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A Computer Vision and Machine Learning based Approach to Assistive Mobility

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ABSTRACT: This research introduces a solution for individuals with severe mobility impairments, specifically targeting patients unable to move parts below their head. The proposed system integrates wireless communication, machine learning, and computer vision to enable independent mobility for users with head pose and eye movement. The design consists of a motorized wheelchair equipped with a WiFi enabled camera system that captures real-time images of the user and streams them to a computer running with machine learning-enabled image processing program.The face and eye movements are accurately estimated by the program and appropriate motor control signals are transmitted to navigate the wheelchair.

KEYWORDS: Wheelchair, Computer Vision, Face recognition, Head pose estimation, Machine Learning (ML), Face encoding.

I. INTRODUCTION

The prevalent method for operating powered wheelchairs relies on joystick control, posing significant hurdles for individuals with substantial physical impairments. Alternatives to traditional joysticks include head joysticks, chin joysticks, sip-n-puff, and thought control [3]-[7]. This project proposes a system capable of being controlled with movement of face and eyes. This paper envisages a powered wheelchair equipped with a wireless webcam in addition to the following [2]:

• Chassis,or drive system: This project uses a total 4 wheels with a motor powered rear-wheel pair.

• Batteries:Required to supply power for a reasonable time even for maximum load condition.It should be light and small enough to be accommodated seamlessly with the wheelchair assembly.

• Controller is the interface between human and machine. A common example is the hand joystick.This project uses a webcam connected over WiFi to a computer running an advanced machine vision algorithm as the interface to enable patients to convey their commands entirely using their facial features.

• Seating system:This part seats the patient in a comfortable position.

The aforementioned wheelchair is envisaged with a webcam to stream videos of patient's faces to a computer program. The system responds to facial commands from authorized users as the computer program processes the video stream and generates command signals to remotely activate motors connected to the microcontroller . The computer program makes use of Machine Learning and computer-vision to identify and authorize users followed by generation of signals to control motors coupled to the wheelchair. The remaining content of this paper is organized as follows: Section-II reviews existing literature in the domain of powered wheelchairs for assistive mobility. Section-III elaborates the methodology and Section-IV discusses the findings from prototype evaluation.

II. RELATED WORK

A comprehensive review of history and research trends in the domain of powered wheelchairs is provided in [2].The paper compares various definitions for powered wheelchair and smart wheelchairs.Different user interface methods and operating modes are discussed with an eye on providing better patient comfort. Implementation with different user

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interfaces are discussed in [3]- [7]. The software implementation of eye blink detection and head pose estimation are discussed in [8] & [9]. Face landmark detection in computer vision based on MediaPipe Face Mesh is elaborated in [1].This paper uses Media Pipe with the same approach to detect 468 facial landmarks.The use of these landmarks to detect blinking of eyes is elaborated in [8].The use of these landmarks for head pose estimation is discussed in [9].Calculation of pose from face mesh landmarks is elaborated in [10].Here principles of pose computation from 3D-2D point correspondence and relevant OpenCV algorithms are discussed.

III. METHODOLOGY

The envisaged wheelchair structure with webcam and motorized wheels are shown in figure 1.

