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Innovative Smart Gloves–Based Assistive Technology for Real-Time Sign Language to Text Conversion

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ABSTRACT: Communication between deaf and mute individuals and normal speakers is a major challenge due to the lack of understanding of sign language. To overcome this problem, an innovative smart gloves based assistive system for real-time sign language to text conversion is proposed. This system uses smart gloves embedded with sensors to detect hand and finger movements used in sign language. The gloves is outfitted with flex sensors than gather information about the gestures. The sensed data is processed using a microcontroller to recognize gestures and convert them into corresponding text output in real time. The proposed system is portable, cost-effective, and user-friendly, making it suitable for daily communication. This technology helps reduce communication barriers and promotes social inclusion of hearing-impaired individuals.

KEYWORDS: Smart Gloves, Gesture Recognition, Flex Sensors, Microcontroller and Wearable Device.

I. INTRODUCTION

Gesture-based control is an emerging technology that enables natural and effortless human–machine interaction by allowing users to communicate with electronic systems through simple hand movements instead of buttons or switches. This project develops a wearable gesture-recognition glove that interprets hand motions and converts them into digital commands in real time. The system is designed to be portable, efficient, and user-friendly. At its core, the STM32 microcontroller processes input signals from flex sensors, which detect finger bending, and the MPU6050 sensor, which captures hand orientation and motion. These sensors together provide comprehensive gesture data for accurate recognition. The processed output is transmitted wirelessly via the HC-05 Bluetooth module to a mobile serial terminal application, ensuring flexibility and ease of use. The system is powered by an 8.4V Li-Po battery with a step-down converter to safely regulate voltage to 5V for the components. This portable power setup enables continuous operation without external adapters. Overall, the project demonstrates effective integration of sensors, microcontroller processing, and wireless communication to create a compact and reliable gesture-based control system.

II. RELATED WORK

Gupta et al. have presented a smart glove–based sign language translator to reduce communication barriers faced by deaf and mute individuals. The system uses MPU-6050 sensors with an Arduino Nano microcontroller and an ESP8266 module for real-time data transmission. The authors suggest using flexible sensors, improved glove design, and hybrid AI models to enhance accuracy and efficiency [1].

Dinesh et al. have developed a wearable device for real-time translation of Indian Sign Language into speech using machine learning techniques. The system uses flex sensors and an MPU-6050 with Arduino and Raspberry Pi for gesture detection and processing. The authors highlight expanding the dataset and improving portability for better performance [2].

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Karthik et al. have demonstrated a smart communication glove for translating sign language into text and speech for hearing- and speech-impaired individuals. The system uses flex sensors and accelerometers with an Arduino microcontroller and pattern-matching algorithms for gesture recognition. The authors advise supporting dynamic gestures and integrating advanced machine learning models [3].

Sharma et al. have presented an IoT-enabled smart glove for real-time sign language to speech conversion. The system uses flex and motion sensors with an Arduino controller and ESP module for wireless communication. Gesture recognition is performed using rule-based and basic machine-learning techniques. The authors suggest improving sensor precision and adopting advanced AI models [4].

Meena et al. have designed a hybrid gesture recognition system combining vision-based and wearable glove approaches. The system uses camera-based image processing along with sensor data to improve accuracy. Machine-learning algorithms analyze gestures, and embedded processing generates text and speech output. The authors highlight optimizing power usage and reducing system complexity [5].

Kumar et al. have Implemented a gesture-controlled virtual telepresence robot for remote operation using hand gestures. The system enables real-time wireless communication with video and audio transmission. It is useful in healthcare, surveillance, and disaster management applications. The authors recommend its effectiveness in reducing human risk in dangerous environments [6].

Kumar et al. have developed a low-cost smart glove for basic sign language recognition using flex sensors and an Arduino Uno microcontroller. Gesture recognition is performed using threshold-based methods, and output is displayed on an LCD. The authors suggest adding wireless communication and machine learning techniques for improvement [7].

