Using Wearable Sensors to Enhance Communication in the U.S. Army

Prepared by

Megan Weaver - Chief Engineer

Kayna Anderson

Ethan Hicks

Christian Kantz

Under the guidance of

Dr. Stephen Cain - West Virginia University Dept of Chemical and Biomedical Engineering

Dr. Russell Cohen Hoffing - U.S. Army Combat Capabilities Development Command

Andy Tennant - National Innovation Security Network

Department of Chemical and Biomedical Engineering

Benjamin M. Statler College of Engineering and Mineral Resources

West Virginia University

18 April 2024

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Abstract

Efficient communication in the military is essential for the success of wars and safety of soldiers. Many current means of communication present in the military are outdated (i.e radio), require soldiers to turn from their line of sight to receive the hand signals, or require sufficient waiting periods to receive the message. Our group devised an innovative approach to address this challenge through a nonverbal hand communication system. The device consists of three main components: an IMU glove for tracking and transmitting hand signals, a heads-up display glasses for receiving incoming messages, and a Commander's app for sending and receiving signals. Our team's objective focused on the proof of concept that IMU gloves can generate and process hand signals for transmission. Using Rokoko smart gloves, we successfully tracked static hand signals from numbers zero to nine. The files were exported, converted, and then inputted in MATLAB for data analysis. Each hand signal comprised 88 unique quaternion points spanned across the hand and onto the arm, recorded at 30 frames per second. Five individuals (2 female, 3 male) participated in recording the hand signals from zero to nine. Quaternion data for each number and individual were initialized and inputted into a machine learning algorithm. The algorithm successfully identified numbers based on finger angle orientations and displayed the designated signal. The machine model achieved 99.9% classification accuracy with 1 false positives and negatives. These findings demonstrate the success of the proof of concept and hold promise for a nonverbal communication device.

Description of the Problem

Our group was tasked with creating a novel technological forecasting device using wearable sensors that help different levels of the Army. The device was designed to enhance performance of soldiers spanning from squad to brigade level and every level in between (10 to 4500 soldiers). The task was to create a device that could recognize human states, cognition for intelligent systems, and improve performance of soldiers.

To complete the assignment, the initial goal was to better understand the army and what technology is available. Many of our group members came in with limited knowledge on how the army operates and what available physiological sensing are out there. The team spent sufficient time understanding those two through conducting literature reviews in both topic areas.

Literature reviews for the army focused on differentiation between squad levels, communication style, and overall basic training. As for physiological sensors, our group researched the basics in how sensor data is analyzed to extract signals, how it infers human states, and how these technologies could improve performance. This task was essential to be completed to gain a strong foundation to complete our project.

Interviewing key stakeholders was our next mission. The team's objective was to find relevant people in the field to help build our fundamental understanding by giving their personal perspective. Our team found relevant soldiers, military commanders, and engineers in the field providing additional information about available technology, potential issues with technology, and future technology they wished was available. Our group continues to stay in touch with these key stakeholders who gave constant feedback on our progress and suggestions as we moved forward.

Next on the agenda was to combine all acquired knowledge and narrowed down the specific scope to within our realm of possibilities. The team refined the scope to problems that are within our possibility of completing in less than a year, have access and financial availability to obtain equipment, and ultimately solve a common problem at hand in the military. Our team had two ways of approaching this problem: a bottom-up approach which was to find a sensor and determine the use case, or top-down approach which was finding use cases then finding sensors to solve the problem.

The subsequent task was to find and purchase the sensor. Afterwards, testing and validation could begin to measure the success and efficiency of the device. The goal for this step was to understand the sensor, begin creating code, and finding specific use cases for the device.

Ultimately the device's clinical population is directed towards the military. The intended goal would be a commanding officer and all his soldiers to have this device in some caliber with the intention to reduce communication time and increase soldier's safety. This would allow commanders to make more informed decisions.

Currently communication between commanders and soldiers is conducted through radios, which in stealth environments is not always ideal. Soldiers could potentially give their position away via their voice. This device could limit the chances of the soldier's position from being identified while also decreasing the communication time. If instead of speaking to their commander, it could be sent through a simple hand gesture, communication time and risk of danger could radically decrease. This device could be a major step to helping win wars!

Project Objective Statement

The overall goal was to create a novel sensor that would be able to enhance a soldier's performance. Initial literature reviews were provided to gain a foundation on military styles, training, and equipment; as well as, availability and functionality of sensors. After a strong foundation was established on basic knowledge on the topic, our group took it a step further by interviewing key stakeholders, or people with military background or specialized in military technology.

Andy Tennant, a retired military commander and currently works for the National Security Innovation Network, gave us his personal experience with the army. He explained the current communication and coordination style among team members in the army and how they are very outdated. Currently, the military follows PACE: primary, alternate, contingency, and emergency where each phrase goes increasingly more dramatic to get the commander's attention. Primary is the common soldiers/commander communication which is extremely outdated radio and cell phones. Andy explained a need for a better, more modern, primary method of communication to ensure the safety of the soldiers.

Dr. Russell Cohen Hoffing, military researcher at DEVCOM, explained current in works military technology. His expertise focused on eye tracking, gaze detection, and virtual/ augmented reality. He explained how combining gaze tracking data of multiple soldiers could be beneficial to detecting hot spots and blind spots. This technology could help notify soldiers where a potential threat may be located due to areas no one has examined yet. He added how this technology could be sent back to the commander where it can be compiled into an argument reality that they can observe from far distances.

Dr. Peter Khooshehadeh, military researcher at DEVCOM, elaborated on his research on measurables of cognitive function. He explained how he obtained baseline data for individuals, which is difficult to obtain due to the subject being nervous during testing, biasing the data. Currently he collects through sleep or taking a 5 minute rest period and only using the last 2 points. Ultimately, his main takeaway was in order to get Commanders to use a product it needs to reduce cost and time or help increase soldier's effectiveness.

Dr. David Whittaker, captain and trauma surgeon for the Navy, provided an interesting perspective of the military from the medical side. His experience gave insight on needs in biotech including wearable sensors for dialysis, CO2 detection for intubation, and gait analysis of the foot. Another novel idea presented was an electrode lollipop that is placed in the soldier's mouth that sends a grid to their tongue to perceive their surroundings. This is in current works for blind people helping them to 'see' their surroundings with their tongue. This perspective helped our group think outside of the box and how sensors are not solely physiological.

Dr. Leslie Saxon, director of Center for Body Computing, who is working on a continuous Health Assessment app called dCORA. The goal of her project is to create a way to have continuous, real-time health monitoring feedback helping athletes or military members check their STATs. The app will include a continuous glucose monitoring, dehydration, arrhythmias, and heat stat that can be read by the person to make modifications to their training. Her feedback gave motivation to include a real -time data component that military commanders can see and adjust depending on the results.

Yohah Lim, Cadet at West Point, gave his personal experience in military situations. He mentioned the need for a quicker way to communicate with his fellow soldiers. Currently a signal is passed back the battle formation line one by one till everyone in the squad receives the message.The battle formation spans over ¼ of a mile to ensure a single bomb will not take out an entire squad but makes communication extremely challenging and lengthy. From this interview, our group saw the need for a way to make communication more effective while decreasing time to send messages between soldiers.