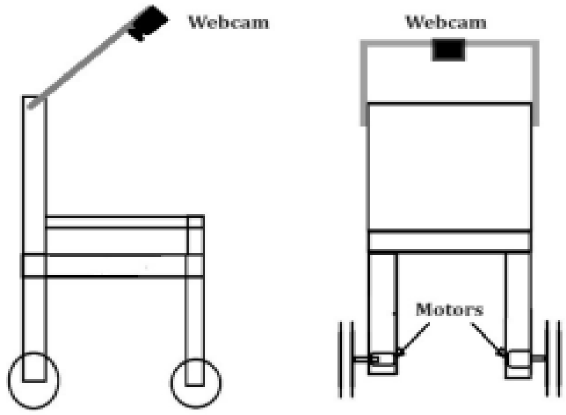

Fig 1 : Wheelchair with motorized wheels at rear and webcam

The system utilizes a webcam to capture the video feed of the user's face.The captured images are processed using a face recognition algorithm.This algorithm identifies and recognizes the user's face among other objects in the scene. Once the user's face is recognized, the system proceeds to eye blink detection to start and Stop wheelchair motors.The system continuously monitors the user's eyes using the webcam feed.An eye blink detection algorithm analyzes the video feed to detect instances of blinking.An eye blink, acts as a command to start or stop the wheelchair, depending on its current state. Head/Face Pose algorithms analyze the position and orientation of the user's head relative to the camera.This information is crucial for determining the user's intended direction of movement for the wheelchair. An ESP32 microcontroller manages the communication between the various components.It receives input from the face recognition, eye blink detection, and head pose estimation modules.The ESP32 processes this input to generate appropriate control signals for the wheelchair's movement.The control signals generated by the ESP32 are sent to the L298N motor driver, which is connected to the wheelchair's motors.The motor driver interprets these signals and regulates the motors powering the wheelchair's movement. The block diagram for the envisaged system is shown in figure 2.

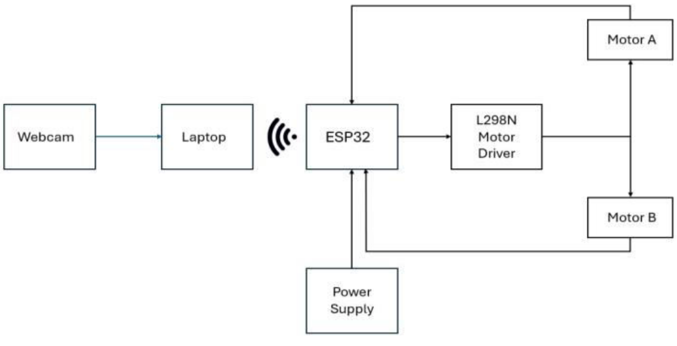

Fig 2 : Block diagram of system

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The flow-chart serving as the basis of operation is shown in figure 3

A. Program to Identify Face and Estimate Facial Commands The program is implemented with OpenCV, dlib,the face recognition library and MediaPipe Face Mesh.Video footage is recorded and saved along with corresponding names.Valid faces are encoded by the face recognition library and it is compared with encodings generated for face in video prior to authorization. The encoding is done by a deep convolutional neural network (CNN). The CNN takes the image of the face and generates a 128 dimensional vector.The norm of difference between vectors shall be very small for the same person but it shall be large for different people. The Face Mesh model in MediaPipe is used to detect 468 facial landmarks with x,y and z coordinates.These coordinates are programmatically processed to determine eye blink and face/head movement.

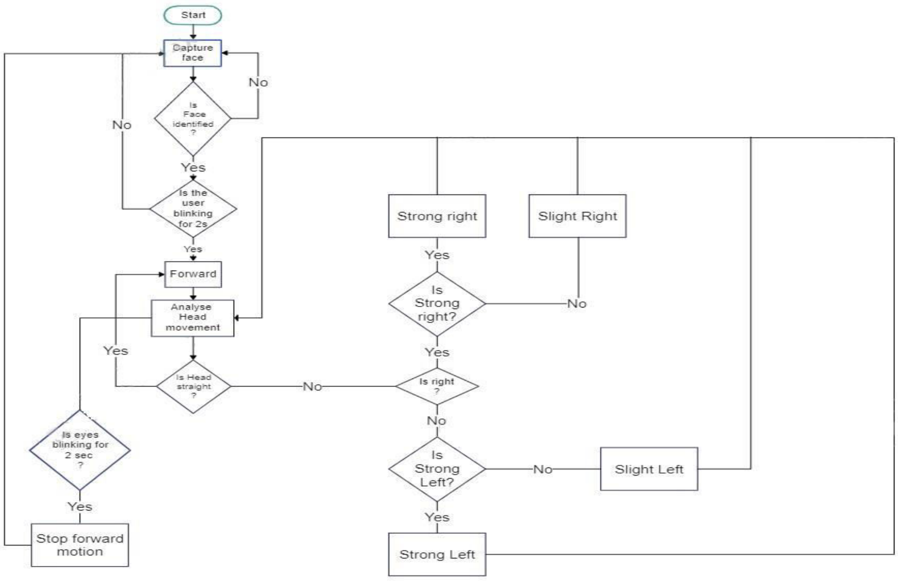

Fig 3 : Flowchart of the system

Landmarks for eyes on either side are chosen, and lines for both eyes are defined in horizontal and vertical directions.Relative euclidean distances of these lines can be used to determine the extent of eye closure to detect blinking.This is shown in figure 4