Al-Khalifa et al. have presented a smart glove system for sign language recognition using machine learning. The system uses flex sensors and an MPU6050 with Raspberry Pi for processing. Classification algorithms such as SVM and RNN are used, supporting multiple sign languages. The authors advise further optimization for scalability [8].

Suresh et al. have designed a wearable smart glove for communication assistance using flex sensors and an ESP8266 microcontroller. The system converts gestures into pre-recorded voice messages using a voice playback module. However, it supports only fixed messages and lacks dynamic speech generation. The authors highlight its simplicity and cost-effectiveness [9].

Patel et al. have demonstrated a sensor-based wearable sign language translator using MEMS sensors for capturing hand movements. The system uses embedded processing to recognize gestures and convert them into text and speech outputs. The authors suggest using deep learning techniques and expanding datasets for improved performance [10].

The research papers reviewed highlight the development of smart glove–based systems for sign language recognition and gesture-based communication. These systems commonly utilize flex sensors, motion sensors such as MPU6050, microcontrollers, and wireless modules along with machine learning techniques to enable real-time gesture detection and conversion into text or speech. However, common challenges include limited gesture vocabulary, reduced accuracy for dynamic or complex gestures, sensor noise, and higher computational requirements in machine learning–based systems. It can be proposed to improve system performance by enhancing sensor accuracy, integrating advanced deep learning models, expanding gesture datasets, and optimizing power consumption. Additionally, incorporating wireless flexible sensors, improving ergonomic design, and enabling multilingual support can further enhance usability and effectiveness.

III. PROPOSED METHODOLOGY

The Smart Glove–based system is developed to enable real-time sign language to speech conversion by capturing and processing hand gestures efficiently. At its core, an STM32 microcontroller manages the flow of sensor data, communication, and output generation, creating a seamless interaction between the user and the system. The fig 1. represents an 8.4V Li-Po battery, formed by connecting two 4.2V cells in series, and regulated using a step-down converter to provide a stable 5V supply. This ensures reliable operation of all components while maintaining portability.

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By integrating sensing, processing, and wireless communication, the system provides an effective solution for real-time gesture-based communication.

