Published by :
https://www.ijert.org/
An International Peer-Reviewed Journal

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14, Issue 06, ACSCON - 2026

Smart Glove With Augmented Sensory Feedback

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Abstract - The purpose of this paper is to create a wireless, gesture-controlled robotic hand system that emulates human finger movements in real-time. The developed system is based upon a smart glove which is fitted with five flex sensors that position each of the flex sensors in their appropriate position in relation to a finger, to evaluate the user's hand gestures. The analog signals are then processed by an Arduino nano microcontroller and wirelessly transmitted by the nrf24l01 rf communication module. The glove-based input method provides a user friendly, low-cost approach to control interfaces, making it easier for users to gain access, especially those with a physical deficit. A receiver unit is built around an Arduino uno which interprets the transmitted data and actuates five servo motors corresponding to the fingers of a 3d-printed robotic hand. This layout allows a finger movement that is exact and reactive, with a tiny amount of latency. System architecture: Its built-in portability, real time performance and ease of integration makes it suitable for a wide variety of applications including upper-limb prosthetics, remote robotic manipulation, nd assistive technologies. The combination has been able to solve problems and develop a solution for a scalable and user-friendly human–machine interaction via embedded sensing and wireless control.

***Keywords:*Human–machineinterface,Real-time actuation, Assistive technology, Bilateral coordination**

I. INTRODUCTION

The project aims to develop an innovative assistive device by integrating a smart glove with five flex sensors, an Arduino Nano, and a wireless communication system using an RF module. This device allows users to control a 3D-printed hand, which is actuated by five servo motors, with precise handmovements.Theflexsensorsonthegolvedetect the bending motion of the fingers, and the Arduino Nanoprocesses these signalsandwirelesslytransmits them to the receiver unit. The receiver, built on an Arduino Uno, interprets the data and controls the correspondingservomotorsin the3D-printedhandto replicate the user's hand movements in real-time.

This system holds significantpotentialfor applicationsin rehabilitation, whereit can assist individuals with limited hand mobility byproviding them with a means to control a 3D-printed hand. Additionally, it serves as a valuable tool in remote operations, allowing users to perform complex tasks without direct physical interaction. The combination of wireless transmission, real-time control, and 3D-printed robotics creates a versatile platform that can be further expanded to include features like sensory feedback, enhanced control algorithms, and even gesture recognition for more intuitive interaction.

Moreover, the modular architecture of the system allows for easy customization and scalability. Different types of sensorssuchasIMUs,pressuresensors,orhapticactuators can be integrated into the glove to capture additional movement nuances or to provide tactile feedback to the user. This opens doors for more immersive human–machine interfaces, especially in fields such as virtual reality,telemedicine,androbotics-assistedsurgery,where precision and responsiveness are crucial.

From an educational and research standpoint, the system serves as an excellent prototype for students and developers working in the fields of biomedical engineering, mechatronics, or human–computer interaction. It offers a hands-on platform to explore concepts like bio-signal processing, real-time embedded systems, and wireless communication. With further development,thesmartgloveandrobotichandsetupcould evolve into a low-cost, open-source solution for rehabilitationcentersandresearchinstitutionsworldwide.

A. Background

Gesture-controlled systems are increasingly popular in fields such as robotics, remote control, and human-computerinteractionduetotheirabilitytocreateintuitive, real-time interfaces. Among these, smart gloves have emerged as effective platforms for capturing finger and handmovements usingembedded sensors. Byconverting physical motion into electrical signals, such gloves can wirelesslycontrolexternalsystemslike3D-printedhands, making them useful for prototyping, industrial applications, teleoperation, and educational purposes.

In this project, we developed a smart glove system consisting of five flex sensors mounted on a glove, interfaced with an Arduino Nano. The sensor data is transmitted wirelessly via an nRF24L01 RF module to a receivingunitbasedonArduinoUno.Thisreceiver

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controls five servo motors embedded in a 3D-printed handtoreplicatetheuser'sfingergesturesinrealtime. The system operates on lowpower andisdesigned to be modular, cost-effective, and responsive, making it ideal for demonstrations of gesture-controlled robotics.

Beyond replication of basic finger movements, the system'sarchitectureprovidesa strong foundation for future enhancements such as gesture classification using machine learningalgorithms. Bycollectingand trainingonvarioushandmovementpatterns,theglove could recognize specific gestures and trigger pre-programmed actions, enabling hands-free control of smartdevices,prosthetics,orindustrialmachines.This would increase the glove's usability in assistive technology for individuals with limited mobility or speech impairments.

