ISSN 2278-3091
Volume 9, No.3, May - June 2020
International Journal of Advanced Trends in Computer Science and Engineering
Available Online at http://www.warse.org/IJATCSE/static/pdf/file/ijatcse153932020.pdf
https://doi.org/10.30534/ijatcse/2020/153932020

Design and Development of Low Cost Humanoid Robot with Thermal Temperature Scanner for COVID-19 Virus Preliminary Identification

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ABSTRACT

Very important and initial challenge in the epidemic of Covid-19 is to identify more probable patients out of crowd of people. Once identified, probable patients may be sent for more Covid-19 test for identification. This initial challenge is tickled by using thermal imaging with the use of thermal cameras over the entire world. It requires the manual operation for scanning of people. It is so risky for human being that handles the whole operation of scanning. Humanoid robot is designed for instructing, alerting and scanning of entering peoples for the sake of more prevention from Corona virus. Low cost humanoid robot is designed using Girl Mannequin plastic body. Hand and neck mechanism is developed using 2-axis Motion Mechanism. All the corresponding motions are modelled for particular action for scanning of person in front of it. Activation of data capturing and scanning schedule is initiated once entry of person is identified using PIR proximity sensor. Temperature data recorded is analysed and decision is taken place by opening and non-opening of entry gate. Buzzer, voice indication with SMS alert is given by robot for further action if scanned data is found abnormal. Whole Robot system is implemented and is tested for real time operation. It is found working satisfactorily.

Key Words- COVID-19, Humanoid Robot, Thermal Scanner, Raspberry Pi, Arduino, Motion Modelling.

1. INTRODUCTION

COVID-19 is a major epidemic that was spread over the entire World. Automation and less human assisting systems are required for controlling the viral effect of this disease. Manual assistance required for scanning is needed to be avoided.

Thermo-graphic scanning is a proven technology based on infrared imaging used in a wide range of applications like monitoring, diagnosis of industrial machines and products and diagnosis of health [1], [2]. Many thermal cameras like ARBOR SENSOR SYSTEM [3], FLIR [4], SATIR [5], FLUKE [6], etc are available in market having different resolutions, features. Some thermal cameras are having the facility of data communication using Ethernet port [3] and some models of FLIR [4] like FLIR E5 [7] and FLIR E8 [7] are having wifi facility for capturing and getting the information.

Since 1985, thermal imaging devices are used for fever detection by Walter T. Hughes [8]. He stated that the most accurate readings were got along the area near eye and E spot- area below the ear lobes. Later based on many clinical studies[9-12] recommendation through different publications of ISO[13], IEC[14] and the reviews of CDC[15], the best area to scan a person´s body temperature is the inner portion closest to the nose where your tear ducts called eye's Lacrimal Caruncle area and the hole of ear. Some of the researchers also recommended to average the temperatures over large area of face or along fore head. Some major companies like Amazon and Walmart are scanning temperatures of their employee with handheld thermometer. Scanner must be close enough to the people for checking that may lead to infection [16]. With a thermal camera, thermal scan is possible automatically.

The proposed system may solve the defined problem in most of the extent. Proposed system includes Humanoid Robot System having major three capabilities as 1) instructional capability, 2) movement capability and 3) decision making capability. System also includes Entry Gate System that is designed for sensing by three ways as 1) sensing of the person entering into the gate, 2) sensing the exact head position and 3) sensing the height of the entered person. Data is sent from Entry Gate System to Humanoid Robot System through wifi connectivity using ESP 01 module. Third major sub-system of proposed system is Face Rotation Identification Algorithm using Machine Learning (FRI-ML) that identifies the rotational angle of entered person for proper scanning.

Positional information has to be captured by Entry Gate System when a person is entered for scanning. It requires various sensors like 1) PIR sensor for entry detection, 2) number of ultrasonic transmitter and receiver pairs for

head position detection, 3) IR transmitter and receiver strips (that are generally used in lift for sensing objects) for detecting of height of person entered, and 4) normal person facing sensor by normal camera for identifying facing direction of entered person.

Information from these four types of sensors of Entry Gate System is processed by Raspberry Pi controller and then sent to Robot System for further operations.

