Carnegie Mellon University

Embedded Systems Design

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TeleTouch

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1 Abstract

Haptic technology recreates the sense of touch by applying forces, vibrations, or motions to the user. Basic haptic feedback systems like gaming controllers exist, but these still lack the ability to explore and touch from the user side. Strides in haptic feedback technology can lend itself to many applications such as virtual reality, security, and medical devices.

In this project, we explore how to relay touch sensations on a model hand to another user's hand wirelessly across any distance. A mannequin hand was covered with sensors to detect pressure in different areas, data was packaged and sent by WiFi between Raspberry PIs, and feedback was triggered using linear resonant actuators on the receiving end. Some of the metrics used to gauge the system's effectiveness included sensor accuracy, sensitivity, communication latency, and actuator strength.

The results and tests show that the fabric, while giving reliable and granular data for different regions, led to most of the inefficiency from varying calibration. Additionally, the system expereinced a significant amount of latency that made the real-time responses difficult. The linear resonant actuators on the glove performed quite well and let users experience different touch sensations on their hand.

Overall, the system explored wireless end-to-end communication of tactile feedback. While there were calibration and latency issues, the ability to accurately feel the touch sensation demonstrates that realistic haptic feedback systems are possible in the future.

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2 Project Description

Teletouch is a remote communication device that mimics the touch on a model hand to the glove on a user's hand. We hope to capture the intimate feeling of holding / touching a hand in different areas and and mimic a realistic touch. Our project consists of two physical parts. There is a model hand that the user can touch and a haptic feedback glove that mimics the feeling of touch. Two users each own a set of model hand and glove so that they can wirelessly hold hands across any distance. We aim to explore the most effective and believable methods of providing tactile feedback and deliver a new way to interact with technology.