Furthermore, integrating feedback mechanisms such ashapticactuatorsorvibrationmotorswouldallowthe system to convey tactile sensations back to the user, closing the feedback loop. This bidirectional communication could significantly benefit rehabilitation scenarios, where real-time feedback on performance and progress is crucial. With continued refinement,thissmartglovesystemholdsthepotential to transform how humans interact with machines acrosshealthcare,automation,andimmersive virtual environments.

B. Objectives

The primary objective of this work is to design and implement a wireless, gesture-based control system for replicating human hand movements using a sensor-integrated glove and a 3D-printed robotic hand. The specific technical goals are as follows:

1. To develop a wearable glove interface equipped with five resistive flex sensors, each corresponding to a finger, for real-time acquisition of analog finger-bending data.

2. To interface the sensor array with an Arduino Nano microcontroller, responsible for analog-to-digital conversion, signal preprocessing, and wireless data packet formation.

3. To establish a low-latency wireless communication linkusingNRF24L01transceiver modules, enabling the transmission of multi-channel flex sensor data from the glove (transmitter) to the robotic hand (receiver).

4. To implement a receiver unit using an Arduino Uno, capable of decoding the incoming data stream and mapping it to precise servo motor control signals.

5. Toactuatea 3D-printedrobotic handusingfive servo motors, each calibrated to replicate the angular displacementcorrespondingtotheuser'sfinger flexioninnearreal-time.

6. To ensure system modularity, scalability, and low-cost deployment using open-source hardware components and standard communication protocols suitable for embedded control systems

II. LITERATUREREVIEW

Wearable glove-based systems have been extensively investigated for gesture acquisition and remote robotic control. Prior implementations typically employ embedded sensorstocapturefinger articulation, followed by wireless transmission to an actuation system for physical replication.

In [1], an instrumented glove utilizing piezoelectric sensors was developed to restore hand function through augmented sensory feedback. Although effective in detecting tactile events, the system was optimized for therapeutic applications rather than open-loop gesture replication.

Aflexiblestrainsensorcomposedofsingle-walledcarbon nanotubes embedded in a PDMS matrix was presented in [2]. This glove enabled real-time robotic control, but the system'shighfabricationcomplexitylimiteditsscalability for low-cost applications.

A soft robotic rehabilitation glove with vision-based intention detection was introduced in [3]. This method utilizeddepth-enhancedconvolutionalneuralnetworksfor multi-posture classification and control. While accurate, the approach required computationally expensive processing and external imaging hardware.

The work in [4] characterized commercially available bending sensors by evaluating their linearity and repeatability under controlled double-joint articulation. Results confirmed their suitability for wearable applications involving analog gesture encoding.

A servo-actuated embedded glove system intended for motor rehabilitation was reported in [5]. Thearchitecture involvedmicrocontroller-basedacquisitionofflexiondata and active joint control via DC servos. However, the implementation included feedback and assistance mechanisms oriented toward clinical use.

Unlike these approaches, the present work employs a reduced-complexity architecture, consisting of resistive flex sensors, analog acquisition via Arduino Nano, and RF-based data transmission to a receiver node (Arduino Uno), which performs direct mapping to servo actuation on a 3D-printed robotic hand. This configuration emphasizes real-time gesture mirroring, minimal latency, and open-source hardware integration for rapid deployment and testing in gesture-controlled robotic systems.

III. SYSTEMDESIGN

The proposed system is a wireless gesture-based robotic hand control architecture comprising two primary subsystems: (1) a transmitter unit embedded within a wearablesmartglove,and(2)a receiverunitresponsible

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forroboticandactuationanduserinstructiondisplay. Thesystemaimstoreplicatehumanfingermovements inrealtimeusinglow-cost,open-sourcehardwareand NRF24L01 RF communication.

A. TransmitterUnit:SmartGlove

Thetransmittersubsystemintegratesfiveresistiveflex sensors, oneperfinger,mountedonthedorsalsurface ofawearableglove.Eachsensoroperatesasavariable resistor, producing analog voltage variations proportional to finger flexion. These signals are conditioned through voltage divider circuits and fed intotheanaloginputchannels(A1–A5)ofanArduino Nano microcontroller. The onboard 10-bit ADC samples each channel, digitizing sensor values in the range of 0–1023.

The digitized values are packaged into fixed-length data packets and transmitted wirelessly via an NRF24L01 2.4 GHz transceiver module. The communication protocol utilizes a fixed channel and address configuration to maintain exclusive pairing with thereceiver. The transmitter ispowered at 3.3V througharegulatedsupplywithdecouplingcapacitors for noise suppression.