Dr. Blake Schwartz, Lieutenant Colonel and professor at US Military Academy, gave an interesting commander perspective on military situations. Many of his points agree with Cadet Lim where a need for a better communication system is essential. His soldiers are spread out throughout the woods and there is an assigned point man that everyone looks at to receive messages. The soldiers have to turn away to see the message. Dr. Schwartz expresses the need for a way to keep all soldiers looking in the immediate area of danger and not have to turn to see a signal.

Ultimately combining all the information we collected over the course of the semester, our group decided on a nonverbal / non-line-of-sight hand communication device. The goal would be to allow soldiers and commanders to communicate in stealth environments and in areas where they are not in their line of sight. The device will encompass two parts: a soldier side and a commander side. The soldier will be boots on the ground wearing an IMU glove and a heads up display glasses.While the commander will be on an offset location with just an app installed on his phone. The IMU glove will track hand gestures and display it as a signal. This signal is then sent to the commander in which they receive it on the app. The commander can respond to the signal to notify the soldier the best course of action, appearing on their heads up display.

This method is first of its kind. As mentioned earlier, communication in the military relies heavily on antiquated technology. However, this device offers a new perspective, not currently available to the military. All aspects of this approach are novel from the soldier's IMU gloves , able to capture hand gestures, to their heads-up display glasses. Currently, no technology like this is used making this approach truly groundbreaking with immense potential to enhance the military.

One of the major overarching themes of the military is communication being insufficient. This device will solve the problem by allowing instantaneous communication to occur. The gloves will record and process in real-time the desired hand gestures that can be sent to the commander or other soldiers. This dramatically decreases communication time where signals will be received instantaneously rather than traveling a quarter of a mile. Another key aspect of this technology is the hands-up display glasses that allow signals to be displayed in their desired view rather than turning around to see the signal. This solves the problem of distracting or hindering the soldier from their target location and allows them to continuously look forward.

In stealth environments where silence is crucial, communication becomes extremely difficult. This device allows soldiers to communicate in those situations. Soldiers can now send messages without the need for verbal communications over radio, which could potentially give away their location. Instead, they can remain completely silent while maintaining effective communications.

The specifications for the design came from stakeholder meetings and mentor requirements. The device needed to help commander's make better, more informed decisions by providing access to additional information. The focus would be to provide additional information, not accessible by present means of communication, while decreasing time for communication. Additionally it was important that the device be first of its kind, introducing a new concept to the field. Furthermore, the device needed to be accurate 100% of the time, outperforming the technology it replaces, and easy to use. This criteria ensures the device meets the needs of the military while also excelling in terms of functionality, reliability, and ease of use.

Documentation of the Design

The design for our proposed nonverbal gesture-based communication tool consists of three main components: gesture recognition technology, the soldier interface, and the commander interface. Gesture recognition is the fundamental backbone, enabling the system to interpret and understand hand signals made by users. The soldier interface should ideally be intuitive and easy to use, serving as the conduit through which vital signals are transmitted silently and without line-of-sight. The commander interface provides a comprehensive overview of the hand signals being relayed by multiple soldiers. This capability would help commanders make informed decisions based on real-time information and mitigate the limitations of current communication tactics. The central focus of this project was using gesture data to achieve hand signal recognition, with the overarching objective of integrating this component into the soldier and commander interfaces envisioned for future development.

It was determined that a wearable sensor glove was most suitable and cost-effective for capturing gesture data. The team purchased a set of Rokoko Smart Gloves[1] to acquire hand position and orientation, modeling the envisioned future technology of sensors embedded in military-grade gloves. The glove design and movability is depicted in *Figure 1*. As users move their hands, the gloves transmit data to the software, which models the gestures in real-time rotating about the elbow joint. The gloves integrate inertial measurement unit (IMU) sensors alongside electromagnetic field (EMF) sensors for comprehensive motion tracking[1]. These sensors include accelerometers, gyroscopes, and magnetometers. The EMF sensors utilize small coils positioned on the gloves to create a local magnetic field, enhancing tracking accuracy through sophisticated algorithms[1]. This combination of IMU and EMF sensors ensures high-quality hardware tracking and provides precise finger positioning data.

Figure 1. Standard design of Rokoko Smart Gloves[1] worn by users to collect gesture data.

The first-party app, Rokoko Studio[2], was utilized for motion capture visualization and hand signal recording. The studio software connects to Rokoko Smart Gloves via WiFi and syncs movement with a virtual character that remains still from the elbow up[2]. The Rokoko Studio[2] streamlines the recording and storage of hand signal motion files to export data for analysis. An example of this software recording is shown by *Figure 2*, where the smart glove user is counting from zero to five.

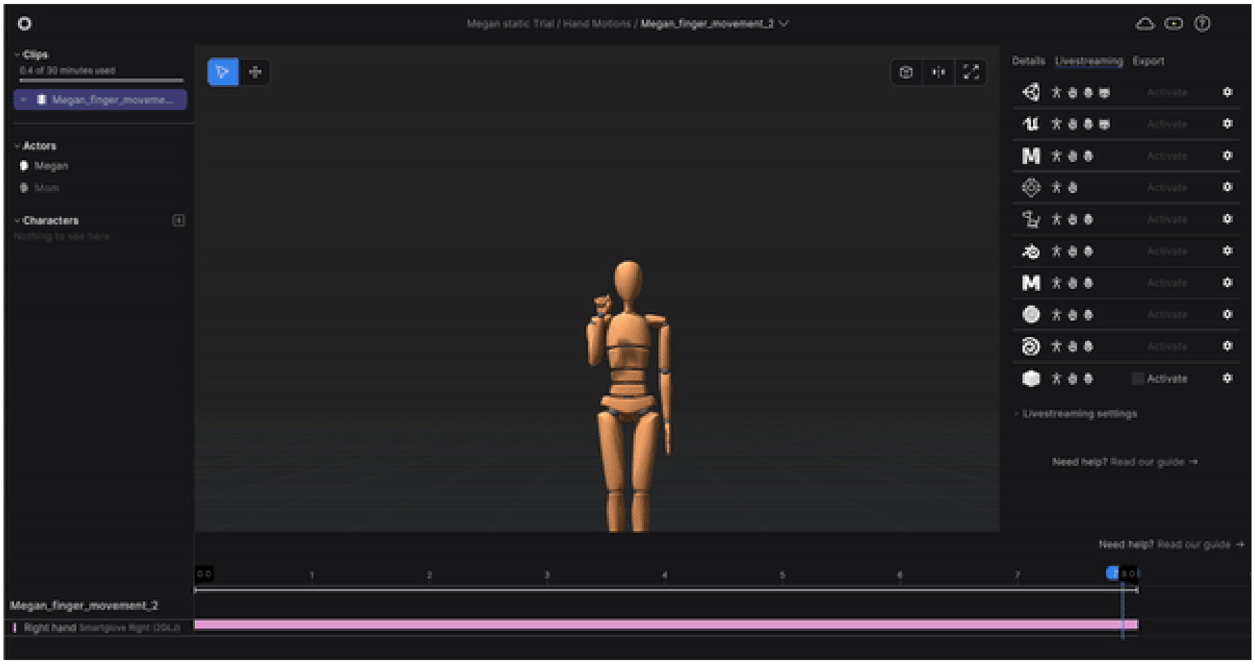

Figure 2. User interface of the Rokoko Studio application.