A novel approach of Data Analysis with Motion Modelling is proposed for the specific operation of Humanoid Robot System that controls the motion of robot for exact positioning and for distance thermo-graphic measurement. High resolution thermal scanner having data accessing facility is used for thermo-graphic measurements. After proper moving/positioning of robot hand (having attached scanner) by robot, it captures thermo-graphic image and also records the temperature of the target person. It is exactly positioning and focusing on forehead of the entered person. Normal camera is also attached to this system to identify the rotation of the person entered. If the person is facing towards the robot then only the scanning is initiated by Robot System. Face Rotation Identification Algorithm using Machine Learning named as FRI-ML is developed for this purpose and implemented into the Robot System with Raspberry Pi controller which then sends the final detected results to the Arduino controller of Robot System using wifi communication through ESP8266 wifi module. Entered persons motion is traced continuously until the scanning is completed. If motion found is excides it limit then the whole process from getting positional information until the scanning is repeated. Main controller used for Robot System is low cost Arduino Uno that can handle all the operation of Robot System like motion control, initialization of scanning and instructing & alerting like operations.

2. METHODOLOGY

Proposed system consists of three major sub-systems as 1) Entry Gate System, 2) FRI-ML System and 3) Humanoid Robot System. Inter-system-communication protocols are defined for sending information between all the sub-systems. Design of hardware & related software and design of required mechanical structure is detailed in this section. Block Schematic Diagram of whole system is shown in Figure 1 and operational flow diagram of the proposed system is as shown in Figure 2. An inter-system-communication protocol is initialized by sensing the signal from PIR sensor connected to Raspberry Pi controller. It starts the process of scanning the data from various sensors to Raspberry Pi controller and sends the communication message to Arduino controller for its start of operation. Raspberry Pi controller also sends another message 'OK' with data after finishing of data scanning. Arduino controller processes the data captured by it and received through communication media and executes the corresponding operation as end of inter-system-communication protocol.

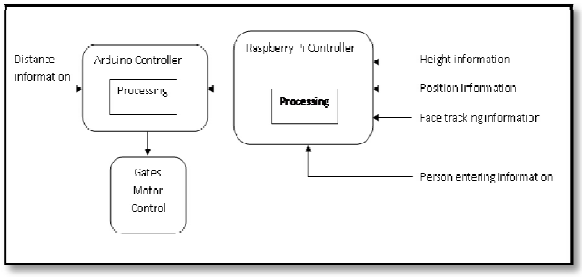

Figure 1: Block Schematic Diagram of Proposed System

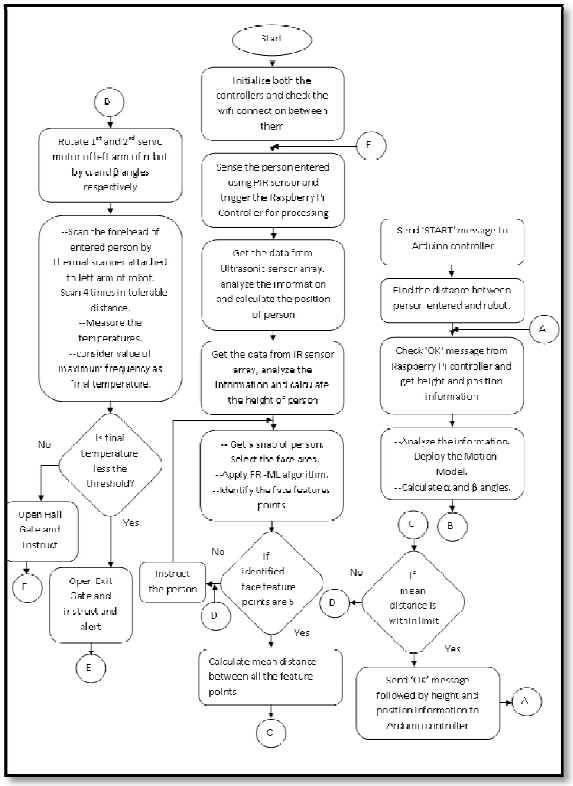

Figure 2: Operational Flow Diagram of the Proposed System

Entry gate System is designed for the scanning of entering persons at the gate of big molls, colleges, universities complexes, cinema complexes and even in to the big gathering hall. One by one person has to enter into the scanning zone where Entry Gate System's mechanism and Humanoid Robot mechanism are installed for quick scanning purpose to identify the suspected Corona affected or fevering person. Entered person has to be stand on the marked position without any movement for few seconds for immediate scanning. Once scanned, immediate information is processed using all the three sub-systems and person is allowed to enter one of the gates out of two gates, one is for entering into the hall and another is for exit. If person is affected by the fever, his entry is denied into the hall and is instructed for immediate treatment and care.

