Sign Language Glove with Visual Device

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Problem Statement & Background

Effective communication is essential for human interaction, yet many face significant barriers. American Sign Language (ASL) is a vital language for millions in the U.S. (estimated 6.4 to 7 million adults), but access to learning resources is often limited, impacting both deaf individuals and families (9 in 10) with deaf children. ASL has a rich history and growing recognition, and our engineering project addresses the need for improved learning tools; it employs an innovative Sign Language Glove and visual system, utilizing a machine learning algorithm to enhance ASL education in an engaging manner and bridge communication gaps.

Design Requirements

Technical Constraints: The flex and contact sensors must accurately capture finger movements, and the MPU6050 must precisely measure hand and wrist orientation. The microcontroller must have sufficient processing power for the sensor data. A significant challenge was the initial lack of understanding of machine learning algorithms.
Economic Constraints: The project was funded by the Engineering Dept ($400) and a NASA Space Grant ($544.20), which influenced the selection of components and the inclusion of a display monitor.
Time Constraints: The one-year timeframe limited the project’s scope to the 26 letters of the ASL alphabet. Ideally, the gesture database would be expanded in the future work.
Glove Material & Comfort: The glove must fit various hand sizes, be non-conductive, and ensure user safety and comfort.
Knowledge Constraint: The team had to learn the ASL alphabet and practice signing for accuracy.
Engineering Standards:

- **ISO/IEC TS 4213:2020:** Ensures the validity of classification performance and that the results meet recognized guidelines for accuracy and reliability in machine learning models.
- **National Electrical Code (NEC):** Proper installation of electrical wiring and equipment for safety and efficiency.
- **USB 2.0 Engineering Standards:** Communication protocols between the microcontroller and the PC, ensuring electrical safety, optimal power regulation, and efficient data transmission.
- **American Sign Language Content Standard:** This standard ensures the accuracy of the ASL instruction and representation in the educational tool.

Design Alternatives

Binary Code vs. Machine Learning Algorithm: A binary code representation of gestures was considered but discarded in favor of a machine learning algorithm. The machine learning approach was chosen for its enhanced ability to classify the complex patterns of human movement in ASL.
Camera Interface: A camera and image processing approach for ASL gesture recognition was considered. However, the glove and sensor system was selected due to its superior accuracy and user comfort. The camera-based approach was deemed less effective for real-time communication and capturing complex hand motions.
Glove Material: A rubber glove was considered for securing the sensors, but a wool glove was chosen for its comfort and fit. The rubber glove was thought to be a good choice because of its insulated material, but it was uncomfortable and not easy to put on and take off.