3 Design Requirements

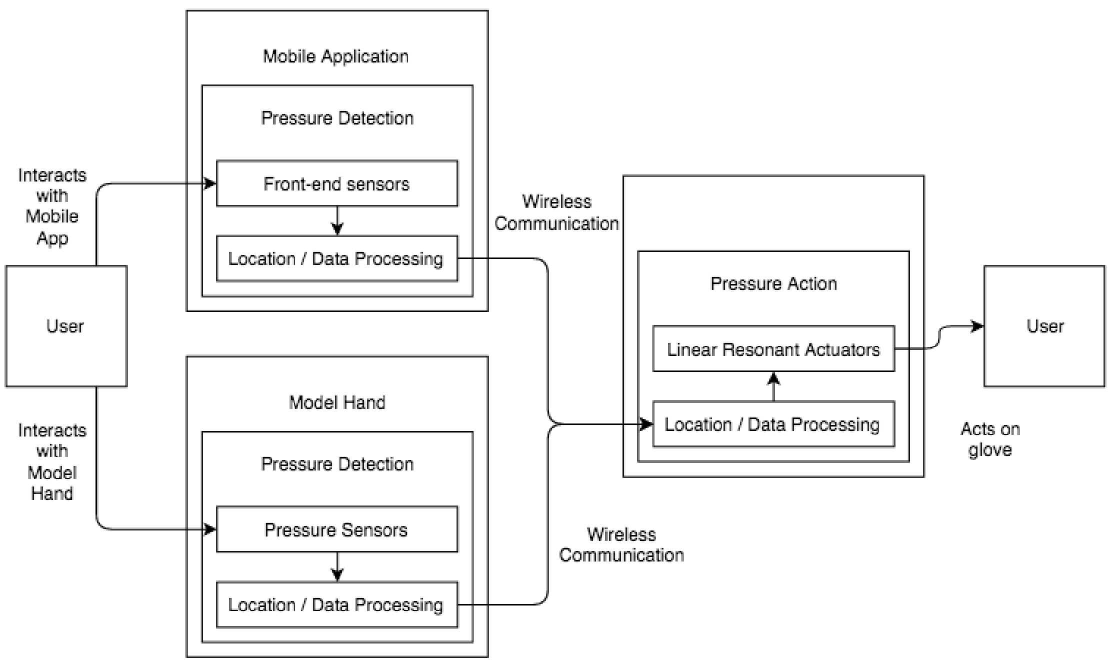
3.1 Functional Requirements

Enacting touch	Collect data about where the user has touched the model hand using pressure sensors.
Receiving touch	Use Linear Resonant Actuators to send haptic feedback to the corresponding areas on glove where the model hand was touched.
Pressure	Accurately reflect the amount of pressure enforced on the model hand to the user's glove with at least 3 different levels of pressure.
Communication	The interaction should be able to take place no matter the distance in-between as long as both the hand and glove are connected to Wi-Fi.
Power	Both the glove and the model hand should be powered via USB cable.

3.2 Non-Functional Requirements

Real-time	After a touch is enacted on model hand, the glove must receive the touch within 2 seconds.
Energy-efficient	Both the glove and the model hand should maintain battery life of at least 2 hours.
Realistic	Users should feel that the glove provides a natural touch.

4 Functional Architecture



5 Design Trade Studies

5.1 Hand Design

Metric	(1) Fabric Square Sensors	(2) Round Force-Sensitive Resistor
Price	$24.95/sheet (12inx13in)	$7.00/sensor
Size	Flexible	2.35in x 0.73in
Sensitivity	Resistance changes by distance from pressure or stretch	10 percent variation by sensor: suggested for detecting weight, not accurate in how much
Pressure Range	0.01lb - 220lb	0.04lb - 22lb
Cost	$93.85	$221.99

The choice of which pressure sensors to use was between EeonTex Pressure Sensing Fabric and Round Force-Sensitive Resistors. Comparing the price of 12 sensors cut out from the fabric sheet to the price of 12 force-sensitive resistors, the fabric saves $4.92 per sensor. The fabric is more flexible to fit on the model hand than the solid force-sensitive resistor. The fabric resistance is a function of the pressure applied and is relatively uniform, while the force-sensitive resistor has a 10% variation of resistance by each sensor, and has been recommended for detecting the presence of weight, and not as a load measurer. Since we are modeling human touch, we care more about the lower end of pressure range capabilities. The fabric has a lower threshold of 0.01lb compared to the force-sensitive resistor threshold of 0.04lb. Comparing every characteristic, the EeonTex Pressure Sensing Fabric is the superior choice to the Round Force-Sensitive Resistors to use as our hand sensors.

5.2 Glove Design

Metric	(1) Vibration Motors	(2) Linear Resistant Actuators
Price	$4.96/motor	$6.66/actuator
Size	10 mm	8 mm
Latency	Time to turn on and off	7ms
Force Range	One speed: 13 krpm/min	Modifiable frequency and amp.
Cost	$168.83	$218.13

The choice of which glove design to use compared the use of vibration motors or linear resonant actuators. Each vibration motor is $1.70 cheaper compared to one linear resonant actuator. The diameter of a linear resonant actuator is 2mm smaller than a vibration motor. The latency of both the motor and the actuator are both fast enough for our purpose. The most important characteristic was the force range, since we want to be able to simulate sensitive touch sensations. The vibration motor was not intended to have many controllable speeds, while the linear resonant actuator responds to changes in frequency or amplitude changes from the AC input and changes its vibration. So, even though the cost of the linear resonant actuator is considerably more than the vibration motors, we chose to use the actuators because of the range of vibration frequencies.