Recordings are exported as a Biovision Hierarchy (BVH) three-dimensional (3D) object files and then converted to Javascript Object Notation (JSON) format using the third-party app Filestar[3]. The conversion process ensures that the gesture data is compatible with integration into MATLAB for further processing and analysis. The JSON file version of the recordings describes the hierarchical structure of a skeletal model, containing meaningful data pertaining to the hands and fingers. The hierarchy starts at the “Spine” bone and descends down to the fingers. Each node in the hierarchy represents a segment of the body, with transformations specifying their position and orientation relative to their parent node. For instance, the hierarchy includes nodes such as “RightShoulder,” “RightArm", “RightForeArm,” and “RightHand,” representing the segments of the right arm leading up to the hand. Further down, there are nodes for individual fingers, such as “RightFinger1Metacarpal,” “RightFinger1Proximal,” “Right Finger1Distal,” detailing the segments of the thumb (Finger 1). This hierarchical structure offers a thorough depiction of the hand and finger anatomy, further detailed in *Figure 3*. The transformation within each node specifies translations and rotations, determining the position and orientation of each segment in reference to the previous segment.

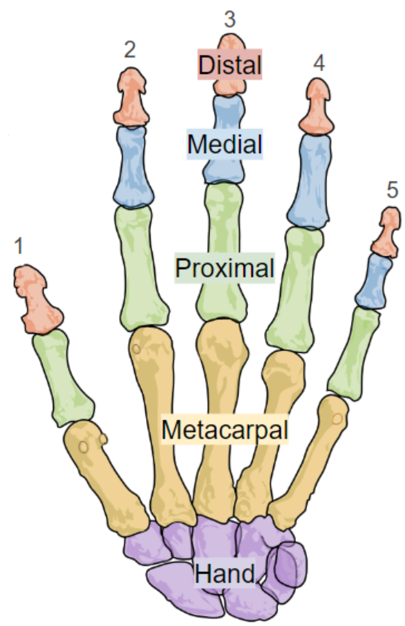

Figure 3. Labeling of hand and finger segments. Note: finger numbering starts at the thumb and progresses toward the pinky.

The gesture data contains a total of 22 segments pertaining to the arm, forearm, hand, and fingers with corresponding quaternion data. Each segment is listed below for the right hand in *Table 1*. A quaternion is a four-dimensional unit vector in the form [ω, x, y, z]. These values are derived from the transformation between nodes at each time point, recorded at a rate of 30 frames per second (fps). Quaternions were initially converted to Euler angles for the medial finger joints, providing a starting point for visualization and analysis. However, to maintain precision and accuracy in subsequent recognition techniques, raw quaternion data was used throughout.

Table 1. List of all data segments used to describe hand gestures.

1	Right Arm
2	Right ForeArm
3	Right Hand
4	Right Finger 1 Metacarpal
5	Right Finger 1 Proximal
6	Right Finger 1 Distal
7	Right Finger 5 Metacarpal

8	Right Finger 5 Proximal
9	Right Finger 5 Medial
10	Right Finger 5 Distal
11	Right Finger 4 Metacarpal
12	Right Finger 4 Proximal
13	Right Finger 4 Medial
14	Right Finger 4 Distal
15	Right Finger 3 Metacarpal
16	Right Finger 3 Proximal
17	Right Finger 3 Medial
18	Right Finger 3 Distal
19	Right Finger 2 Metacarpal
20	Right Finger 2 Proximal
21	Right Finger 2 Medial
22	Right Finger 2 Distal

Once the data was better understood, a library of static number hand signals was recorded. A total of 10 recordings were collected for five subjects, each approximately two seconds in duration. Each subject held a static number hand signal ranging from zero to nine according to the graphic in *Figure 4* from the U.S. Army training circular for Visual Signals (TC 3-21.60)[4].

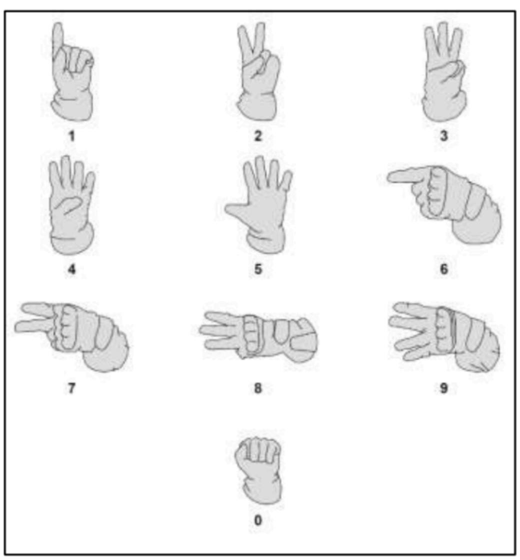

Figure 4. Guide to numerical hand signals zero to nine as published by the U.S. Army.

The smart gloves captured the gesture data corresponding to each number, providing a comprehensive dataset of diverse hand measurements for classification training. This dataset was analyzed using the MATLAB Classification Learner app, a tool designed to train models for classifying data using supervised machine learning techniques[5]. Quaternion values acted as predictors, with the hand signal number serving as the response variable. After processing through a fine decision tree, the resulting trained model was exported for further use.

This trained model achieved accurate prediction of numerical hand signals with a prediction output for each time point of a recording. To distinguish between held signals and noise resulting from transitions between hand positions, a specialized function was utilized. This function identifies blocks of repetitive data, enabling the differentiation of genuine signals and temporary fluctuations. It also provides the ability to decipher sequences of digits communicated through hand signals like "one-zero-one" (1-0-1) and multiple-digit numbers like "twenty-seven" (27). This capability enables the interpretation of complex numerical sequences conveyed through single-digit hand signals.

Once the system could handle static hand signals and sequences, the capability to decipher certain dynamic hand signals was pursued. A new library of moving hand signals was collected from one subject. These signals included the hand and arm motions commonly used by the U.S. Army[4] to communicate the commands "rally point," "move up," and "column formation," which are depicted in *Figure 5*.

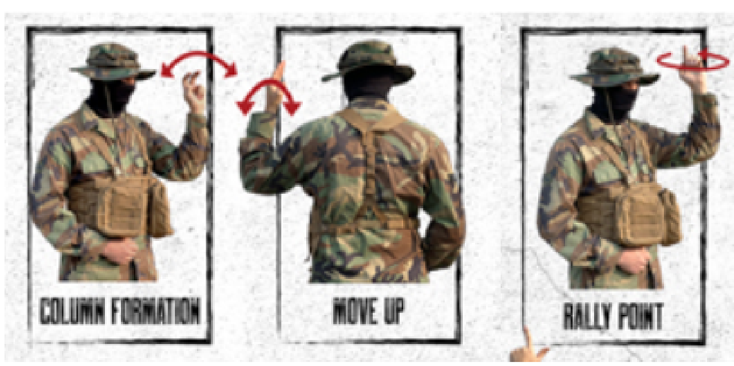

Figure 5. Guide to certain hand signals that require motion according to the U.S. Army.