2.1. Entry Gate System

Entry gate System consists of entry mechanism attached with sensor networks which are configured along Raspberry Pi controller. All the signals from the array of sensors are conditioned and processed for extracting required information for motion modelling. One high resolution camera module, one PIR sensor, an array of ultrasonic transmitter and receiver pairs and an array of IR transmitter and corresponding array of IR receiver, are interfaced to Raspberry Pi controller through its corresponding Conditioning/driver circuits. 8 megapixels Sony IMX219 camera sensor is used for capturing the image of face of entering person. PIR motion sensor module with LHI788 probe is used for motion sensing of entered person. It triggers the system to capture the information from sensor network and in-turn triggers the actuation process of the Humanoid Robot System. An array of ultrasonic transmitter (TX) and receiver (RX) pair (Figure 3) is constituted with 11 pairs of Tx and Rx is utilized for the purpose of measuring the distances of person body (as a top view) at different locations along the sensor array affixed horizontally over the head of person entered.

The time-of-flight method [17] is involved in measuring the shape of a person from top of the entering gate by using ultrasonic wave pulses (amplitude modulations) through which the distance information obtained is analyzed by the Raspberry pi Processor for measurement and recognition of shape in terns the position of person.

An array of IR transmitter and corresponding array of IR receiver are affixed in vertical direction in parallel to the body of entering person along the mechanical structure as shown in Figure 4. IR rays transmitted from IR transmitter will be reaching to the corresponding IR receiver in straight line when empty Entry Gate. When a person enters the Entry Gate, he cuts the IR rays transmitted by IR transmitter and the rays are not reaching to the corresponding IR receiver indication the height of entered person. Signals from the IR receiver are decoded in to the height of person by controller and the information is stored. Al the information from all the sensors are encoded and sent to the Humanoid Robot System's Controller.

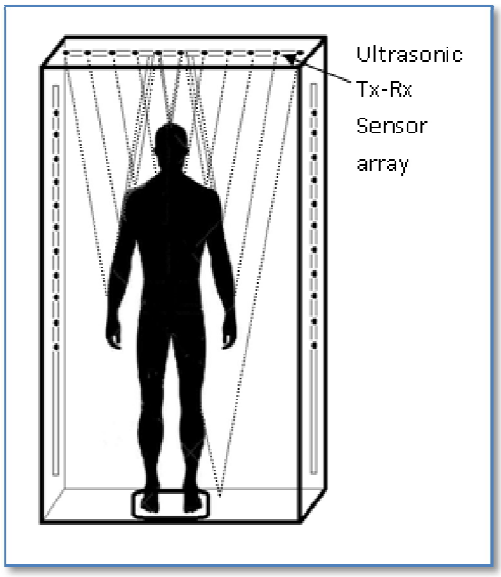

Figure 3: Ultrasonic Transmitter and IR Receiver Pair Array for Mechanical Assembly

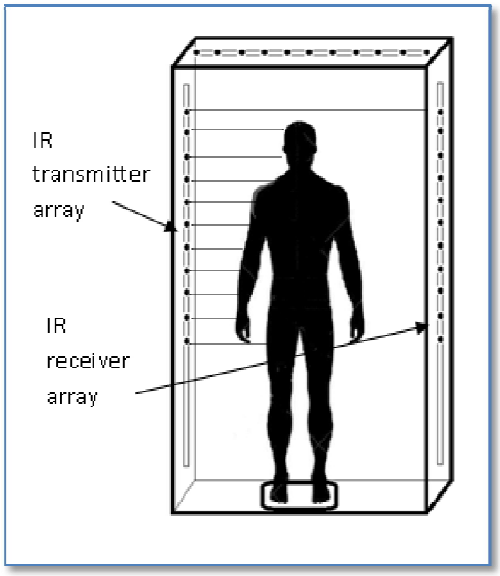

Figure 4: IR Transmitter and IR Receiver Array for Mechanical Assembly

Let H is the height of the entered person (measured by the Raspberry Pi controller using IR transmitter and receiver array), h is the shoulder height of robot (measured by the Raspberry Pi controller using Ultrasonic transmitter and receiver pair array), D is the distance between entered person and the robot (measured by the Arduino controller using distance sensor). From the geometry as shown in Figure 6, angle rotational angle $\alpha 1$ will be given in equation Eq. 01.

