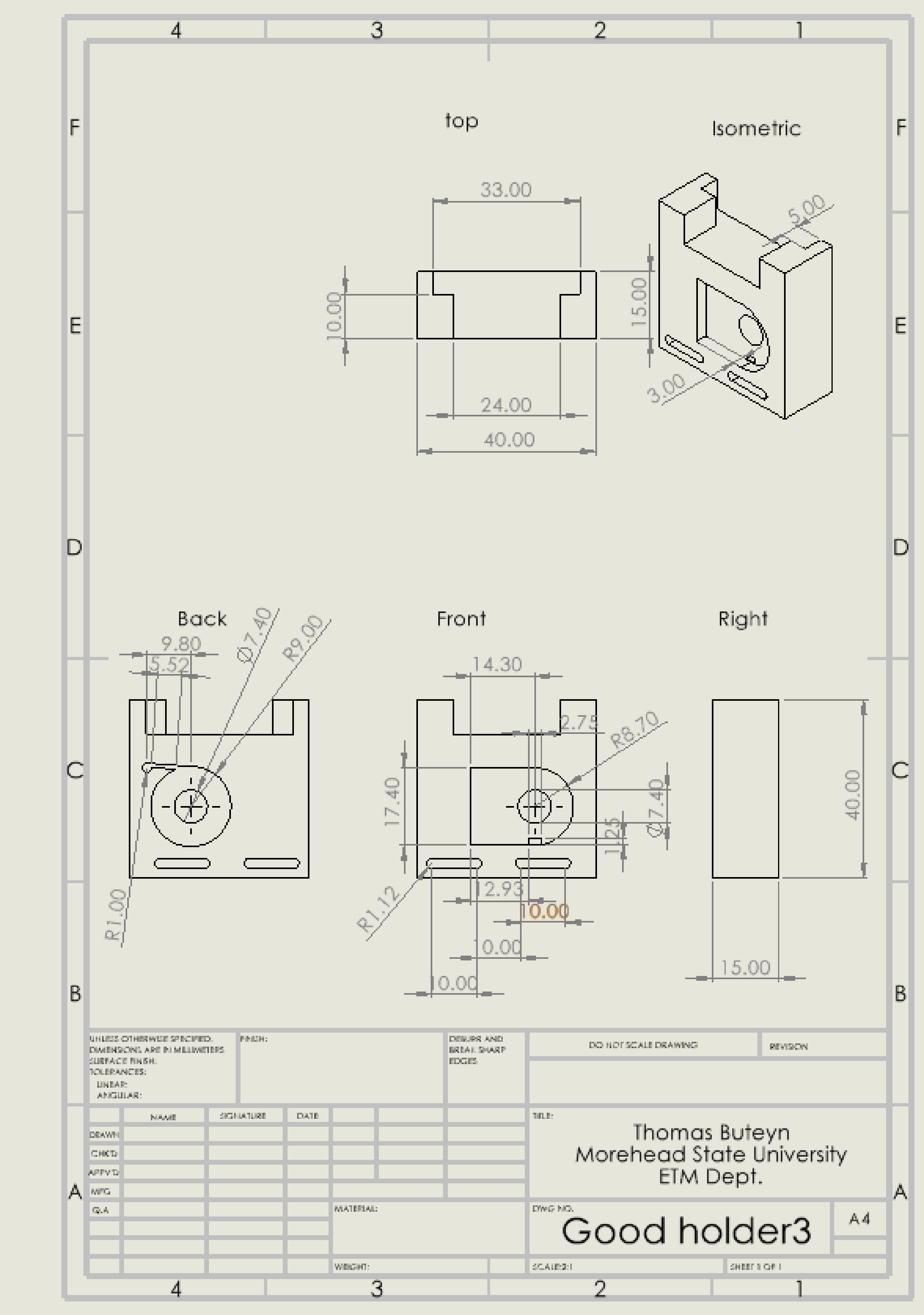
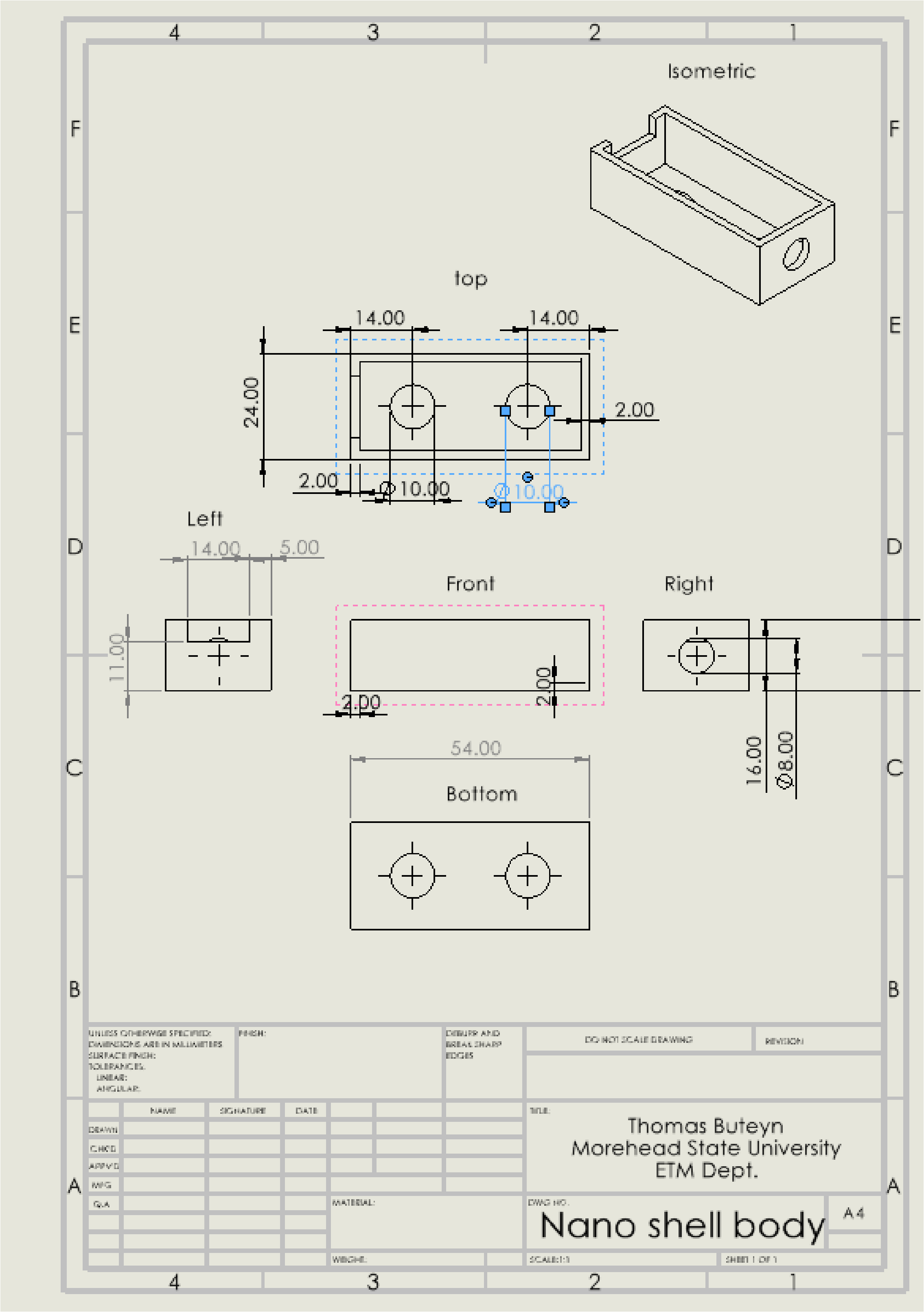
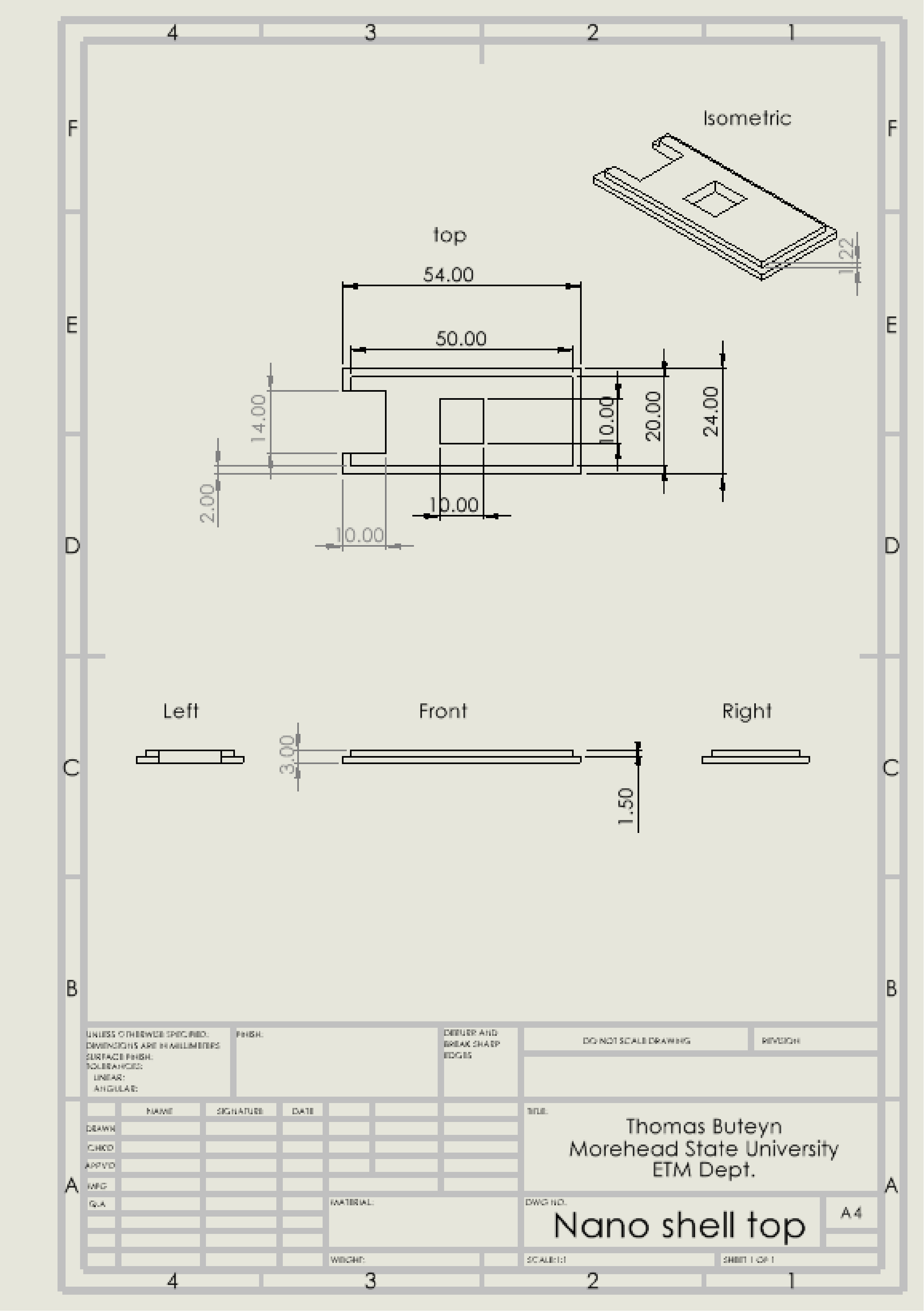