An update to the data processing file included calculation of angular velocity from quaternion data at each time point. The magnitude of each angular velocity vector was calculated and included in the labeled training data with corresponding quaternion data. This training data matrix for dynamic signals was labeled with numeric responses for compatibility with machine learning, where the number “10” indicates “rally point,” “11” indicates “move up,” and “12” indicates “column formation.” A new model was trained separately from the classifier for static hand signals zero to nine. This capability enables the interpretation of dynamic hand signals that rely on motion to convey a message, demonstrating the potential for integrating additional signaling techniques.

The trained classification models were ultimately used to test and validate the effectiveness of the system demonstrating the feasibility of the concept. An assortment of test data was collected by recording separate trials of static number signals and sequences and dynamic hand signals that were not included in the training data. These recordings were exported from Rokoko Studio[2] as BVH 3D object files and converted to JSON files. All data processing capabilities were compiled into one MATLAB script file for ease. This script file appears in the appendix. The program prompts selection of a JSON file where the user can choose the test data recording. This file is then loaded and decoded in MATLAB. The quaternion data for the right hand, arm, and fingers is extracted and used to compute angular velocity magnitudes. In order to determine the correct trained model (static zero to nine or dynamic), the average of angular velocity magnitudes across all timepoints is compared against distinct threshold values. If the average angular velocity is low, this indicates minimal hand movement, so the file is processed through the static trained model to determine number predictions at each timepoint. The output is then blocked by repetition to recognize a singular number or a sequence of numbers. If the average angular velocity is high, then the data is processed through the dynamic trained model, which outputs the assigned numerical label of the moving hand signals. This value is then converted back to the command that it represents.

In the design aspect of this project, we were able to leverage wearable sensor technology and data programming to capture, analyze, and classify hand signals, achieving accurate prediction even for dynamic signals. The feasibility of our concept and its potential for enhancing military communication tactics was demonstrated. The design process reached its completion with the creation of a prototype, and the system underwent further testing and validation for completeness.

Prototype of the Final Design

Our prototype serves as a pivotal step in demonstrating the feasibility and potential impact of our nonverbal gesture-based communication system in military operations. Our current iteration features a MATLAB App, providing a visual representation of the tracking and processing of hand signals. This app, while basic in its presentation, offers viewers a more intuitive understanding of our system's functionality compared to raw code. It acts as a bridge between the technical intricacies of our algorithms and the practical application of gesture recognition in a military context. This sample design serves as a fundamental proof of concept, highlighting the robustness of our gesture recognition algorithm and the efficacy of post-processing techniques in deciphering and responding to predefined gestures. It is important to note that while this app serves as a demonstration tool for this presentation, it will not be a part of the final prototype, as the heads-up display will be the designated interface to display the signals in real-time.

Upon initiating the app, users are prompted to load a hand signal, which is then processed using our MATLAB-based coding process. The output, associated with the recognized hand signal, is then displayed for the user, showcasing the system's ability to interpret gestures and generate appropriate responses.

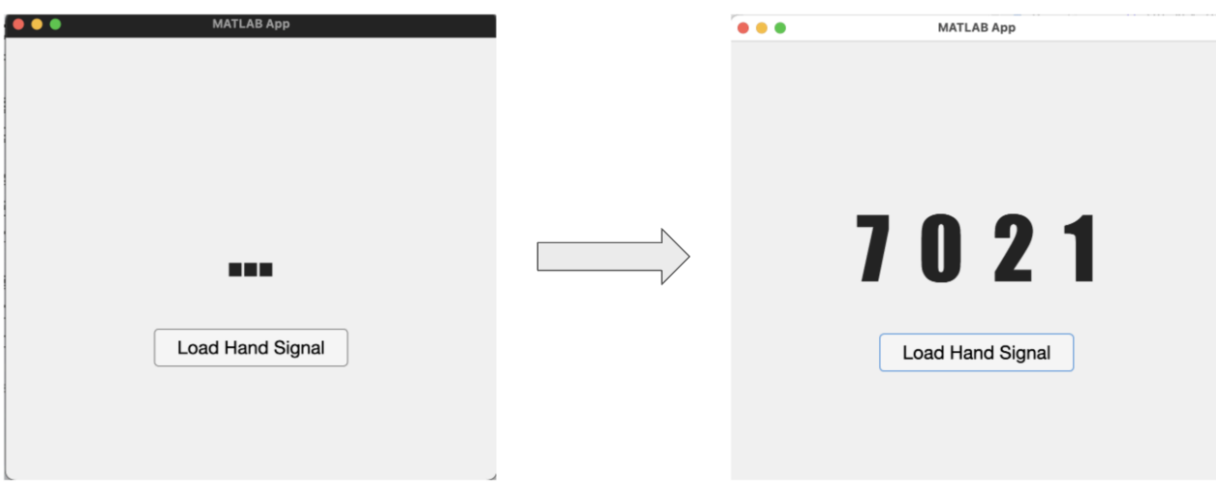

Figure 6. Loading of Hand Signal on MATLAB App and associated signal response.

A link to a zip file demonstrating the app's feasibility is provided in the appendix to further illustrate its functionality and usability.

Transitioning from this preliminary stage to our final prototype, we envision a comprehensive system comprising three key components: wearable smart gloves, a heads-up display (HUD) visor interfacing with the soldier, and a commander interface app. Our final prototype will evolve to incorporate live streaming capabilities, enabling real-time processing of hand signals regardless of environmental conditions. This advancement will empower soldiers with instantaneous communication, facilitating swift decision-making and response coordination on the battlefield.

The smart gloves, equipped with sensors to track hand, wrist, and finger movements, will serve as the primary input device for soldiers and the cornerstone of our communication system. Their design should ensure comfort and reliability, allowing soldiers to communicate effortlessly in dynamic battlefield environments. These gloves will seamlessly capture and transmit gestures to the HUD visor as well as the commander interface app, where communication signals will be displayed for the wearer or user, respectively.

The HUD visor, designed to overlay visual information onto the soldier's field of view, will provide intuitive and unobtrusive communication, enhancing situational awareness without distracting from the mission at hand. Displayed communication signals will provide soldiers with vital insights into enhanced situational awareness such as troop movements, enemy encounters, and strategic directives, which will empower them to make informed decisions in real-time.

Simultaneously, the commander interface app will enable commanding officers to receive and transmit communication signals to soldiers within their brigade. This app, accessible from offsite locations, will leverage advanced networking capabilities to relay commands and gather real-time updates from the field. Commanders can issue directives, gather intelligence, and assess the battlefield's evolving dynamics with unprecedented efficiency, facilitating rapid response coordination and mission execution. By bridging the gap between command and frontline units, our system ensures streamlined communication and enhanced operational effectiveness.

In a military context, these components would revolutionize communication and coordination on the battlefield. Here are two compelling examples of real-world scenarios where our communication system addresses critical military needs, validated through our collaboration with the US Army.