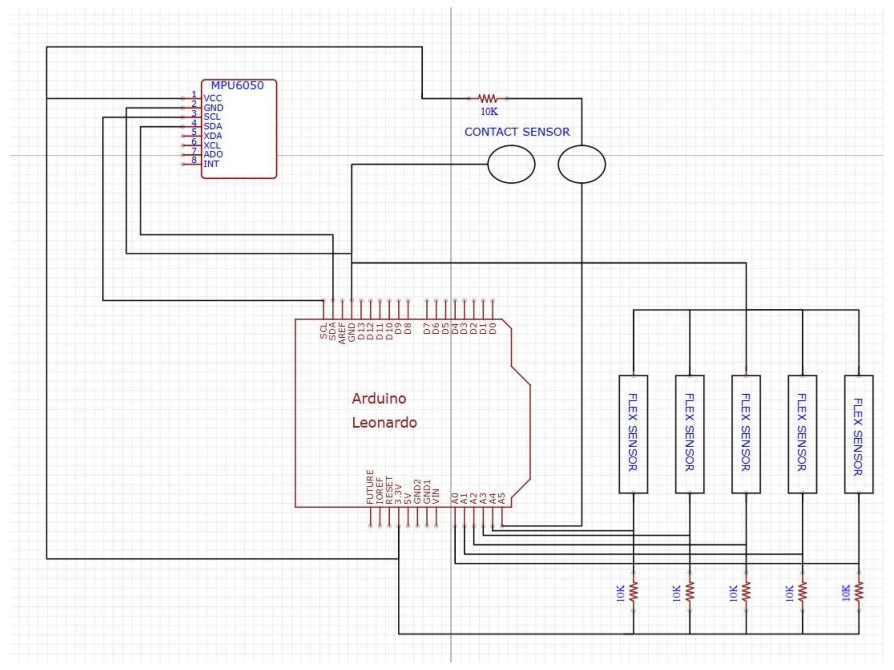
References

[1] R. Mitchell and T. Young, "How Many People Use Sign Language? A National Health Survey-Based Estimate," 2022.
[2] National Institute on Deafness and Other Communication Disorders, "American Sign Language," National Institutes of Health. [Online]. Available: https://www.nidcd.nih.gov/health/american-sign-language#:~:text=their%20sign%20languages.-,Where%20did%20ASL%20originate%3F,or%20Langue%20des%20Signes%20Fran%C3%A7aise).
[3] “ISO/IEC TS 4213:2022”. [Online]. Available: https://www.iso.org/obp/ui/en/#iso:std:iso-iec:ts:4213:ed-1:v1:en
[4] “The National Electrical Code (NEC)”. [Online]. Available: https://www.esfi.org/workplace-safety/industry-codes-regulations/the-national-electrical-code-nec/
[5] “USB 2.0 Specification”. [Online]. Available: https://www.usb.org/document-library/usb-20-specification..
[6] “K-12 ASL Content Standards”. [Online]. Available: https://aslstandards.org/standards/

Hardware Components

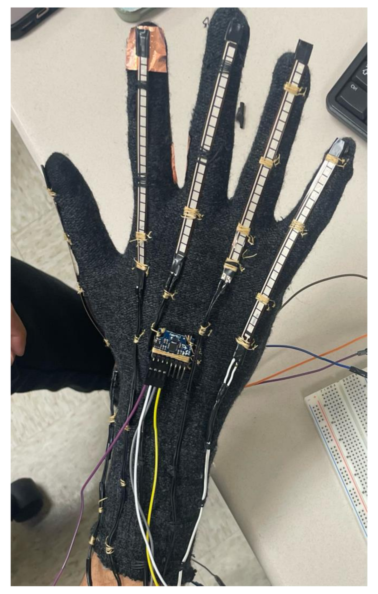
Arduino Leonardo: Microcontroller that collects and processes data from the glove's sensors. Acts as the "brain" of the glove system.
Flex Sensors (5): Measure finger bending. Part of a voltage divider circuit to determine resistance changes.
MPU 6050: 3-axis gyroscope and accelerometer. Measures hand and wrist movement and orientation.
Contact Sensor: Made of copper tape. Detects contact between specific finger locations. Provides additional data for gesture recognition.
Wool Glove: Provides a base for mounting the sensors. Chosen for comfort and flexibility.
Wiring: Connects sensors to the Arduino Leonardo. Transmits data from the sensors to the microcontroller.
PC: Receives data from the Arduino via USB. Used for data collection and processing. Will interface with the machine learning algorithm.
Visual Device: A portable touchscreen monitor that displays ASL learning prompts, receives glove input, and provides visual feedback.

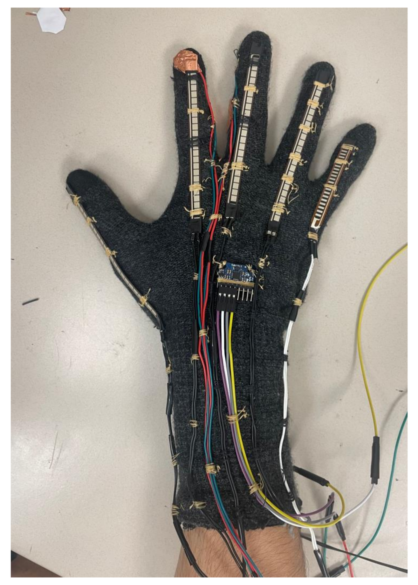
Glove Circuit Diagram



Glove Prototype Iterative Process


First Prototype


Second Prototype


Third Prototype

The overall development of the glove prototype consisted of changing the quality of the flex sensors, using different sewing techniques to stitch the equipment onto the glove in a more effective and efficient manner, the addition of the contact sensors on the index and middle finger, and the MPU6050 in the center. Because the glove was made of wool, it felt more comfortable when taking off and putting on, better adjusting to the user's hand. The glove was able to perform all the ASL alphabet gestures adequately, and the wiring was also stitched onto the glove to avoid any tangling or disconnecting of the wires system.