Fig 4 : Ratio comparison for open and closed eyes

A loop is started to continuously capture frames from the video source. For each face, MediaPipe FaceMesh contains a bounding box of the detected face and an array of 468 keypoints. Each keypoint or facial landmark has 2D (x, y) or 3D (x, y, z) coordinate locations of facial features, such as lips or eyes corners, points on the eyebrows, irises, and face contours, and intermediate points on the cheeks and forehead [10].The indices of the landmarks commonly used in

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programming are 1(nose tip), 33(right corner of right eye), 263(left corner of left eye), 61(right corner of lips), 291(left corner of lips), and 199 (chin) which are evenly distributed on the face. 3D & 2D coordinate points for the corresponding index can be obtained from MediaPipe FaceMesh. The nose projection of the captured and reference image can be compared to obtain face/head pose. [9] & [10] explains the procedure as below:

• Find face landmarks using Mediapipe 'FaceMesh'

• Produce rotation vector with solvePnP function.This function returns the rotation and the translation vectors that transform a 3D point expressed in the frame of reference image into the frame of captured image.

• Pass rotation vector to OpenCV Rodrigues (cv2.Rodrigues) function to get rotation matrix.Here it converts a rotation vector to a rotation matrix.

• Finally, decompose the rotation matrix to get Euler angles with function cv2.RQDecomp3x3. The above program codes to analyze the patient's facial commands (eye blinks and face tilting)are embedded in a larger program with codes to establish communication with an ESP32 micro-controller. B. Motorized Wheelchair Navigation The program on the computer generates following signals in response to facial expressions of patients.

1) Blink:The program sends a character over blue-tooth to trigger an if condition within the on-board program of ESP32 to produce signals on its pins to signal L298N motor driver to stop both motors or start both motors with equal speed of rotation.
2) Turn with varying speed in the direction of head/face pose:The program sends a character over blue-tooth to trigger an if condition within the on-board program of ESP32 to produce signals on its pins to signal L298N motor driver to send a pulse width modulated signal with a preset duty ratio to one of the motors and other motor at zero speed of rotation.

The wheelchair's motors are equipped with encoders to provide feedback on their actual movement, allowing for precise control.This facility need not be used in indoor applications on clean and level floors but is necessary to ensure intended direction of motion in applications on uneven or extremely soiled/slippery floor surfaces.

IV. EXPERIMENTAL RESULTS

The wheelchair was operated on tiled floor in a properly illuminated room.It was observed that the program responded to the facial commands of only authorized users as follows: • The system always identified and responded to the authorized users and prevented access to unauthorized users.Snapshot of response to matched video frames are shown in figure 5. • Deliberate eye blinks were detected and worked as start or stop commands alternatively.This is shown in figure 7.

• To move forward: The motors were programmed for equally fast rotation for head/face posed within x coordinate values of -3 to 3.This is shown in figure 8.

• To turn right slowly: The left motor was programmed for slow rotation while the right one was stopped for head/face posed within x coordinate values of 3 to 10. This is shown in figure 8.

• To turn right at moderate pace: The left motor was programmed for moderate rotation while the right one was stopped for head/face posed within x coordinate values of 10 to 15. This is shown in figure 9.

• To turn right quickly: The left motor was programmed for fast rotation while the right one was stopped for head/face posed with x coordinate values greater than 15.This is shown in figure10.

• To turn left slowly: The left motor was programmed for slow rotation while the right one was stopped for head/face posed within x coordinate values of -3 to - 10.This is shown in figure11.

• To turn left at moderate speed: The left motor was programmed for moderate speed of rotation while the right one was stopped for head/face posed within x coordinate values of -10 to -15.This is shown in figure12

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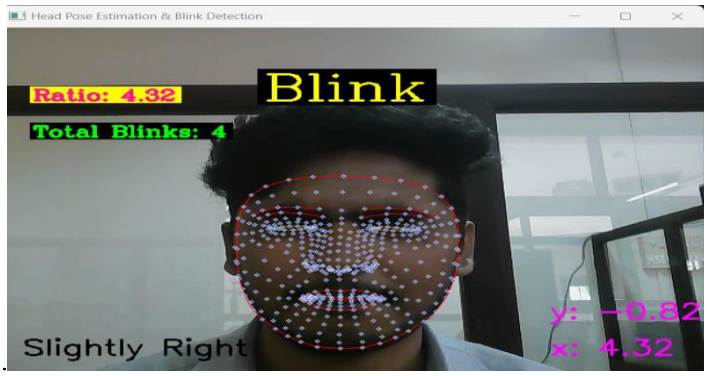