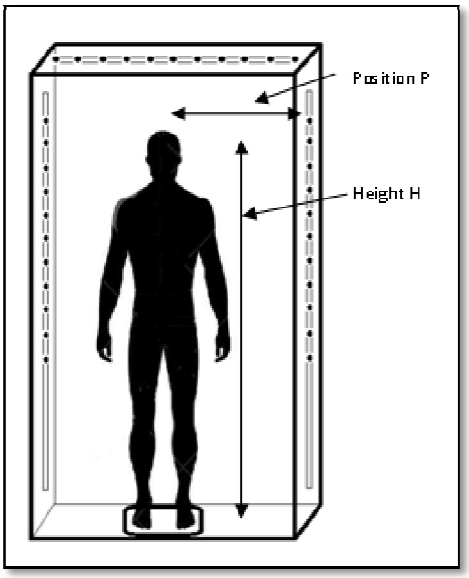

Figure 5: Height and position measurement along for Mechanical Assembly

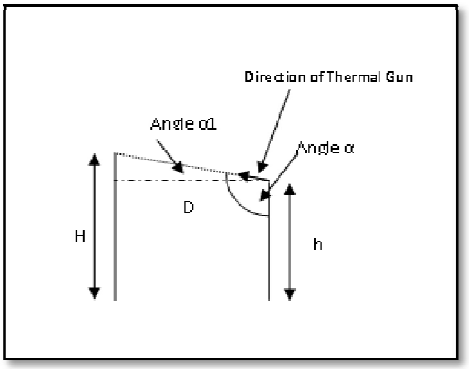

Figure 6: Geometry for Calculation of Angle α

$$\alpha 1 = \sin^{-1}[(H-h)/D] \qquad \text{Eq. 01}$$

And rotational angle α (Eq. 02) is given as,

$$\alpha = \alpha 1 + \pi/2 = \pi/2 + \sin^{-1}[(H-h)/D] \qquad \text{Eq. 02}$$

If entered person is standing at different position than the centred specified position, it is immediately recorded by the ultrasonic sensor array. It measures the length P of position of entered person as seen in Figure 5.

As shown in Figure 7a and Figure 7b, M is the length of mid-point of Ultrasonic Sensor Array from its extreme end. Let P be the length of position of entered person's head from extreme end. According to the geometry, the horizontal rotational angle of robot arm β is given in equation Eq. 03.

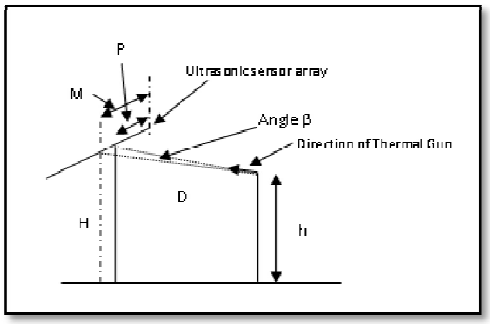

Figure 7a: Geometry for Calculation of Angle β (side view)

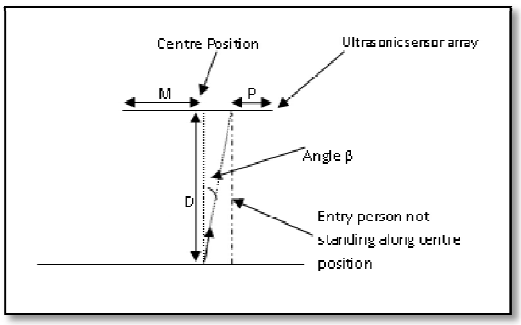

Figure 7b: Geometry for Calculation of Angle β (top view)

$$\beta = \sin^{-1}[(M-P)/D] \qquad \text{Eq. 03}$$

Raspberry Pi controller of Gate Entry System captures the data from all the sensors; calculates the required information like H and P and sends it to Arduino Controller of Humanoid Robot System. Rotational angles α and β is calculated by Auduino controller and according to it left arm of robot is actuated for the target tracking.