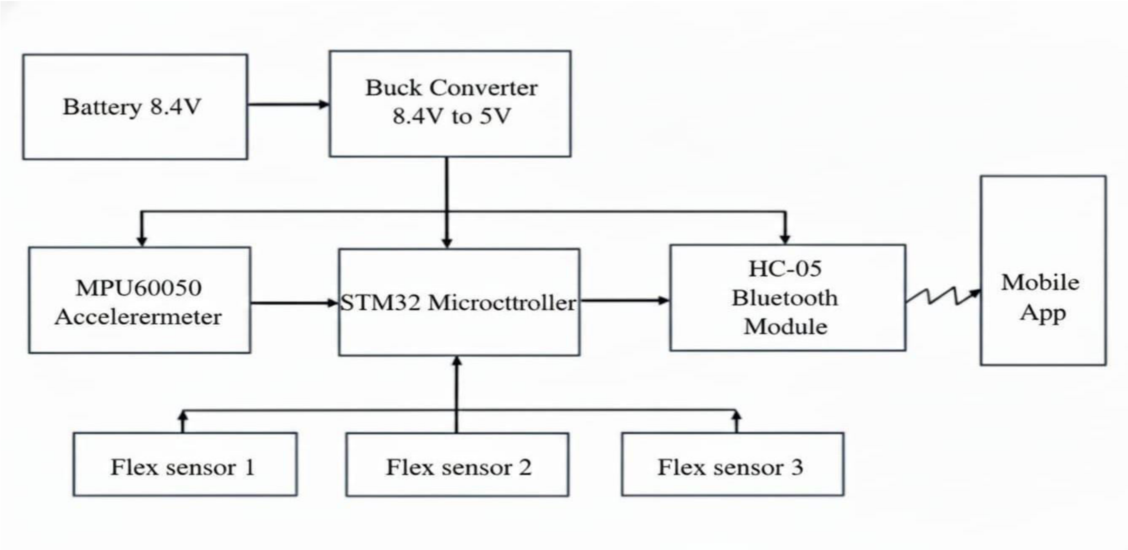

Fig .1: Block diagram of Real Time Sign Language to Text Conversion

At the outset, the system captures gesture data using flex sensors and an MPU6050 motion sensor integrated into the glove. The flex sensors continuously measure finger bending by generating variable analog signals, while the MPU6050 records hand orientation, tilt, and acceleration. These sensors together provide a complete representation of the user's hand movements. The STM32 microcontroller acts as the main processing unit, collecting, filtering, and analyzing the sensor data to identify specific gesture patterns. Once a gesture is recognized, the microcontroller generates a corresponding command and transmits it to the HC-05 Bluetooth module. The Bluetooth module then sends the processed data wirelessly to a mobile serial terminal application, where the output is displayed in real time.

IV. HARDWARE DESCRIPTION

STM32 Microcontroller

The STM32 is a family of 32-bit microcontrollers developed by STMicroelectronics, based on the ARM Cortex- M processor core. It offers high performance, low power consumption, and a rich set of peripherals. The fig.2 represent STM32 supports multiple communication interfaces such as UART, I2C, SPI, and has built-in ADC, timers, PWM, and GPIO pins for interfacing with sensors and actuators. It also provides good processing speed, reliable real-time performance, and several low-power modes, making it ideal for battery-powered projects.

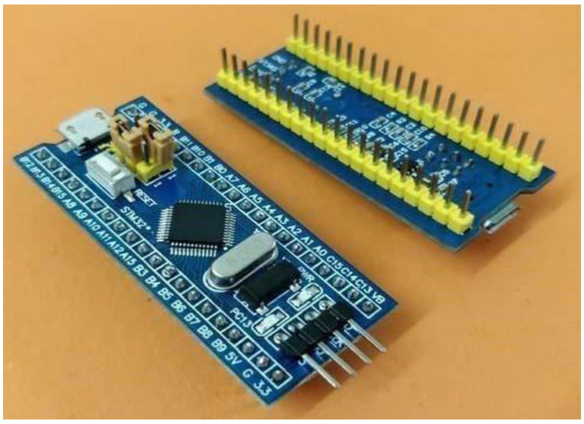

Fig .2: STM32 Blue pill MC

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HC-05 Bluetooth

The HC-05 is a popular Bluetooth module used for wireless serial communication between microcontrollers and smartphones. The module communicates using the UART interface with a default baud rate of 9600, allowing easy data exchange with devices like STM32. The fig.3 represents HC-05 Bluetooth module which works within a range of 10 meters and uses around 30–40 mA current, making it suitable for low-power applications. The HC-05 comes with simple pin connections such as VCC, GND, TX, RX, EN/KEY, and has LED indicators that show connection status. Its configuration can be modified using AT commands, enabling users to change the device name, password, baud rate, and mode of operation because of its low cost, ease of use, and stable wireless performance.

Fig .3: HC-05 Bluetooth

MPU6050 Accelerometer

The fig.4 represents the MPU6050 Accelerometer which contains a 3-axis accelerometer, which measures acceleration along the X, Y, and Z directions. This helps in detecting the hand's movement and orientation. It can sense tilting, lifting, and directional changes of the hand, allowing the system to understand how the hand is positioned during a gesture. The module includes an internal Digital Motion Processor (DMP) that filters and combines data, providing stable and accurate motion readings for gesture recognition. It communicates with the microcontroller through the I2C protocol, which requires only two pins (SCL and SDA). This makes integration simple and reduces wiring complexity in wearable devices.