5.3 WiFi Modules

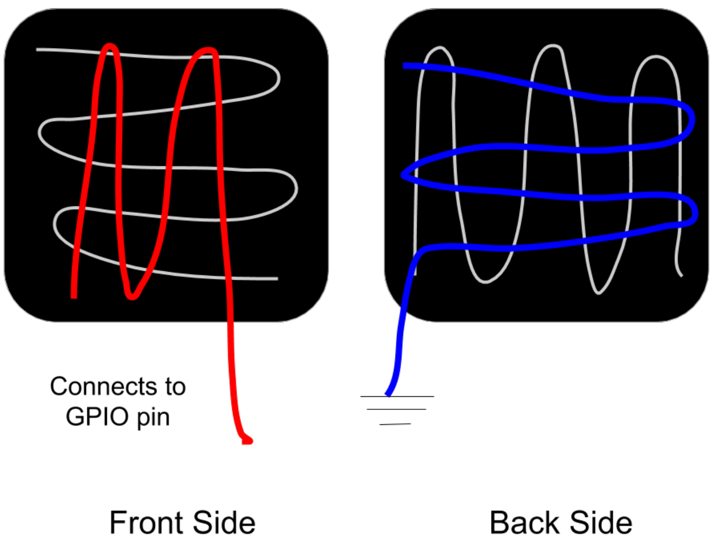
Metric	(1) SMD Module - CC3000	(2) ESP8266 (TCP/IP)
Price	$26.95 / module	$6.95 / module
Size	16.3 mm x 13.5 mm x 2 mm	16 mm x 24 mm x 3 mm
Throughput	4 Mbps	320 kbps
Cost	$53.90	$13.90

One of the main operations of our system is communicating sensor data wirelessly from the mannequin hand to the glove. The system architecture includes one module on the mannequin and one module on the glove, each of which communicate through a cloud server. Two of the WiFi modules that were considered were the CC3000 and ESP8226. Since the data packets being sent are mostly numbers that translate to operations for each vibration motor, throughput was not a huge factor in deciding between modules. Online research also indicates the ESP8266 is more performant, has better modularity for hardware, and is significantly cheaper.

6 System Description/Depiction

6.1 Fabric Square Sensors

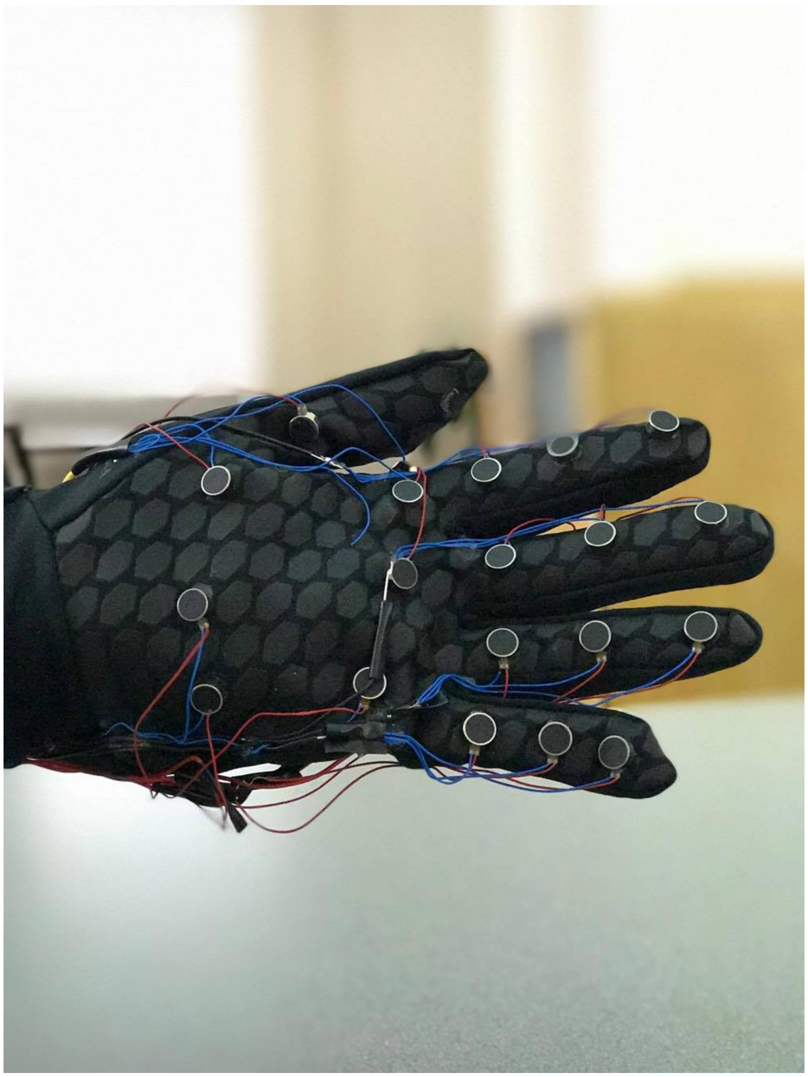
The mannequin hand is covered in 20 1in x 1in EeonTex Pressure Sensing Fabric on the palm of the hand and fingertips. Each fabric square has a measured resistance that is sent as data to the glove.