Block schematic diagram of Entry Gate System using Raspberry Pi controller is shown in following Figure 8.

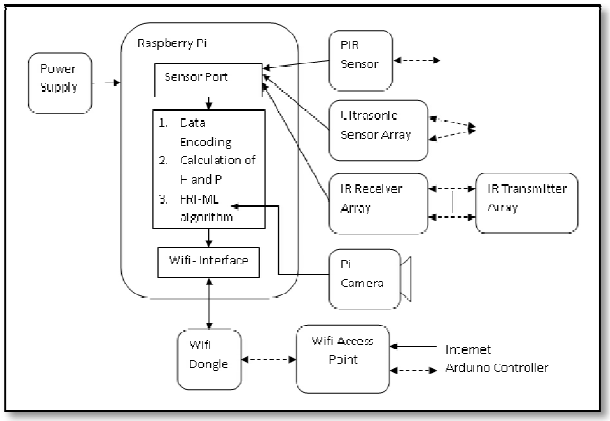

Figure 8: Entry Gate System using Raspberry Pi Controller

Algorithmic steps for Entry Gate System with Raspberry Pi controller using Python Programming are as follows.

1. Initialize the system. Initialize the connection to Arduino controller using wifi connection.
2. Read the information from PIR sensor.

3. If PIR sensor doesn't sense the entry person, repeats the step 1) and 2)
4. If it senses the entry person, initialize the schedule of action and sends the 'START' message to Arduino controller through wifi connection.
5. Read the information from IR receiver. Calculates the height H from received information by decoding the data.
6. Read the information from ultrasonic sensor. Calculates the positional information P from received information by decoding the data.
7. Call the FRI-ML algorithm for face scan and for rotational analysis. If the identified face is not facing towards the robot then instruction is provided to entered person. And repeats the face scan using step 7)
8. If the identified face is facing towards the robot then sends 'OK' message to Arduino Controller. Sends the data as H and P for current entered person to Arduino controller.
9. Once the data is received (by knowing acknowledgement), repeats the step 1) to 8) for next person to be entered.

2.2. Face Rotation Identification Algorithm using Machine Learning (FRI-ML)

FRI-ML algorithm is used to identify the rotation of entered person by tracking the face in captured image. If specific features of face is identified like nose, lips, eyes etc are identified, the head is said to be facing towards the Robot System else instruction is given to person for proper positioning. For exact facing of head, FRI-ML algorithm is developed. The algorithm was initially tested on face database [18] for verification and then tested on captured real images. The algorithm is developed with Multi Task Cascaded CNN machine learning classifier [18].

The algorithmic steps for FRI_ML are as follows.

1) Select the image having face view.
2) Resize the image into the image pyramid.
3) NMS and Bounding Box regression in stage 1 of P-Net [18].
4) NMS and Bounding Box regression in stage 2 of R-Net [18].
5) NMS and Bounding Box regression in stage 3 of O-Net [18].
6) Display the rectangle and face points along face view.
7) Measure the face point. If number of identified face points is five then face if identified in proper rotation.
8) Else, face is rotated in different direction.

2.3. Humanoid Robot System

Humanoid robot is designed with low cost Girl Mannequin plastic body using 2-axis Motion Mechanism along the rotating shoulder arm and rotating neck. 2-axis Motion Mechanism is formed with two servo motors and steel mechanism as shown in Figure 9, whose rotational angle varies from 0^o to 120^o horizontally in angle β and vertically in angle α (Figure 11 and Figure 12) in-front of robot to cover maximum area of interest. 2-axis Motion Mechanism is positioned on the shoulder position of both arms and on the neck position (Figure 13) for moving and focusing in pre-defined manner and in particular direction. Servo motors for each 2-axis Motion Mechanism are electronically controlled using Arduino controller through 12 bit servo controller. It is configured with distance sensor to avoid the obstacles in motion of robot arms. Block schematic for electronic control for Humanoid Robot System is as shown in Figure10.