Fig 5 : Response to eye blink

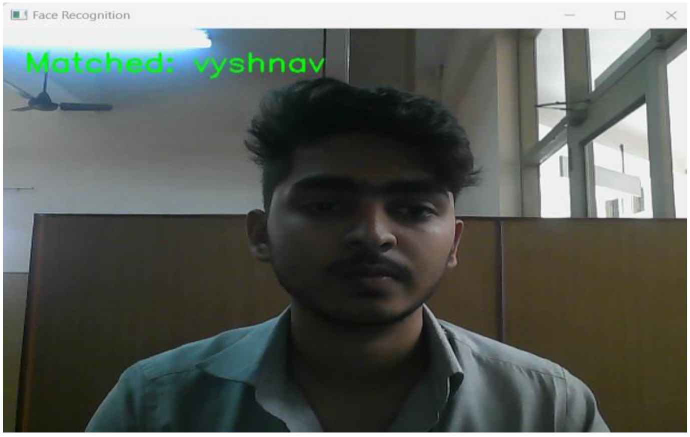

Fig 6 :Response to an authorized user

• To move forward: The motors were programmed for equally fast rotation for head/face posed within x coordinate values of -3 to 3.This is shown in figure 8.

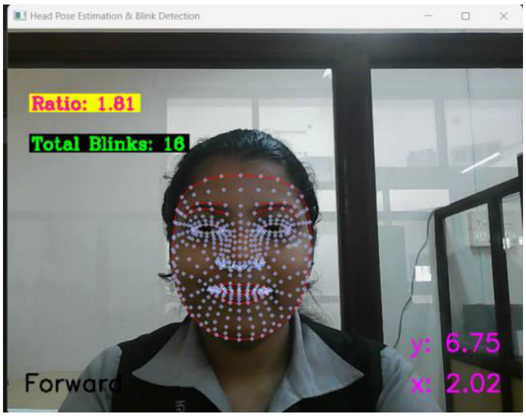

Fig 7 :Facial forward command

• To turn right slowly: The left motor was programmed for slow rotation while the right one was stopped for head/face posed within x coordinate values of 3 to 10.This is shown in figure 8.

• To turn right at moderate pace: The left motor was programmed for moderate rotation while the right one was stopped for head/face posed within x coordinate values of 10 to 15. This is shown in figure 9.

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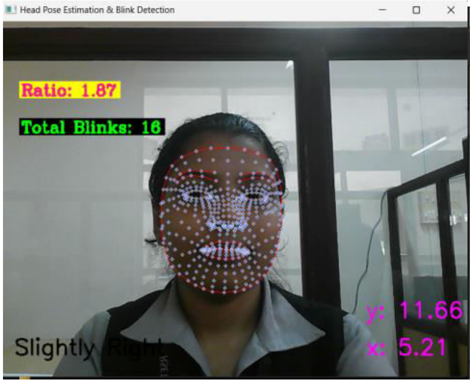
• To turn right quickly: The left motor was programmed for fast rotation while the right one was stopped for head/face posed with x coordinate values greater than 15.This is shown in figure10.