Each side of the fabric square is sewn with conductive thread (gray line) in a zig-zag pattern, and thin wire is interlaced between the thread and secured with electrical tape. The zig-zag pattern must be perpendicular to the zig-zag pattern on the other side since maximum number of intersections in the front (red) and back (blue) wires results in more reliable resistance measurements.

6.2 Linear Resonant Actuators

Black elastic glove is lined on the inside with 20 linear resonant actuators on back of hand, palm, and fingertips to mirror sensor placements on mannequin hand. Resistance data from each sensor in the cloud server is translated to corresponding force output in linear resonant actuator. Different forces are controlled by modifying actuator amplitude and/or frequency to simulate pressure.



7 Project Management

7.1 Project Schedule

Date	Milestone
2/13	Basic Website Landing Page
2/17	Purchase Components Deadline
2/21	Website Sections Created and Filled
2/21	Setup Pressure Meshing
2/24	Website Check 1
2/24	Design for Pressure Meshing Mappings
2/28	Live Updating of Pressure Meshing
3/6	System Demo 1
3/10	Website Updated System Demo 1 Post Mortem
3/14	Vibration (Tactile) Mesh Design Complete
3/14	Design for Pressure Mesh to Vibration Mesh Mapping
3/20	System Demo 2
3/24	Communication between Mesh Layers
3/24	Website Updated System Demo 2 Post Mortem
4/3	System Demo 3
4/3	Website Updated System Demo 3 Post Mortem
4/7	Website Check 2
4/7	Full Vibration Mesh Control via Wireless Communication
4/10	System Demo 4
4/12	Website Updated System Demo 4 Post Mortem
4/15	Basic Feel via Vibration Mesh from Human Interaction
4/15	Ability to touch a model hand sensor and feel it on glove
4/17	System Demo 5
4/17	Website Updated System Demo 5 Post Mortem
4/24	Refined Feel via Vibration Mesh from Human Interaction
4/24	Ability to touch a model hand anywhere and feel it on glove
4/25	System Demo 6
4/25	Website Updated System Demo 6 Post Mortem

7.2 Team Member Responsibilities

Team Member	Primary	Secondary
Rohan Jadvani	Mobile App, Actuator Design	PCB Design
Chelsea Kwong	Wireless Communication, PCB Design	Sensor Design, Website
Lisa Yan	Sensor Design, Model Hand Design	Sensor/Actuator Research
Cristian Vallejo	Glove Design, Actuator Design	Automation