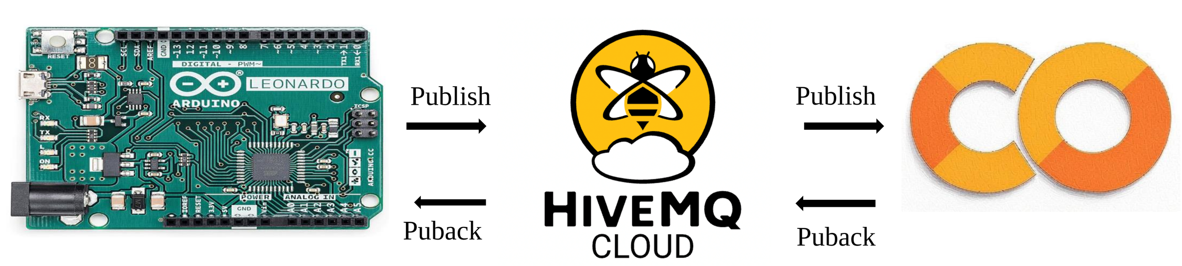
Software Components

Arduino Code: Code on the Arduino that processes sensor data and transmits it via HiveMQ Cloud.
HiveMQ Cloud: A broker that facilitates data communication between the Arduino and Google Colab.
Python Script: Script used to communicate with the Arduino, connect to HiveMQ Cloud, and run the machine learning algorithm (scikit-learn) for ASL gesture classification.
Google Colab: A platform for running the Python script and machine learning algorithm, providing libraries and processing resources.

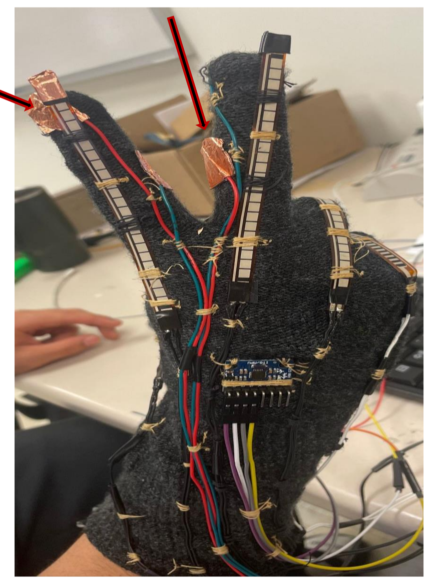
Machine Learning Algorithm

In our machine learning approach to ASL gesture recognition, we are evaluating Support Vector Machine (SVM) and Random Forest for classifying the 24 static letters of the ASL alphabet using data from glove sensors. SVM excels at establishing optimal decision boundaries in complex data, utilizing a 'one vs all' strategy for this multi-class problem. Random Forest, an ensemble learning method, enhances prediction accuracy and robustness by aggregating the outputs of multiple decision trees, which is valuable for handling the inherent variability in sensor data. Our ongoing work involves carefully engineering features from the sensor data to train and compare these two machine learning models for the accurate recognition of these 24 static ASL gestures.

Serial Communication to Cloud



Contact Sensors



On the left is the contact sensor that is used mainly to differentiate between letters U and V. On the right is the contact sensor that is used to mainly identify the letter R. These sensors are made of copper tape and were wrapped with a layer of electrical tape for additional precautions.