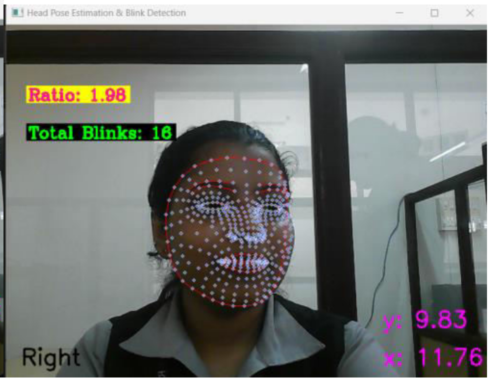


Fig 8 : Facial slight right command

Fig 9 : Facial right command

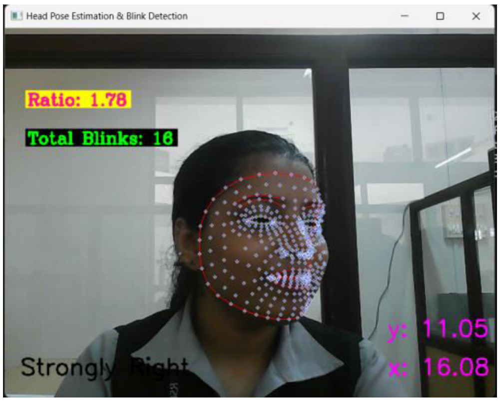
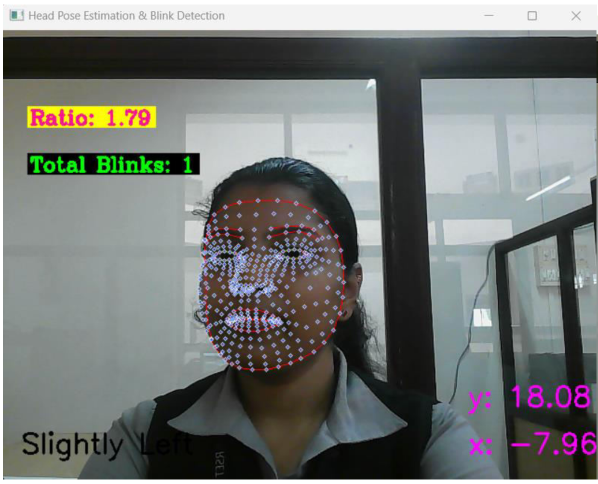


Fig 10: Facial strong right command

• To turn left slowly: The left motor was programmed for slow rotation while the right one was stopped for head/face posed within x coordinate values of -3 to -10.This is shown in figure11.

• To turn left at moderate speed: The left motor was programmed for moderate speed of rotation while the right one was stopped for head/face posed within x coordinate values of -10 to -15.This is shown in figure12.



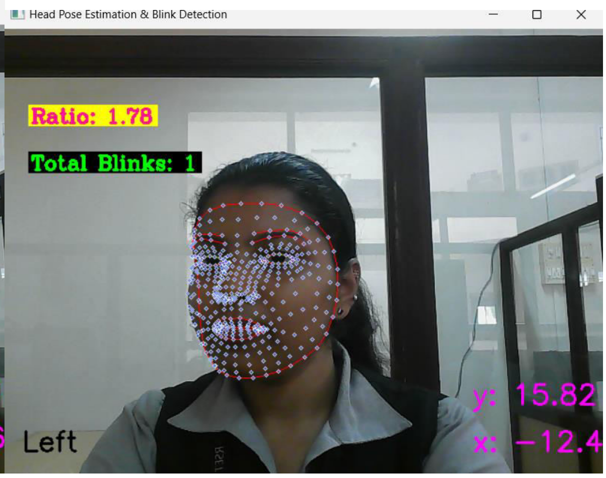


Fig 11 : Facial slight left command

Fig. 12.: Facial left command

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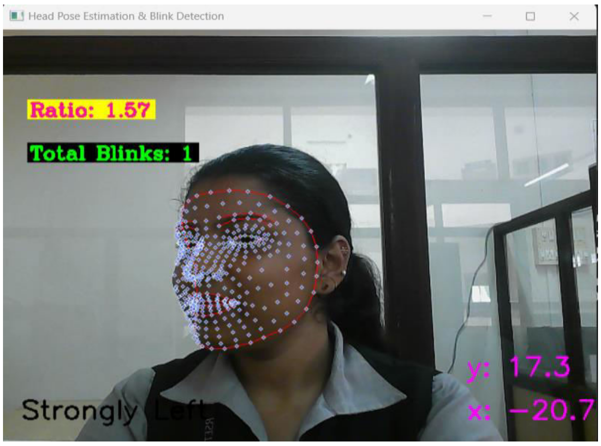

Fig 13 : Facial strong left command

• To turn left quickly: The left motor was programmed for fast rotation while the right one was stopped for head/face posed with x coordinate values of less than -15.This is shown in figure13.

The prototype could be used without encoder feedback satisfactorily on a regular tiled floor clean from slippery material and sand. Thus it is recommended to use the system on an even floor without excessive slipperiness or friction.It is also recommended to calibrate the speed of wheelchair turning to the comfort of user on the floor of actual deployment.The calibration is to be done by changing the program in ESP32 to adjust the rpm of motor for slow and fast turnings.