Scenario 1: Commander's Situational Awareness

In a dynamic battlefield environment, situational awareness is paramount for effective decision-making and mission success. Our nonverbal gesture-based communication system offers a revolutionary solution, enhancing the commander's understanding of the operational landscape. Imagine a scenario where a commander, overseeing multiple squads, seeks to gather real-time information about enemy encounters. With our system in place, the commander accesses the commander interface app from an offsite location. Through the app, the commander initiates a query to a squad leader, requesting details on the number and location of enemy forces encountered by their unit. The squad leader, equipped with our system's smart gloves, swiftly responds by inputting the relevant hand signals representing the encountered threat levels. These signals are processed in real-time and relayed back to the commander's app.

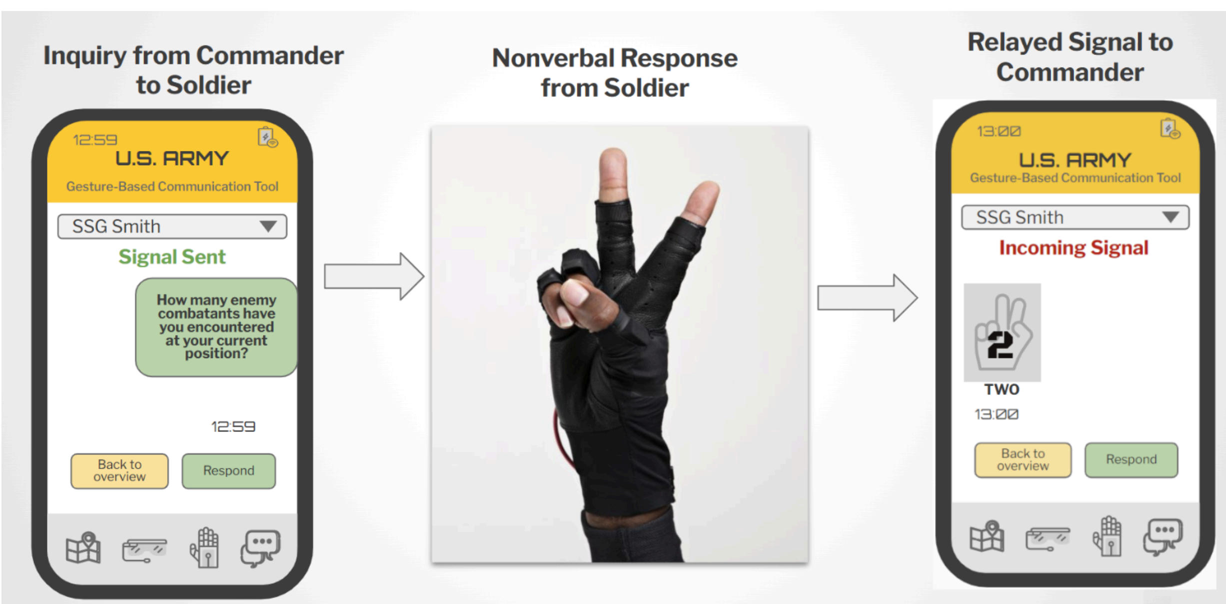

Figure 7. Input and relay side of Scenario 1: Commander's Situational Awareness.

Instantaneously, the commander gains a comprehensive understanding of the tactical situation, allowing for informed decision-making regarding troop movements, reinforcements, or strategic maneuvers.

Figure 8. Response / Commander decision side of Scenario 1: Commander's Situational Awareness.

The seamless interaction between the commander, squad leader, and frontline units exemplifies the transformative potential of our communication system in enhancing situational awareness and operational effectiveness on the modern battlefield.

Scenario 2: Stealth Mission Coordination

In covert operations, maintaining stealth and coordination are paramount to mission success and survivability. Our nonverbal gesture-based communication system offers a discreet and efficient means of communication, enabling seamless coordination among team members without compromising operational security. A potential use case of the system includes nighttime stealth missions. In such a mission, a squad which is led by a point man may encounter an enemy patrol or threat of some sort. In such a scenario, communication must be swift and silent to avoid detection and maintain the element of surprise. With our system deployed, the point man, equipped with IMU gloves, initiates a silent signal to halt the squad's advance upon sighting the enemy. This signal, detected by the HUD visors worn by each team member, instantly halts their movements without the need for verbal commands or a direct line of sight of the individual in front of you giving commands.

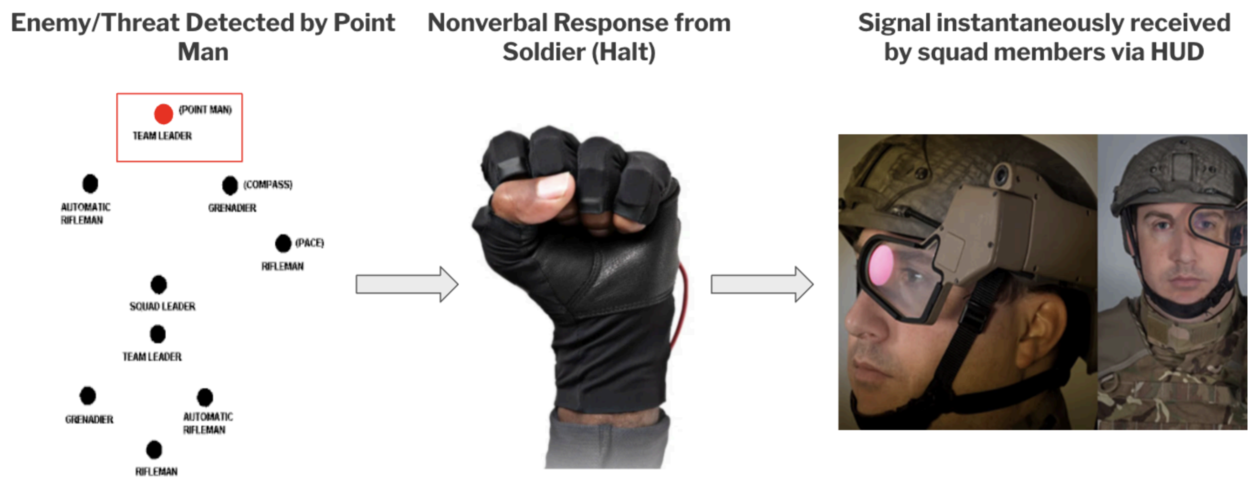

Figure 9. Outline of Scenario 2: Stealth Mission Coordination.

The squad maintains position, poised to react to any developments without alerting the enemy to their presence. Through the seamless coordination facilitated by the communication system, the squad navigates the hazardous terrain with precision and stealth, exemplifying the transformative potential of our technology in enhancing operational effectiveness and survivability in covert missions.

These examples are just the beginning of the potential use cases for the system. The opportunities for its utilization are vast and varied, limited only by the military's discretion and imagination. As we continue to refine and develop our prototype, we remain committed to unlocking the full potential of nonverbal communication in military operations.

Testing and Validation

The current prototype's proof of design and functionality hinges on the integration of the glove, machine learning code, and MATLAB app output. Future works to combat the overall problem and address broader challenges will include a functional commander app and a heads up display system. By revisiting the problem and objective, the design is supposed to enhance soldier communication to the commander and other soldiers using a novel sensor base system that can be integrated into army infantry soldiers. This project specifically focuses on a nonverbal communication tool that can produce common army commands and language.