B. ReceiverUnit:RoboticHandControllerand Instruction Display

The receiver unit consists of an Arduino Uno interfaced with a second NRF24L01 module configured in receives mode. Upon reception, the microcontroller extracts five flex sensor values corresponding to each finger and maps them linearly to servo motor angles within a 0°–180° range, matching mechanical finger articulation.

Five SG90/MG90S servo motors connected to digital I/Opinsactuatetheindividual fingersofa 3D-printed robotichand.PWMsignalsaregeneratedwithprecise timing to ensure smooth and synchronized finger movement. The system operates on an external 5 V power source rated at ≥2 A to satisfyactuator current demands during simultaneous operation.

Additionally, an I2C-based 16x2 LCD display is connectedtothereceiverArduinotoprovidereal-time user instructions based on finger positions. Specific gestures trigger predefined messages to enhance interaction and convey user needs
intuitively:

- Littlefingerflexiondisplays“Washroom”
- Middlefingerflexion:“Emergency”
- Thumbflexion:“MedicineTime”
- Ringfingerflexion:“NeedFreshAir”
- Indexfingerflexion:“needwater”

These instructions are continuouslyupdated toreflect thecurrenthandposturewithoutaffectingtherobotic hand’scontrollatency.

C. CommunicationProtocol

The NRF24L01 transceiver modules interface with the microcontrollersviaSPI,operatingonafixedchanneland address for secure pairing. Data packets comprise five bytes—one byte per sensor—and are transmitted at 1 Mbps to balance communication range and robustness. Automatic acknowledgment (ACK) is disabled to reduce latency and maintain continuous data streaming. The system tolerates minor packet loss as sensor readings are sent continuously, ensuring up-to-date gesture information.

D. SystemArchitectureOverview

The overall system enables closed-loop, wireless gesture controlwithan end-to-endlatencybelow50ms,ensuring near real-timereplication ofhuman finger movementson the robotic hand. The modular design supports easy component replacement and future system scalability, such as incorporating additional sensors or enhanced feedback mechanisms. Byintegratingan LCDinstruction display,thesystemenhancesuserinteraction,deliveringa low-cost, efficient, and intuitive platform for gesture-controlled robotic actuation.

IV. METHODOLOGY

Thesmartglovesystem captures finger movementsusing five flex sensors mounted on a glove. An Arduino Nano processesthesensordataandtransmitsitwirelesslyviaan NRF24L01 RF module. The receiver unit, using an Arduino Uno, interprets this data to control servo motors attached to a 3D-printedrobotic hand. This setup enables real-time replication of gestures. The system is designed for intuitive control and is applicable in rehabilitation, assistive devices, and remote manipulation.

The smart glove system comprises two main units: the senderunit(glove)andthereceiver unit (3-Dprinthand).

1. SenderUnit(SmartGlove):Thisunitcaptures theuser'shandmovements.Flexsensorsareplacedonthe glove's fingers to detect bending, converting the finger movements into analog electrical signals. An Arduino Nano microcontroller reads these analog signals and processes them. The processed data, representing the degree of finger flexion, is then transmitted wirelesslyto the receiver unit using an NRF24L01 RF transmitter module. The sender unit is powered by a suitable power supply.

2. Receiver Unit (3-D print hand): This unit receives the movementdataandreplicatesitona3D-printed3-Dprint hand. An NRF24L01 RF receiver module receives the wireless transmission from the sender. An Arduino Uno microcontroller interprets this data and controls servo motors.Eachservomotorisattachedtoafingerofthe3D-printed hand, and their rotation corresponds to the finger

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bendingdetectedbytheflexsensors.Thiscoordinated movement of the servo motors allows the 3-D print hand to mimic the user's hand gestures. An optional LCD screen can be connected to the Arduino Uno to display information, such as finger angles or system status. The receiver unit is powered by an external power supply to provide sufficient current for the servo motors.

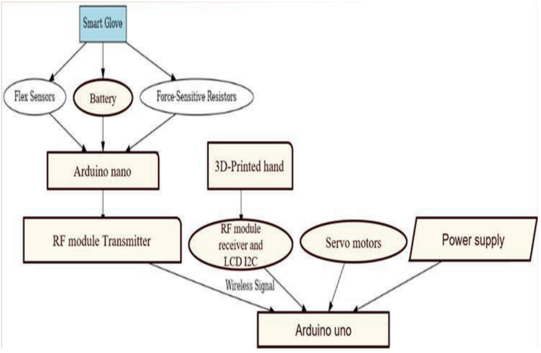

fig1:BlockdiagramofSmart-glovewithaugmentedsensoryfeedback

A.OverallSystemArchitecture

The smart glove system uses a wireless bilateral coordination framework to control a 3D-printed robotic hand in real time. Flex sensors on the glove detect finger movements, which are processed by an Arduino Nano and transmitted via NRF24L01 RF modules.AnArduinoUnoreceivesthedataanddrives servo motors to replicate gestures. An I2C LCD provides feedback on hand positions and system status. The architecture is low-power, precise, and suitable for applications in rehabilitation, teleoperation, and assistive robotics.