V. CONCLUSION

This paper discusses an approach that enables patients to self navigate wheelchairs with eyes and face.The system integrated face recognition, eye blink detection, and head/face pose estimation seamlessly and controlled wheelchair movement without perceivable delay. This system offers a comprehensive and intuitive interface for patients rendered immobile below head due to extremely adverse medical conditions to improve the quality of their life by enabling them to move around independently at their own convenience.Future work can involve analyzing patient facial expression to detect medical emergency and trigger an automatic mechanism to alarm a caregiver.

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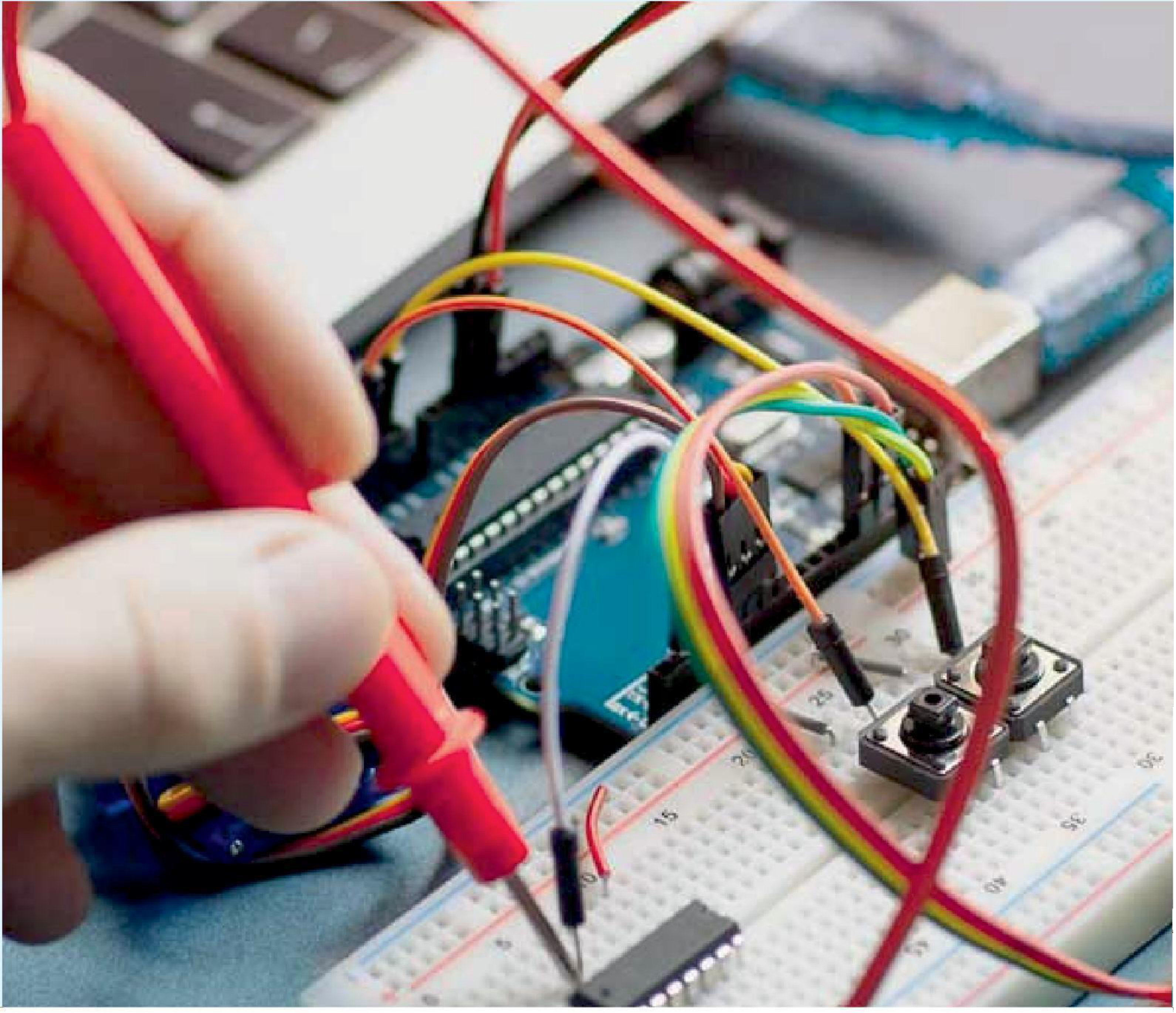

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