One of the leading proofs of functionality is the classification of the different hand gestures used by the army. By leveraging machine learning with the obtained data, number gestures zero to nine, and three dynamic hand gestures can be classified at an accuracy of 99.9% and 100%, respectively. The training model accuracy and confusion plots can be seen in *Figure 10* and *Figure 11*. This shows that it is possible to recognize hand gestures at a high efficiency. Moreover, the system's adaptability is showcased by its capacity to accommodate additional gestures and training data, thereby enhancing its robustness and efficiency over time. This flexibility enables the army to tailor, expand, or innovate gestures based on evolving combat and infantry requirements.

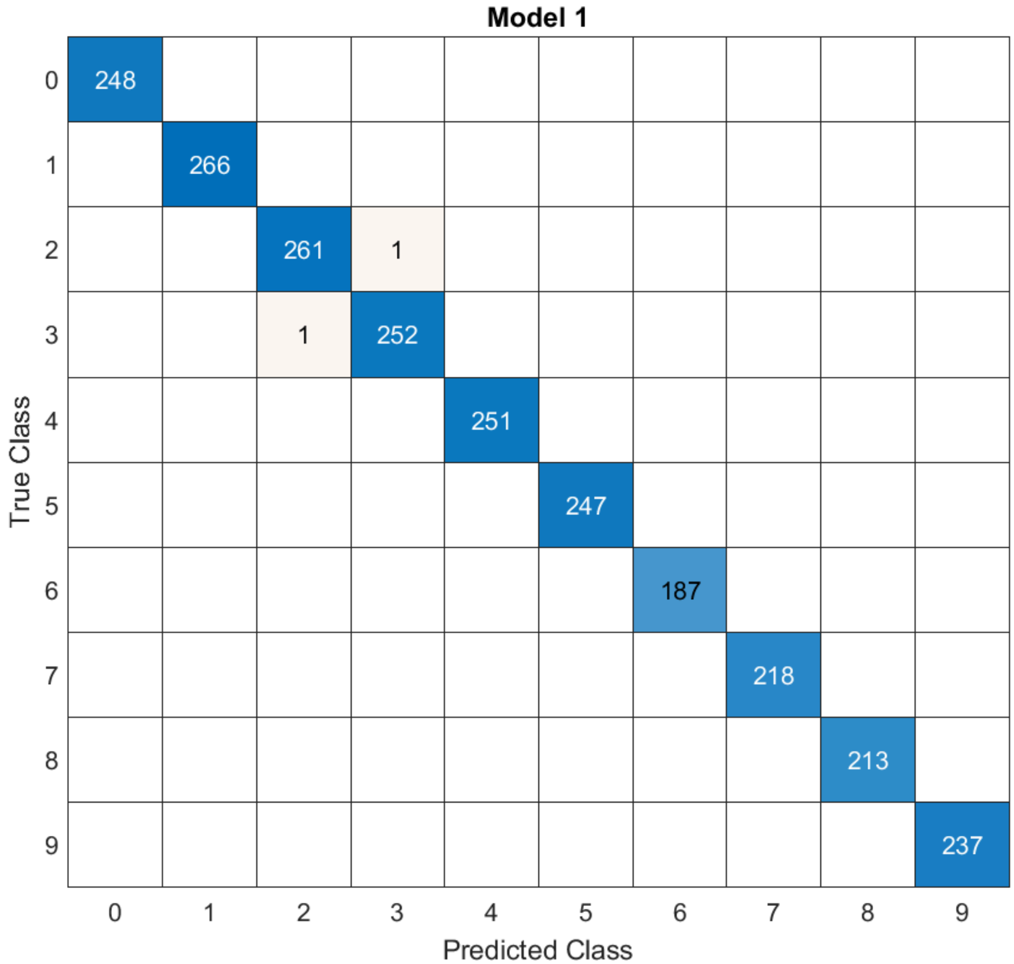

Figure 10. Confusion matrix for zero to nine classifier. Model trained with 5-fold cross validation using a fine decision tree. Achieved 99.9% accuracy with 2382 observations, 88 predictors, and 10 response classes.

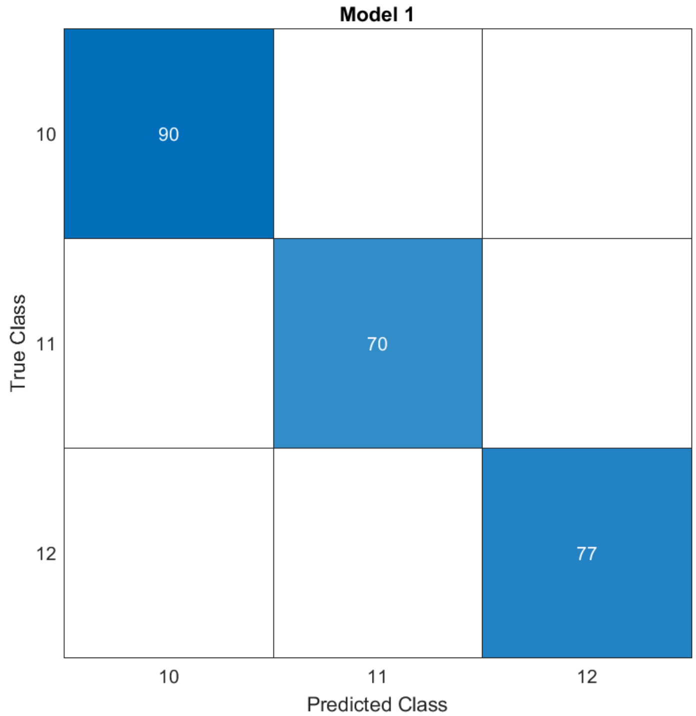

Figure 11. Confusion matrix for dynamic signal classifier. Model trained with 5-fold cross validation using a fine decision tree. Achieved 100% accuracy with 237 observations, 110 predictors, and three response classes.

True output and functionality can be seen through the MATLAB app, which seamlessly translates loaded hand gestures into actionable commands. In addition to assessing classification accuracy and analyzing confusion plots, we conducted straightforward testing to verify the functionality of our design. This involved labeling the .json file with the specific commands or sequences of numbers executed during the trial. By doing so, we were able to confirm the success of each trial by ensuring that the code and the app consistently and accurately output the corresponding gesture. This approach provided an additional layer of validation, reinforcing our confidence in the reliability and effectiveness of our system. For example, upon completion of a hand gesture trial where the participant performed the gestures seven, zero, two, one in sequence, the zero to nine training model was used and the MATLAB app exported 7 0 2 1 as shown in *Figure 6*. This output shows that the training models work. Integration of the numbers could mean multiple things. Numbers can be seen as is, if asked a question from the commander along the lines of, “How many enemy soldiers can you see in your position?” to where a soldier can respond with a gesture or gestures that represent the number. It can also be used as an iteration of numbers that are code for a pre-recognized signal or command. For example, a 1-1-1 signal sent back to the commander could mean heavy fire being received, extra backup is needed. The dynamic gestures already used by the army, like the ones seen in *Figure 5*, can be used in conjunction from soldier to soldier when they can't be seen by each other or are in stealth situations. Teams in the army are notated by numbers in their squad so a gesture command from the squad leader may look like, 4-'move forward gesture', which would notate soldier #4 to proceed and move forward. This allows soldier #4 to keep his eyes in front of him without looking back, or hearing a verbal command.