7.3 Budget

Item	Vendor	Quantity	Price
Model Hand	Amazon	2	$18.99
Linear Resonant Actuators	Precision Micro-drives	40	$266.40
Pressure Sensing Fabric	SparkFun	4	$99.80
WiFi SMD Module	SparkFun	2	$26.95
Black Elastic Glove	Cabela's	1	$24.99
Raspberry Pi WiFi Adapter	Amazon	1	$7.95
MCP23017 Expander	Adafruit	2	$2.95
2x20 Header	Sparkfun	2	$0.95
Raspberry Pi WiFi Adapter	Amazon	1	$9.99
IC Sockets 0.3" 28 Pin	Adafruit	1	$1.25
Gorilla Glue	Amazon	1	$5.53
Ribbon Cable	Adafruit	2	$2.95
External Battery Pack	Amazon	2	$19.99
16 Channel Servo	Adafruit	2	$17.5
Brass Standoffs	Adafruit	3	$0.75
Female Ended Wire Sets	Adafruit	3	$3.95
HAT Stacking Header	Adafruit	3	$2.5
Conductive Thread	Sparkfun	1	$2.95
10 uF Capacitors	Digikey	40	$0.065
2.2 kOhm Resistors	Digikey	40	$0.014
Dual Male Header	Adafruit	2	$0.95
Conductive Thread	Adafruit	1	$5.95

7.4 Risk Management

7.4.1 Design Risks

1. Sensors are not accurate or do not work as expected
    (a) Change the design to an alternative or use other sensors that will work more closely with our needs.
    (b) Focus on software side with the mobile application.
2. Actuators can not deliver sensation in the way expected.
    (a) Find a different set of actuators to deliver tactile feedback.
3. Communication over certain protocols may not serve the device properly
    (a) Using our research on differing methods for wireless communication we would use an alternative protocol to achieve our design

7.4.2 Resource Risks

1. Availability issues with group member
    (a) Have overlapping responsibilities so that no areas of the project fall behind
    (b) Have excellent communication between team members so that the team is able to keep the project moving
2. Part Failure
    (a) Order multiple of each part so that should one fail there is a back up.

7.4.3 Scheduling Risks

1. Incorrect Estimations for Task Completion Deadlines
    (a) Reevaluate deadlines weekly to ensure people are staying on task

2. Incorrect Analysis on the Importance of Subsystems
    (a) Should it become apparent that an element of a certain subsystem should need to be worked on first the schedule will be altered to better reflect the team's needs

8 Evaluation

8.1 Functional Requirements

Enacting touch	Collect data about where the user has touched the model hand using pressure sensors.
Receiving touch	Use Linear Resonant Actuators to send haptic feedback to the corresponding areas on glove where the model hand was touched.
Pressure	Accurately reflect the amount of pressure enforced on the model hand to the user's glove with at least 3 different levels of pressure.
Communication	The interaction should be able to take place no matter the distance in-between as long as both the hand and glove are connected to WiFi.
Power	Both the glove and the model hand should be rechargeable via USB cable.

With both the application and the model hand, we were able to collect touch data to gauge fidelity between pressure and feedback. The app had a slider representing pressure, and touching the hand image selected the appropriate actuator location on the glove.

The model hand measured touch with RC Circuit charging time for each piece of fabric in different areas. The glove's 20 linear resonant actuators were able activate the sensors that corresponded to the hand being touched from the app or model hand.

Each linear resonant actuator could output normalized pressure in the range 50-250 Hz by correlating the data collected from the sensors to changing frequencies for the linear resonant actuators.

Both Raspberry Pis had WiFi modules and were able to send data to each other wirelessly using UDP.

Both the hand and the glove are powered by USB cable from a battery pack.

8.2 Non-Functional Requirements

Real-time	After a touch is enacted on model hand, the glove must receive the touch within 2 seconds.
Energy-efficient	Both the glove and the model hand should maintain battery life of at least 2 hours.
Realistic	Users should feel that the glove provides a natural touch.

A touch from the app is able to be felt in the glove after about 5 seconds. After a touch is enacted on the model hand, the glove receives the touch after a significant delay, sometimes more than 10 seconds. We believe this is due to the latency of the connection between the hand and glove.

With the power pack, the hand and the glove each can last at least 3 hours.