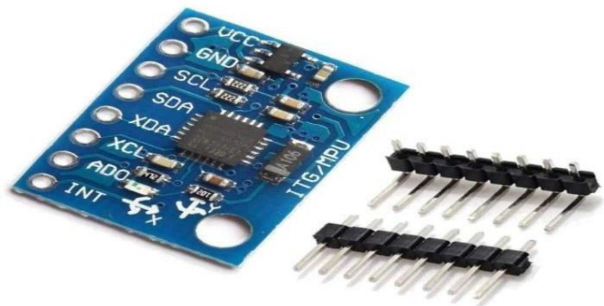

Fig .4: MPU6050 Accelerometer

Flex Sensor

Flex sensors are resistive sensors that change their resistance when they are bent. The more the sensor bends, the higher the resistance becomes. They are commonly used to measure finger movement, as the bending of each finger produces a measurable change in the sensor's output Flex sensors provide an analog voltage output, which can be easily read by the microcontroller to determine the degree of bending. The fig.5 represents the flex sensor they are lightweight, thin, and flexible, making them ideal for wearable applications such as smart gloves, gesture controllers, and rehabilitation devices.

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In this project, three flex sensors are placed on selected fingers to detect specific sign-language gestures, helping convert hand movements into meaningful digital data.

Fig .5**:** Flex Sensor

Buck Converter

The fig.6 represents a buck converter it is a DC–DC power electronic converter that converts a higher DC input voltage into a lower, regulated DC output voltage with high efficiency. It is widely used in battery-powered embedded systems to provide a stable supply voltage to electronic components. In this project, a buck converter is used to step down the Li-Po battery voltage (3.7–4.2V DC) to a stable 3.3V DC, which is required by the STM32 Blue Pill microcontroller, MPU6050 sensor, flex sensors, and HC-05 Bluetooth module.

Fig .6: Buck Convertor

Li-Po Battery

Our project uses two 4.2V Li-Po cells connected in series, giving a total of 8.4V, which provides higher power for sensors and wireless modules. The fig.7 represents the Li-Po battery, they are lightweight and compact, making them suitable for wearable or portable devices like your project. They deliver stable power output, ensuring smooth performance for components like the STM32 controller, MPU6050, flex sensors, etc. Li-Po cells offer high energy density, so the system can run longer without frequent charging. They require balanced charging and careful handling to prevent over-charging or deep discharge and maintain battery health.

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Fig .7: Li-Po Battery

V. SOFTWARE DESCRIPTION

The software development of the proposed sign language detection system is carried out using the Arduino Integrated Development Environment (IDE), which provides a flexible platform for coding, debugging, and real-time monitoring. The system utilizes essential libraries such as Wire.h for I2C communication and MPU6050_tockn.h for simplified access to accelerometer and gyroscope data, enabling efficient integration of the MPU6050 sensor. During initialization, the MPU6050 is calibrated to ensure accurate angle measurements, while flex sensors connected to analog input pins are configured for detecting finger movements. The system performs auto-calibration at startup to establish baseline sensor values and includes a smart calibration feature to allow recalibration during operation. The microcontroller continuously monitors sensor data, including orientation angles and flex sensor readings, and processes them in real time to detect gestures based on predefined conditions such as hand tilt and finger bending. Once a gesture is recognized, the corresponding output is displayed on the Serial terminal, along with sensor values for monitoring and debugging purposes. This integrated software approach ensures accurate gesture recognition, real-time response, and reliable system performance.

VI. RESULTS

The fig.9 Shows the hardware setups of the proposed system, this project successfully demonstrates a Smart Gloves–Based Assistive System that converts real-time sign language gestures into text output.