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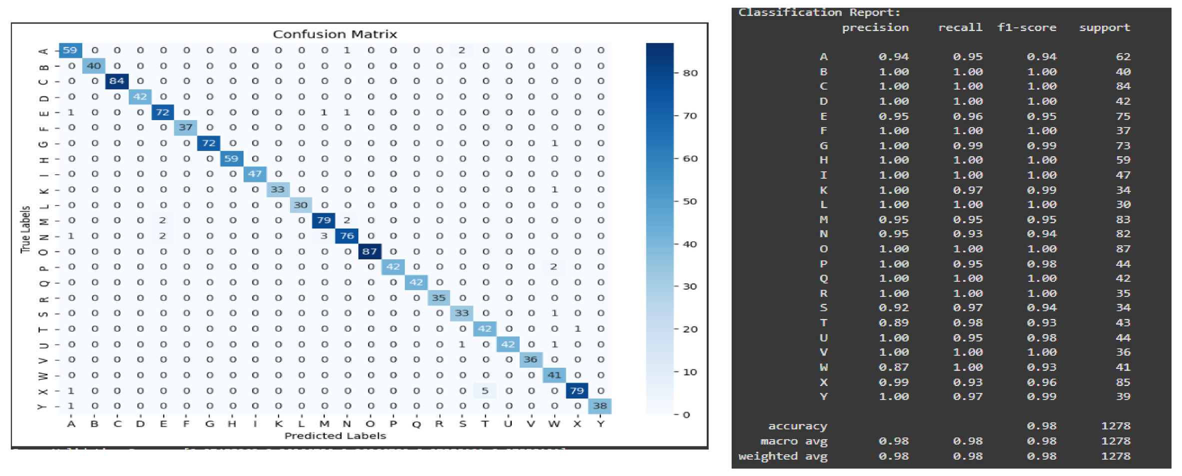
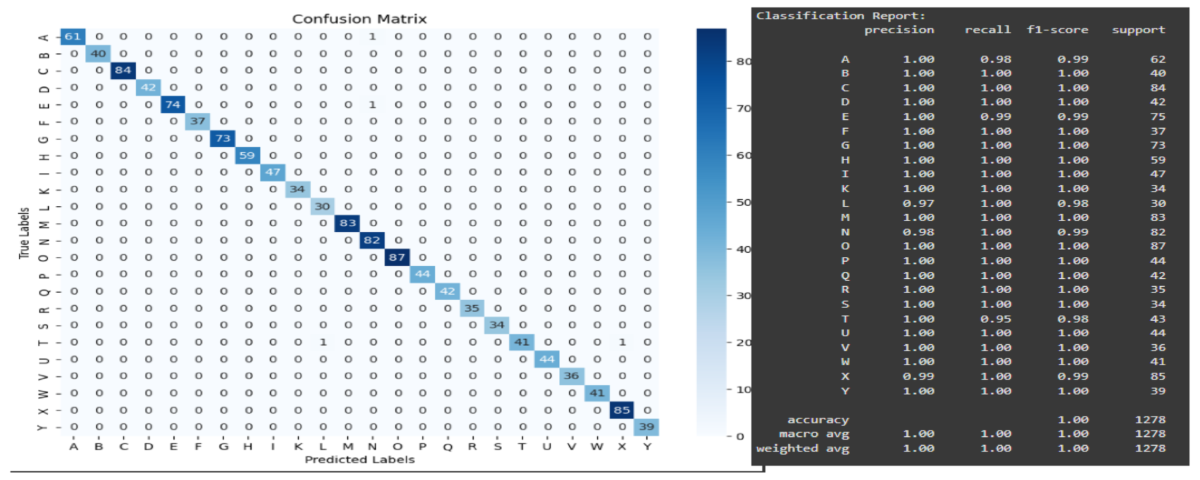
Results



SVC Algorithm Results



Random Forest Algorithm Results

While, Random Forest achieved slightly higher accuracy in this comparison, the Support Vector Classifier (SVC) is considered the better option. This is because the perfect accuracy exhibited by Random Forest across nearly all classes suggest a strong likelihood of overfitting. Overfitting means the model performs exceptionally well on the training data but may fail to generalize effectively to new, unseen data. In contrast, although SVC had slightly lower accuracy, its performance demonstrates a more balanced precision and recall across different classes. This indicates that SVC is a more robust model that is less prone to overfitting and likely to generalize better in real-world applications. Notably, both models successfully predicted most gestures, but encountered challenges with gestures involving similar finger bending, such as A, M, N, E, and X.

Conclusion & Future Work

We have successfully constructed a glove prototype that is comfortable and accessible. All of the sensors on the prototype function properly, there is real time communication from the Arduino board to Google Colab, and the machine learning model can properly identify 24 of the 26 gestures with the SVC algorithm.
Moving forward, our primary focus will be to expand the ASL database of the learning device to include letters J and Z, and even full words beyond the alphabet. Other opportunities include incorporating other sign languages beyond ASL. We believe this device can serve as a valuable resource to anyone interested in learning ASL.

Budget

Item	Quantity	Cost per item	Total	Part #	Vendors
Thin Film Pressure Sensor Flex Sensor	5	$7.76	$41.25	ZD10-100	Amazon
SparkFun Flex Sensor 2.2"	5	$14.95	$80.30	B074KN9PV9	Amazon
SparkFun Flex sensor 4.5"	5	$19.68	$108.4	SEN-08606	Mouser Electronics
Copper Foil Tape (2inch X 33 FT)	1	$9.99	$11.05	CFT-01	Amazon
Electrical Insulated Gloves	1	$10.79	$11.00	JSBAGGT	Amazon
MPU-6050	1	$6.49	$6.49	3-01-0122	Amazon
Solderless BreadBoard	1	-	-	-	Given by Andrew Musulin
Arduino Leonardo	1	$24.90	$24.90	A000057	Amazon
10 kΩ Resistor	6	-	-	-	EE lab
Wool Glove	1	$6.99	$6.99	B0CN5XM49M	Amazon
Wires	-	-	-	-	EE lab
Google Colab Pro+	1 month subscription	$49.99	$53.16	-	Google
Visual Device	1	$389	$389	MRPM-15602-T	Amazon
MYFON Micro USB Cable	1	$5.49	$6.28	680360118548	Amazon
1.5In x 16Ft Cinch Straps Heavy Duty With 20 Buckles	1	$9.99	$11.06	JINBO3805VCS	Amazon
TOTAL			**$758.88**		