Sensor Body Rev.3



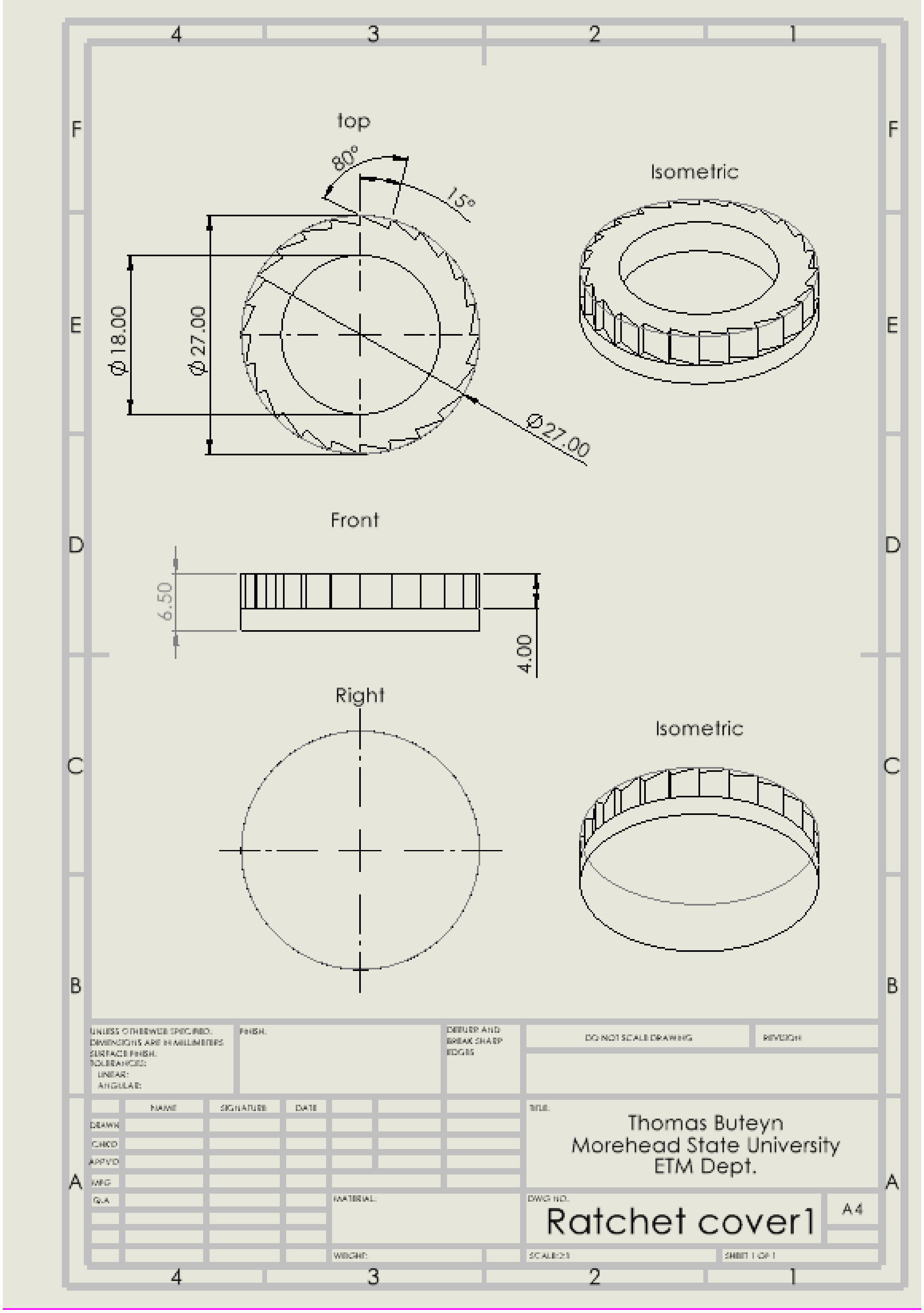
<u>Nano Shell body</u>



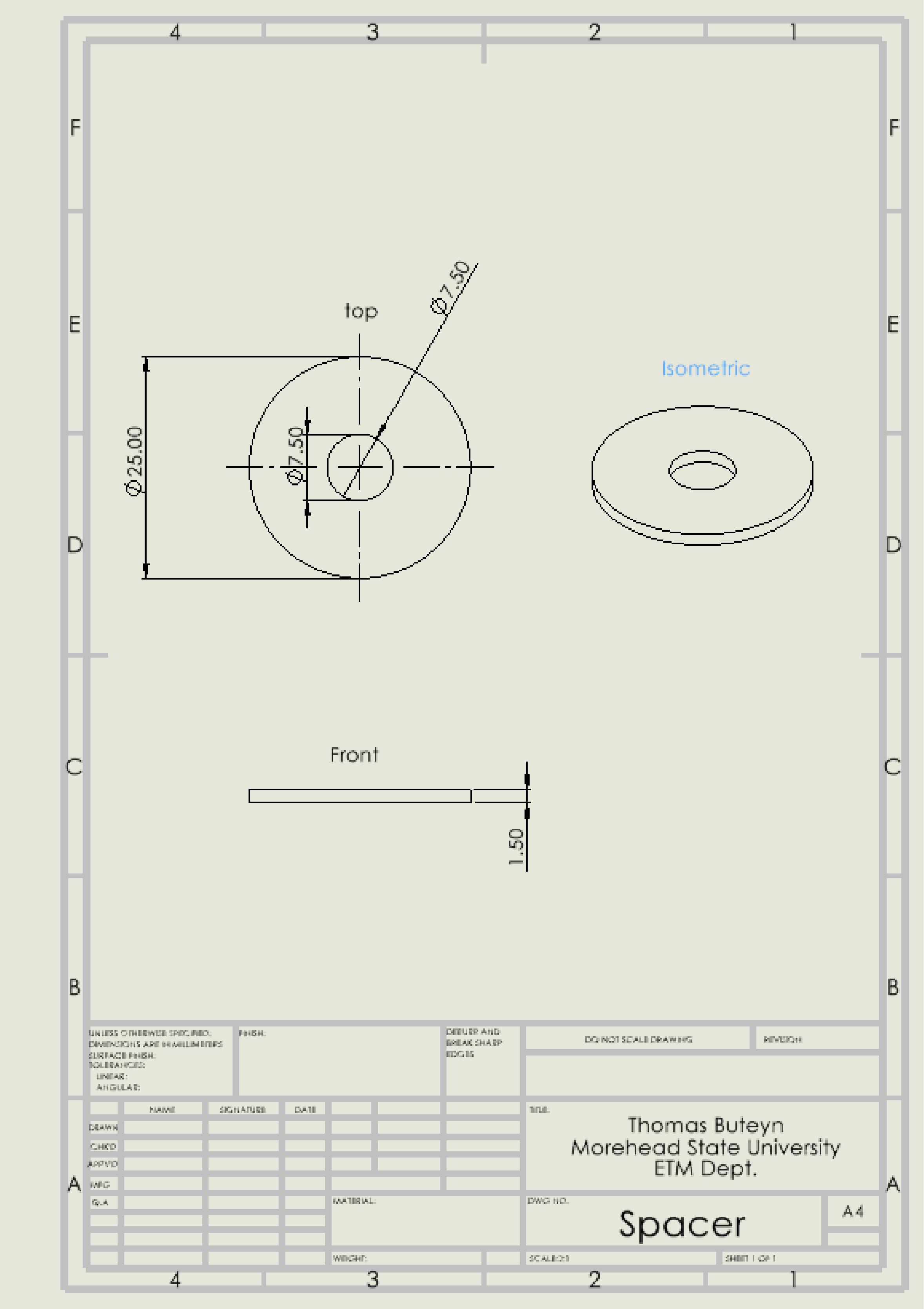