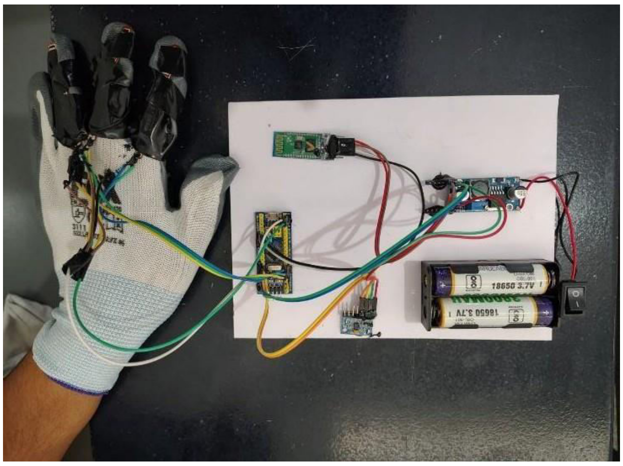

Fig .9: Hardware Setups of the Proposed System

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The experimental results obtained from the system are shown in Fig. 10. The mobile terminal application displays continuous real-time data including flex sensor values and orientation angles (Angle X and Angle Y), which are used for gesture recognition. The system also performs an initial calibration process, where the user is prompted to keep the hand in open and closed positions to establish baseline sensor values.

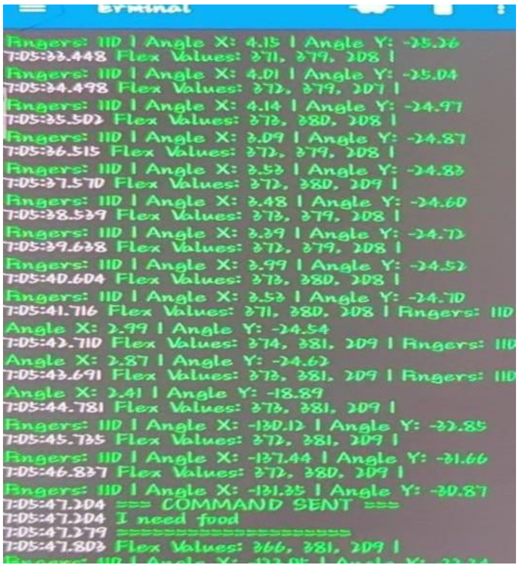

Fig .10: Real Time Gesture Data Transmission and Display through Bluetooth

The fig.11 shows displayed output, it can be observed that the system continuously monitors finger movements and hand orientation. When a specific gesture condition is satisfied, the system successfully detects the corresponding gesture and generates a predefined message. For instance, the command "I need food", "I need to sleep" is displayed when the required combination of finger bending and hand tilt is identified. This confirms that the gesture recognition logic is functioning correctly.

Fig .11: Serial Data Output on Mobile Application

Additionally, the calibration process shown in the figure ensures improved accuracy by adjusting sensor readings based on user hand positioning. The continuous stream of sensor data and command outputs indicates that the system operates in real time without noticeable delay. The results validate that the proposed system can effectively convert hand

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gestures into meaningful text, thereby enabling efficient communication.

VII. CONCLUSION

The proposed Smart Gloves–Based Assistive Technology for Real-Time Sign Language to Text Conversion system was successfully designed, developed, and tested. The system effectively captures hand gestures using flex sensors and an MPU6050 motion sensor, processes the data using a microcontroller, and converts the recognized gestures into meaningful output. During the implementation, sensor data corresponding to finger bending and hand motion was accurately acquired and processed to identify predefined gesture patterns. The recognized gestures were successfully mapped to corresponding outputs, demonstrating reliable performance. Experimental results indicate that the system achieves satisfactory accuracy for commonly used gestures and provides real-time response, making it suitable for practical applications. Overall, the proposed system demonstrates that assistive technologies can significantly enhance communication for individuals with disabilities

VIII. FUTURE WORK

The proposed system can be enhanced by increasing the number of recognizable gestures and enabling full-sentence interpretation for more natural communication. Integration of advanced machine learning techniques can improve accuracy and adaptability across different users. Future improvements may include the improvements in glove design, component miniaturization, and power efficiency can enhance portability and user comfort. Features such as multilingual output, cloud-based processing, and IoT integration can further expand the system's functionality and real-world applicability.