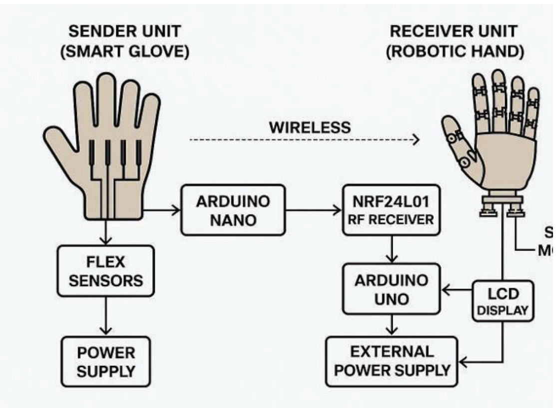

fig 2: Systemarchitectureofsmart glovewithaugmentedsensoryfeedback

1.SenderUnit(SmartGlove)

Thesenderunitusesflexsensorsplacedontheglove's fingers to detect hand movements by measuring changes in resistance during bending. These signals are converted to voltage via a voltage divider and read by an Arduino Nano. The microcontroller processes, calibrates, and formats the data, then transmits it wirelessly using an NRF24L01RFmodule.Thisenablesreal-time,untethered controlofthe3D-printedhand.Thesystemismodularand supports future upgrades with additional sensors for enhancedgesturerecognitionandapplicationsinVR,AR, and robotics.

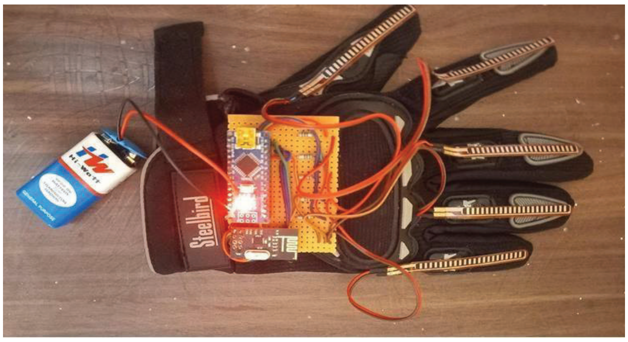

fig3:Smart glove.

2. ReceiverUnit(3D-PrintedHand)

The receiver unit uses an **NRF24L01** module to receive motion data from the smart glove. An **Arduino Uno** processesthisdatatodeterminefingeranglesandcontrols **servomotors** thatreplicatetheuser'shandmovementson a3D-printedhand. An optional**LCD display**shows real-timefeedbacksuchasfingeranglesandsystemstatus.The system can be expanded with **Bluetooth or Wi-Fi** for cloud connectivity or mobile app integration, making it adaptableforapplicationsliketelepresence,rehabilitation, and assistive robotics.

fig4: 3-DPrint hand.

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V. RESULT

The smart glove system efficiently taken the individual finger movements by using five flex sensors placed on the glove. These sensors produced analog signals which is linear to the degree of finger bending. The **Arduino Nano** operates on the signals, by converts them into digital data. The data was transmittedwirelesslyvia **NRF24L01modules** tothe receiver, were the exchange of data was reliable and real-time communication. The system exhibited accuracy and independent tracking for finger flexion, which forms a robustframeworkforgesture with multiplication usingthe3D- printedhand.

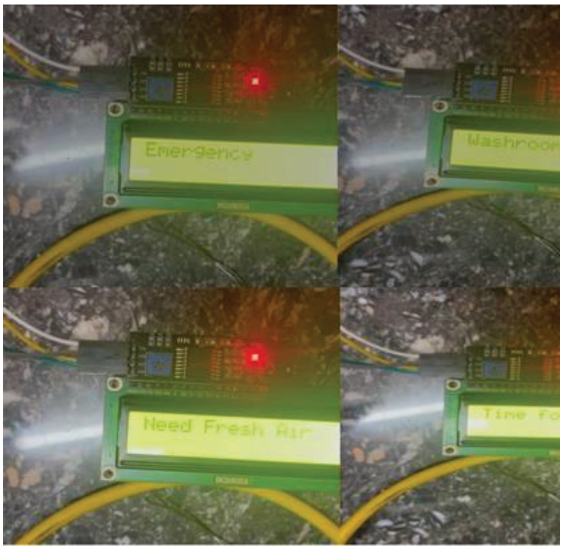

fig5:Gestureinstructionsdisplayed

VI. CONCLUSION

The smart glove technology successfully exhibited the practical and effective approach to process a 3-D printed robotic hand by the use of individual finger flexion. The sensed and Multiplied through the use of flex sensors and Arduino microcontrollers, which resulted in the real-time captured of the hand gestures.