The glove was able to provide a more accurate touch sensation when receiving from the app. The glove reenacting touch sensations is not that natural when receiving from the model hand since it was more difficult to calibrate each of the sensors. If the threshold level is too low, the glove vibrates without anyone touching the model hand, and if the threshold level is too high, only a really strong touch can be felt. There is also a significant amount of latency which doesn't relay a natural touch.

9 Conclusions

9.1 Lessons Learned

Our biggest success was that we got our glove and model hand basic hardware implemented and tested very quickly, and had end-to-end functionality quite soon. We had enough time to design the glove's 3D-printed mount for the Raspberry Pi and organize the wires neatly, as well as completely iterate on our model hand to perform better and be more robust with a new sensor design.

However, we could have saved a lot of effort by taking more time to consider our sensor design for the hand so we wouldn't have had to waste time making the first one. We bought conductive thread as a more flexible, thinner version of thin wire. We soon realized that it was unable to be soldered to wire reliably, but since they sensors were already glued to that hand, we had to make due with solder and tape. We ultimately made our second version by sewing the thread and intertwining the thin wire, which worked much better and required less soldering since we tested this before we glued it.

Another lesson we learned was to thoroughly research the capabilities of our components when designing our hardware. During the planning process assumptions were made about the capabilities of the raspberry pi to send PWM over I2C. Our solution was based on the assumption that the pi could do this, however learned that it is not possible simply using i2c. In order to solve our problem we had to do research on a non custom solution to our problem and found the servo hat to send extra channels pwm on the pi. The original PCB designed to expand the raspberry pi GPIO pins to drive the receiving glove was no longer used - something that would not have happened with better project planning.

9.2 What We Would Do Differently

If we could start again, we would probably explore other flexible sensor options outside of the fabric. Because we had to use an RC circuit to measure the resistance of the fabric sensor, the data measurement was difficult to calibrate and changed very often for each individual sensor. The model hand would be much more effective if the sensors used could be quantitatively more precise.

Another consideration would be the durability of our product. Looking into alternate methods to attach the actuators to the glove as well as a more well thought out wiring scheme. This would allow for the glove to be able to be stretched more as the wires would not be pulled on or strained as much as they are in the current design. This would stop the sensors from being disconnected as we saw in our final glove after it had been worn by many people.

9.3 Future Work

Since the hand-to-hand touch was just an exploration of haptic technology, we would probably start exploring the combination of mechanical and haptic feedback to provide an even more realistic experience. We could look into more specific interactions such as a handshake or a hug to combine movement and touch sensations. Heat sensors and heating fabric could also contribute to a more realistic touch.

10 Related Work (Competition)

10.1 GloveOne

GloveOne is a haptic glove designed to feel objects in VR. The gloves transfer data using either a low latency USB connection or via Bluetooth. The glove vibrates with varying intensities and frequencies to recreate touch sensations for the user. The glove also uses Leap Motion and Intel RealSense and has a price tag for $200 for each glove. Our team has an edge on this glove in different ways. GloveOne is not able to communicate long distances due to using a USB connection or Bluetooth. Our design, however, is able to communicate over WiFi allowing it to be used anywhere a connection is available. The glove is comparable in price to what it takes to make our proposed project. The actuators for GloveOne and our design are similar since they both “vibrate independently at different frequencies and intensities, reproducing accurate touch sensations”. However, their design uses 10 actuators, while the size of ours allows us to use 40.

10.2 Hands Omni

Hands Omni is a haptic glove as well that uses inflatable bladders to simulate pressure on touch. Inflatable bladders may create a more realistic sense of physical pressure on the hand compared to vibrating actuators, but since the device relies on air compressions to drive interactions, the latency of the device is a huge hurdle for real-time interactions.

References

[1] Hayden, Scott. *2 VR Gloves Promising Haptic Feedback, 2 Very Different Approaches.*