The functionality and proof of the core nonverbal communication can be seen through the use case examples, accuracy of the trained models, gesture library, and output. More work will eventually need to be done with the commander interface app, and integration of a heads up display to make this a fully functional system in real time infantry. As for now, one of the main goals was to show the proof of concept and possible ability, which has been done and the future problems and additions will work themselves out through technological advancements or integration.

Engineering Standards

The device will be implanted in a stealth, military environment where security, encryption, and durability will be on top most concern. Many engineering codes would need to be followed to ensure the device is well encrypted, will not give the soldier's location to enemy troops, and will hold up over many uses.

The first code to consider is **NIST SP 800-53:** Security and Privacy Controls for Information Systems and Organizations[6]. The purpose of this code is to give requirements to be followed in regards to security and privacy controls that agencies and organizations use to protect their information and data. It helps protect the information from security and privacy risk. Our device needs to follow these engineering standards to ensure that security is maintained and soldiers' location is safely guarded.

Another relevant engineering standard is **MIL-STD 461:** Requirements for Control of Electromagnetic Interference Characteristics of Subsystems and Equipments[7]. This code details specific emissions testing, susceptibility testing, and electromagnetic compatibility considerations requirements that need to be met before the military system can operate effectively. This code is important to be considered to ensure the device meets electromagnetic compatibility to avoid the device being susceptible to enemy interference helping to protect the soldiers.

Another code to consider is **MIL-HDBK-217**: Reliability Prediction of Electronic Equipment which outlines reliability of electronic equipment through the design process [8].It gives specific requirements on the failure rates and mean time between failures that needs to be carefully identified and measured to give an overall reliability of the military device. Our device is obligated to adhere to this standard because having the correct signal in an appropriate, fast time frame is essential for implementing the device into the military. Many of these signals that are displayed will be of utmost importance to making a calculated decision that could potentially put lives at risk, so ensuring repeated reliability needs to be closely monitored.

Additionally the specification of engineering standard **MIL-STD-810**: Environment Engineering Considerations and Laboratory Testing, requires careful consideration for our device[9]. The code outlines a series of tests that need to be performed on the device in order to measure the durability, reliability, and performance in military situations. The device will be subjected to extreme temperature, humidity, and impact, all of which the device must pass and still continue to operate effectively. To ensure compliance, the device must adhere to these guidelines ensuring that the device will not break when in military situations. The device needs to be designed to work in not ideal conditions and continue to work for a long period of time afterwards.

Results of Patent Search

A patent search regarding components of this system design yielded a basis of invention and technology in the area of gesture recognition. Additional research is required to identify patented technology involving augmented reality and digital applications with regards to the soldier and commander interfaces. Primarily, the focus of this project was placed on patents relating to the gesture recognition component.

The proposed system incorporates flexible smart glove technology invented by Ravi Shankar and Olivier Leneel and patented by STMicroelectronics Pte Ltd under U.S. Patent No. **9529433B2**[10]. This patent describes a special type of wearable technology that can detect fine hand and finger movements. This smart glove is thin and lightweight which permits the user to make hand gestures with ease and precision. The design incorporates capacitive microsensors built onto segments of pliable material at each finger joint that can measure strain on the back of the hand and pressure on the palm. Hand motion data is transmitted wirelessly from the glove to a microprocessor in real time.

The Rokoko Smart Glove used in our prototype is a wearable technology designed for motion capture applications. Sensors in the glove detect changes in position and orientation of the hands and fingers in real-time. They are commonly used in various industries such as animation, virtual reality, gaming, and biomedical research. The Rokoko Smart Glove incorporates technology outlined in the flexible smart glove patent to provide an intuitive and immersive way to record human motion for analysis. The trademark "Rokoko" registered under the serial number **86705121**[11] represents a brand associated with technologies and services related to motion capture, particularly in the fields of animation, virtual reality, and similar digital applications. Specifically in the prototype of our proposed system, the Rokoko Smart Glove is used to record hand gestures and access position and orientation data in the form of quaternions.

The technology responsible for automated gesture recognition is patented by the Glasgow School of Art under European Patent No. **1810217B1**[12]. This involves a quaternion-based technique that focuses on accurately recognizing gestures performed by users through analyzing sensor data. The system employs quaternion mathematics to represent and process the orientation of the user's hand movement in 3D space. The input gesture signature is systematically compared to the corresponding vectors of a series of library gestures stored in a database. This patent is significant in the field of gesture recognition, particularly for applications involving 3D motion analysis and interaction with digital interfaces. A similar process is incorporated with machine learning capabilities to achieve hand signal recognition in our proposed nonverbal gesture-based communication tool.

Anticipated Regulatory Pathway

For this novel device, FDA approval is not required. The FDA defines a medical device as "an instrument, apparatus, implement, machine, contrivance, implant, in vitro reagent, or related article"[13]. This glove system does not affect the users in any way alter the function of the body or intend to diagnose any medical disease or conditions. The intent of the device is to provide another source of communication for infantry soldiers, who have to be medically cleared to perform their job. When looking at the material, the glove uses common sensors and materials with nothing intravenous. Due to the intent of use and materials used, FDA approval will not be necessary.

Reimbursement

Being that the device is not a medical product it cannot qualify for medicare or medicaid. Since there is no doctor or patient, the cycle of care for the device is nonexistent. There is no promotion, prevention, diagnosis, treatment, management, and rehabilitation of any disease or injury with this product. If this device were to be used for medical purposes it could qualify under the HS 9027 code which refers to instruments and apparatus for physical or chemical analysis[14]. This is due to the fact that the glove data can give joint angles for medial, proximal, and distal sections of the fingers.

Ethics

In the development and deployment of our proposed nonverbal gesture-based communication system, several ethical considerations must be addressed to ensure the responsible use and effectiveness of the technology.

Moral concerns regarding accuracy and reliability are important in this design. The system's effectiveness in interpreting and responding to gestures directly impacts the safety of service members. It is essential to prevent misinterpretations of gestures that could lead to errors or misunderstandings in critical situations. This system would require rigorous testing and validation to minimize false positives and negatives, as well as ongoing monitoring and refinement to address any emerging issues. The system must not introduce distractions or burdens that could compromise situational awareness or decision making in high-pressure situations. In essence, prioritizing the accuracy and reliability in the design shows a commitment to the ethical obligation of protecting the safety and effectiveness of military personnel.

Protecting the privacy and data security of device users is a critical ethical consideration. The collection and processing of gesture data may raise concerns about the potential for unauthorized access, misuse, or breaches of sensitive information. Implementation of this system would require robust encryption, access controls, and data anonymization measures to safeguard situational data. Additionally, transparent communication about how data is handled among those using the system is essential for maintaining trust and compliance with ethical standards.

Ethical considerations regarding adaptability and accessibility revolve around ensuring that the system can accommodate the diverse needs and capabilities of device users. This includes designing the system to recognize a wide range of hand gestures and account for variations in hand size, shape, and dexterity. Efforts should be made to provide training and support so that all military personnel can effectively use the technology, regardless of physical abilities and backgrounds.