The design of the project creates new doors to a more dynamic approach to robotic hand control, where it has been in practical uses in rehabilitative and assistance technology applications.

This project with an objective to improve upon the common disadvantage in 3-D printed hand systems.

Among these are the insufficient user controls, excessive wiring, and usage of insufficient of real-time responsiveness, leading to confusion and inefficient movement.

The new system has been brought here as a project to a step up as afrom this problem.

A.FUTUREWORKS

1 To Increase the performance a sensor and decrease the drift by high resolution sensors with advanced calibration approaches included

2. To Install haptic feedback technologies for enhancement , realism and speed of the interaction provided by the system.

3.To Increase the control algorithm for precision and dexterity of hand's actions, which possibly going beyond linear control.

Linear increase of the wireless capabilities by considering Bluetooth technology for controlling the device remotely through a smart phone application.

4. To Consider machine learning algorithms that can be used for gesture detection and predict to develop more intuitive controls.

5. Utilize for incorporation of further in order to bridge a wider range of data inputs and feedbacks from the user & environment

VII. REFERENCES

[1]. O. N. Zestas, N. Souvatzis and N. D. Tselikas, "A Smart-Glove Approach in Upper limb Rehabilitation Assessment,"2024PanhellenicConferenceonElectronics & Telecommunications (PACET), Thessaloniki, Greece, 2024, pp.

[2].V.S.Sooraj,H.J.MagadumandL.Alluri,"iTouch – Blind Assistance Smart Glove," 2021 10th International Conference on System Modeling & Advancement in ResearchTrends(SMART),MORADABAD,India,2021, pp.

[3]. E. Rho et al., "Multiple Hand Posture Rehabilitation SystemUsingVision-BasedIntentionDetectionandSoft-Robotic Glove," in IEEE Transactions on Industrial Informatics, vol. 20, no.

[4],pp.4.VendrameE,ColettiA,CappelloL,MastinuE, Cipriani C. “A Wearable Device for Hand Sensorimotor Rehabilitation Through Augmented Sensory Feedback”. IEEE IntConfRehabil Robot. 2023 Sep.

[5].VendrameE,CappelloL,MoriT,BaldiR,Controzzi M, Cipriani C. “An Instrumented Glove for Restoring Sensorimotor Function of the Hand Through Augmented SensoryFeedback”.IEEETransNeuralSystRehabilEng. 2024

[6].S.KumarT.,S.B.Arun,G.S.Jatadhara,A.Majumder and A. Dhar, "Design and Fabrication of Rehabilitation-basedExoskeleton for ParalyticArm,"2020International Conference on Smart Electronics and Communication (ICOSEC), Trichy, India, 2020, pp.

[7]. M. Borghetti, N. F. Lopomo and M. Serpelloni, "CharacterizationMethodforBendingSensorAppliedfor Smart Glove," 2024 IEEE International Workshop on Metrology for Industry 4.0 &IoT (MetroInd4.0 &IoT), Firenze, Italy, 2024, pp.

[8]. Baloda, Suraj et al. “Development of SWCNTs/PDMS Composite Strain Sensors Integrated SmartGloveforHuman-MachineInterfaceApplications.”

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 14, Issue 06, ACSCON - 2026

IEEESensorsJournal25(2025):2400-2407.

[9]. K. Umapathy, D. K. Sri, G. Poojitha, A. S. Samvida, D. M. Sharma and S. B. S. Sairam, "Rehabilitative Embedded Hand Glove for the Paralyzed," 2023 5th International Conference on Smart Systems and Inventive Technology (ICSSIT), Tirunelveli, India, 2023, pp. 27-31, doi: 10.1109/ICSSIT55814.2023.10061056.

[10]. Vendrame E, Cappello L, Mori T, Baldi R, Controzzi M, Cipriani C. An Instrumented Glove for RestoringSensorimotor Function oftheHandThrough Augmented Sensory Feedback. IEEE Trans Neural System Rehabilitation Eng. 2024..