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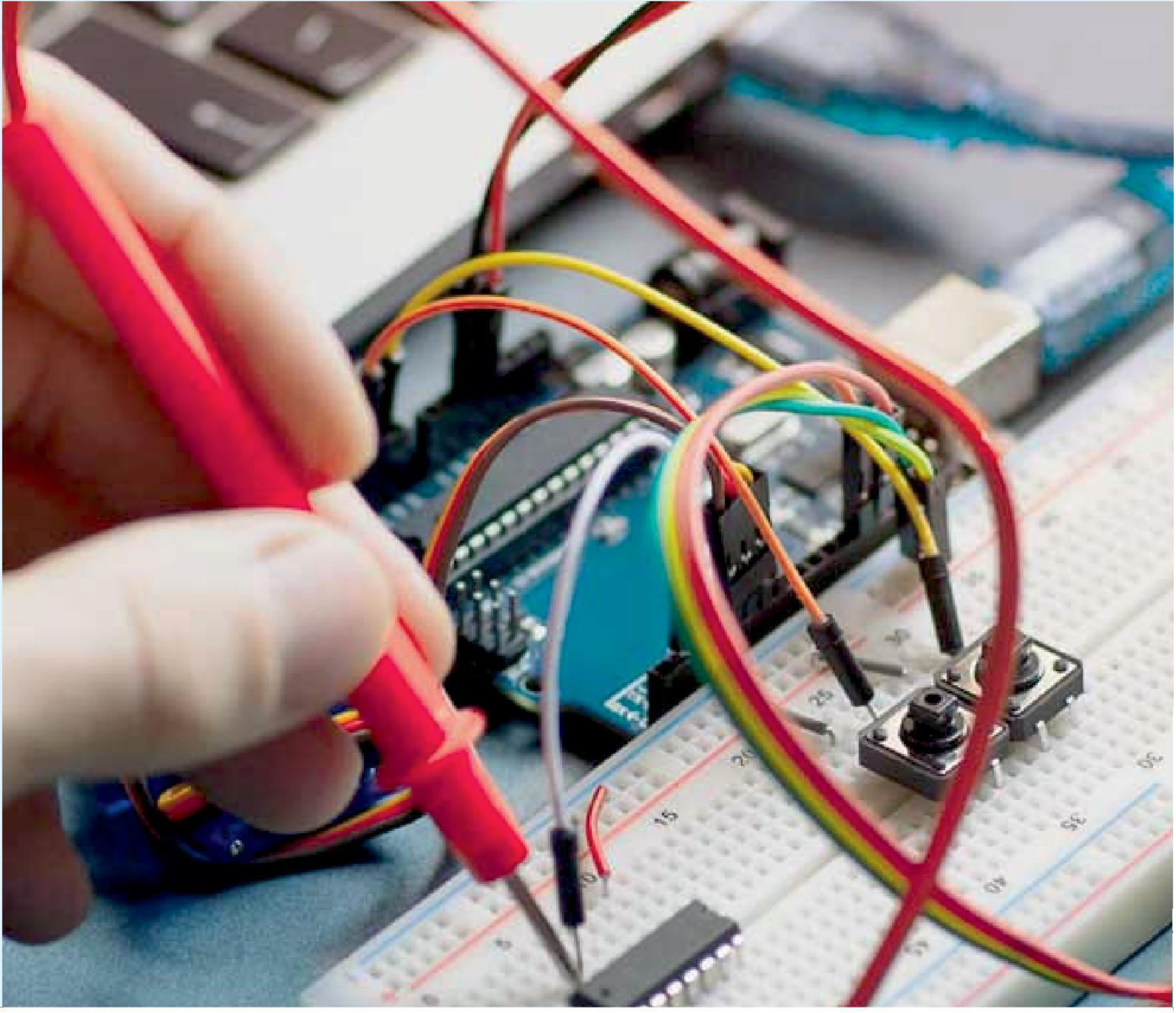

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