Maintaining human oversight and control of the system is essential for balancing the benefits of automation with the need for human intervention in complex or ambiguous situations. While automated gesture recognition can enhance communication efficiency, human oversight is necessary to confirm the accuracy and moral use of the system. Further development should consider providing users with the ability to override commands, clarify unclear gestures, and intervene in situations where the system may not be functioning as intended. Additionally, clear guidelines and protocols should be established to delineate the roles and responsibilities of the automated system technology and the humans using it.

Estimated Cost of Manufacturing

In considering the estimated cost of manufacturing for our proposed nonverbal gesture-based communication system designed for military application, we confront the immediate reality of our current product: Rokoko smart gloves, priced at $1,495 for a pair[1]. However, for our envisioned military deployment, soldiers would likely require only one glove each, given their other hand's occupancy with weaponry. Thus, while we can anchor our current cost assessment to the purchase of the Rokoko gloves, the transition to a comprehensive military solution necessitates a broader cost analysis.

Beyond the gloves, which represent the sole tangible expense at this stage, we must account for the integration of gesture recognition technology into the existing military gear, given that the current gloves will likely not be directly incorporated into military operations. This will require potential adjustments and modifications to accommodate sensors and electronics seamlessly into a suitable wearable that the soldiers will be willing to add to their current uniform. This will demand investment not only in components but also in labor for assembly and quality assurance processes to ensure reliability under rigorous military conditions. Rigorous quality assurance will be paramount to guaranteeing the functionality and durability of our system in high-stakes operational environments. Additionally, considerations for volume discounts, should production scale up as envisioned if the technology is utilized across the Army, could potentially mitigate per-unit costs.

Furthemore, the leap to our final product introduces substantial uncertainties, particularly regarding the incorporation of a heads-up display and the development of a commander interface app. The development of a smart visor incorporating heads-up display technology and the associated costs should be explored. Additionally, the development and deployment of the commander interface app, while having negligible ongoing costs, may require initial investment in software development. These advancements, while essential for military utility, currently elude precise cost estimation due to the lack of development and integration of these stages at this point in time.

Potential Market and Impact

In contemplating the potential market and impact of the communication system, its significance within military contexts worldwide is easily recognizable. With communication being the center of effective military operations, this system offers a revolutionary approach, particularly for infantry and special operations units. Pricing strategies for such critical systems will hinge on factors including manufacturing costs, competitive landscape, and the unique value proposition that the solution offers. Distribution channels are likely to involve government contracts, defense contractors, and established military procurement processes.

However, beyond the transactional aspects lie the core stakeholders: the customers and end-users. The former encompasses military organizations and governmental agencies responsible for defense procurement, while the latter primarily comprises the soldiers who will rely on our system in the field. It would be ideal if all foot on the ground soldiers could be equipped with the glove and heads-up display, maximizing communication efficiency and situational awareness across the entire force. However, if costs or logistics do not permit universal adoption, then at the bare minimum, the commander, squad leader, and potentially the point man should have access to this technology. Each level of the military hierarchy, from squad leaders to commanding officers equipped with the commander interface app, stands to benefit from enhanced communication capabilities. Moreover, within the tactical environment, individual soldiers, particularly point men or lead soldiers, will find immediate utility in our system's real-time communication features, potentially reshaping the dynamics of battlefield awareness and coordination. Thus, while the journey from concept to deployment remains uncertain, the potential impact of a nonverbal communication system on military operations is substantial, promising enhanced efficiency, safety, and effectiveness on the modern battlefield.

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Appendix

All Code: DEVCOM Capstone April 2024

Script File: trainedModel_dynamic.m

```
% This file reads JSON files and extracts quaternion and angular velocity
% data. Data is then run through respective trained classification model
% to predict static or dynamic hand signals of test trial videos. Signal
% output is determined by repetition and displayed as number sequence or
% signal name.

% Prepare workspace
clear all % clear workspace
clc % clear command window

%% Read in JSON file
[filename, pathname] = uigetfile('*.json', 'Select JSON data file');
fullFilePath = fullfile(pathname, filename);

fid = fopen(fullFilePath); % Open file
raw = fread(fid, inf); % Read raw JSON data
str = char(raw'); % Convert to character array
fclose(fid); % Close the file
data = jsondecode(str); % Decode JSON data

%% Extract quaternion and angular velocity data from hand/arm/finger channels
L = length(data.animations.channels(12).rotationkeys);
i = 1; % index
c = 0; % index
rot_key = [];

while i < 75
	rot_key_length = length(data.animations.channels(i).rotationkeys);
	if rot_key_length > 2
	c = c + 1;
	for sample = 1:L %
		rot_num =
(data.animations.channels(i).rotationkeys{sample,1}{2,1})';
		rot_key(sample,1:4) = rot_num;
	end
	q =
quaternion(rot_key(2:L,4),rot_key(2:L,1),rot_key(2:L,2),rot_key(2:L,3));
	ang = angvel(q,1/30,"frame"); % angular velocity

	segmentName = data.animations.channels(i).name;
	movement.(segmentName).q = rot_key; % quaternions
	movement.(segmentName).w = ang; % angular velocity
```

```
        movement.(segmentName).w_mag = vecnorm(movement.(segmentName).w,2,2); %
ang vel magnitude

        clear rot_key
        clear ang
        end
        i = i + 1;
end

%% Compile matrix of quaternion and angular velocity values
segmentNames = fieldnames(movement);

allq = [];
allw = [];

for j = 1:length(segmentNames)
        if j == 1
        allq = movement.(char(segmentNames(j))).q;
        allw = movement.(char(segmentNames(j))).w_mag;
        else
        allq = [allq, movement.(char(segmentNames(j))).q];
        allw = [allw, movement.(char(segmentNames(j))).w_mag];
        end
end

allq = allq(2:end, :); % remove first row of reference quats
alldata = [allq, allw]; % first 88 columns are quat, next 22 columns are w

%% Figure out if file is static one signal, static series, or dynamic and
display accordingly
avg_w = mean(allw(2:end,:));

if avg_w < 1
        disp('Static Hand Signal:')
        load('trainedModel_0to9_FINAL.mat');
        yfit = trainedModel_0to9_FINAL.predictFcn(allq); % Outputs yfit
        disp(mode(yfit))

elseif avg_w < 2
        disp('Static Hand Signal Series:')
        load('trainedModel_0to9_FINAL.mat');
        yfit = trainedModel_0to9_FINAL.predictFcn(allq); % Outputs yfit

        % Use findblocks function to determine series of signals.
        [block_ind, block_length] = findblocks(gradient(yfit)==0);
        kk = 1;
        for jj = 1:length(block_length)
        if block_length(jj) >= 20
```

```
            sequence(kk) = mode(yfit(block_ind(jj,1):block_ind(jj,2)));
            kk = kk + 1;
        else
        end
        end
        disp(num2str(sequence))

else
        disp('Dynamic Hand Signal:')
        load('trainedModel_dynamic_FINAL.mat');
        yfit_d = trainedModel_dynamic_FINAL.predictFcn(alldata); % Outputs yfit

        % Use assigned numerical values to show word signal
        if yfit_d(1) == 10
        disp('Rally Point')
        elseif yfit_d(1) == 11
        disp('Move Up')
        elseif yfit_d(1) == 12
        disp('Column Formation')
        end
end
```