Nano shell top



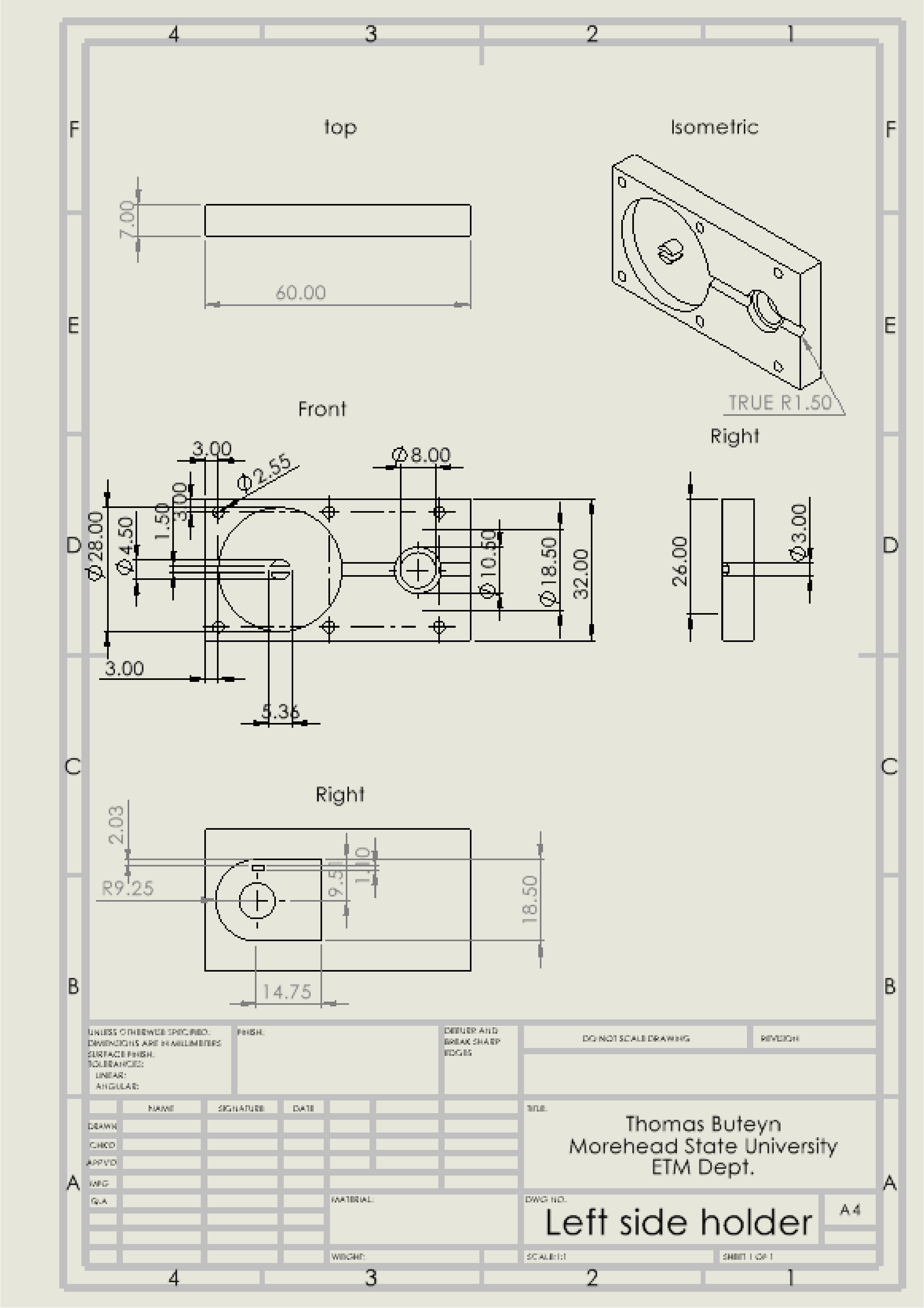
Ratchet cover



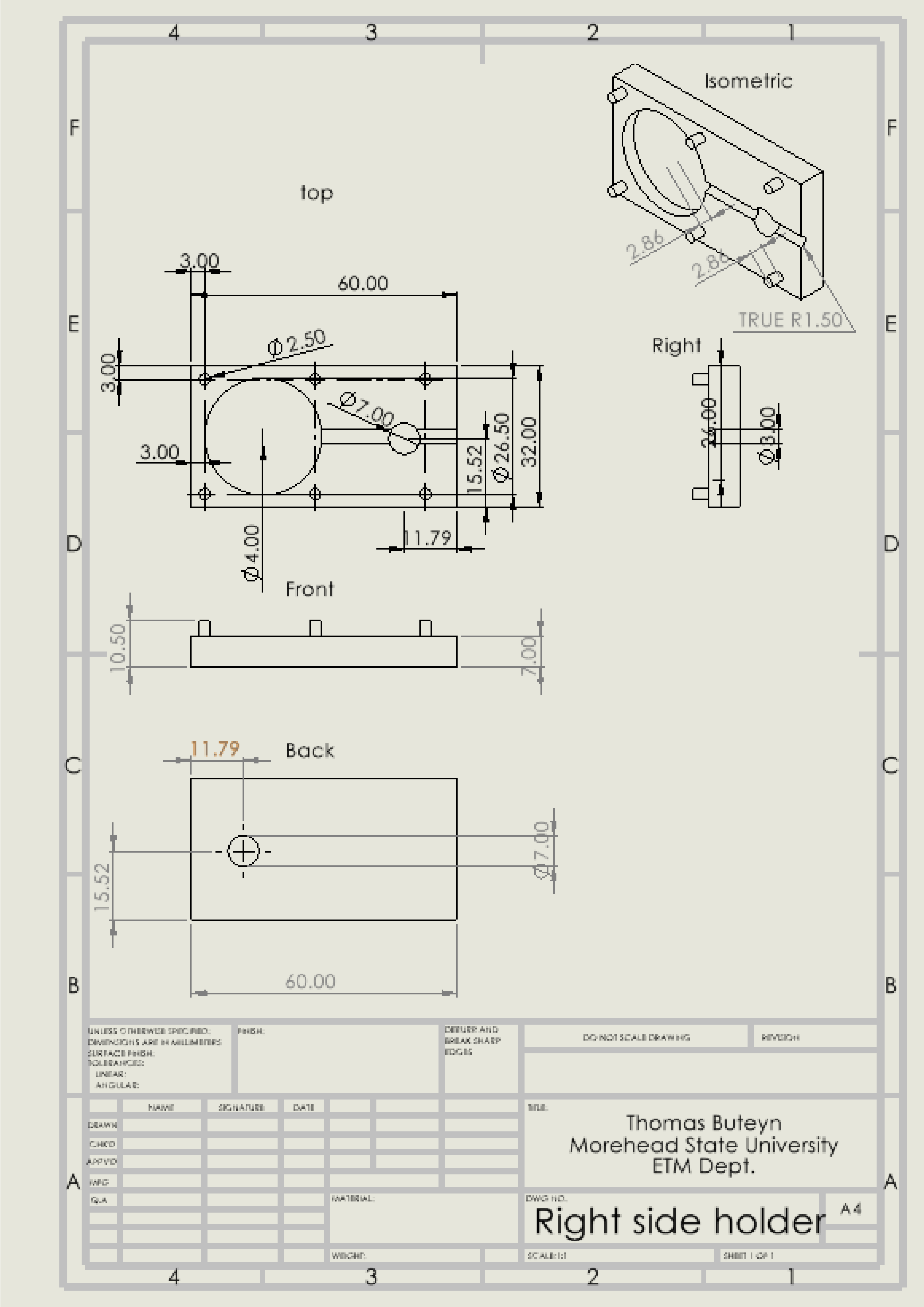
Spacer


top
Ø7.50
Ø25.00
Ø7.50
Isometric
Front
1.50
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN MILLIMETERS
SURFACE FINISH:
TOLERANCES:
LINEAR:
ANGULAR:
FINISH:
DEBURR AND BREAK SHARP EDGES
DO NOT SCALE DRAWING
REVISION
NAME
SIGNATURE
DATE
DRAWN
CHK'D
APPV'D
MFG
Q.A
MATERIAL:
WEIGHT:
TITLE:
Thomas Buteyn
Morehead State University
ETM Dept.
DWG NO.
Spacer
A4
SCALE:2:1
SHEET 1 OF 1
4
3
2
1
F
E
D
C
B
A

Left half holder v1



Right half holder v1



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