Figure 9: 2-axis Motion Mechanism

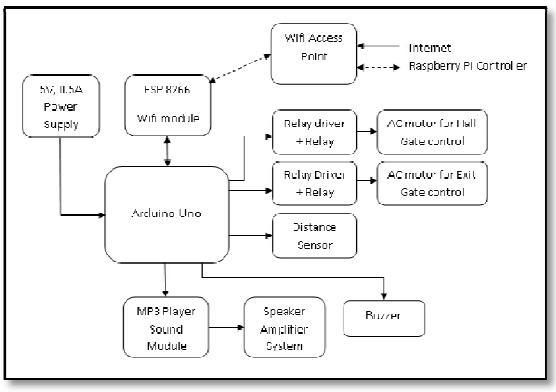

Figure 10: Electronic Control for Humanoid Robot System

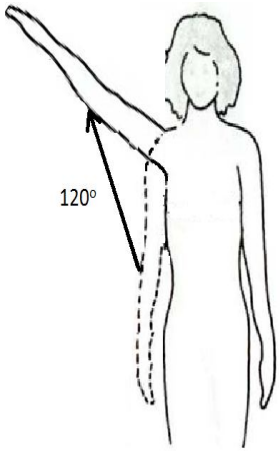

Figure 11a: Variation in rotational angle from 0^o to 120^o and vertically in angle α

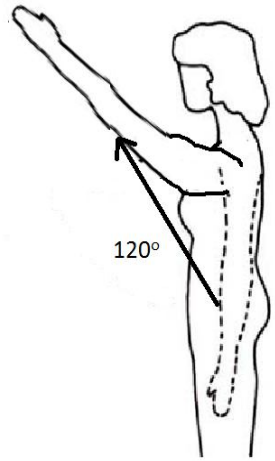

Figure 11b: Variation in rotational angle from 0^o to 120^o horizontally in angle β

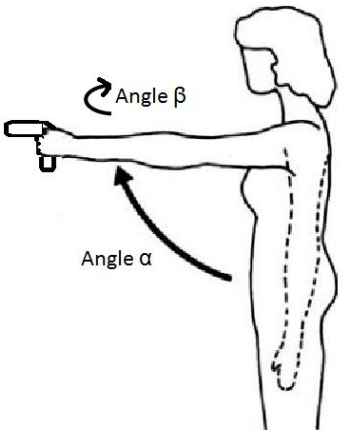

Figure 12: Variation in angle α and angle β

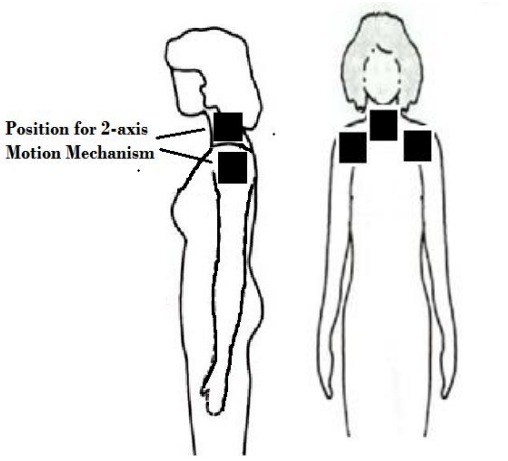

Figure 13: Position of 2-axis Motion Mechanism along shoulder and neck

PIR sensor available in Entry Gate System initiates the data capturing process and immediately informs to Arduino controller for initialization of its process. Arduino controller measures the distance between the entered-person from it as D value.

Robot arm motion is modelled using equations Eq. 01 to Eq. 03. Arduino Controller analyzes the data received from various sensors and calculates angle α and β. According to it, it performs the vertical motion and horizontal motion of left arm for tracking /scanning of entered person's forehead.

After receiving 'OK' command from Raspberry Pi controller, Arduino controller scans the forehead of entered person and measures and records the temperature using thermo-graphic measurement (using thermal scanner). It is then compared with normal value of temperature. If measured temperature is less the normal threshold value, it allows the person to enter the hall by opening the Hall Gate. Else, it records the information as abnormal information. It assumes the entered person as suspected infected person and opens the Exit Gate, ON the buzzer and sends the alert information to authorized person through online SMS. It presents the audio instruction to the infected person before opening Exit Gate.

Algorithmic steps for data analysis and deployment of motion model by Humanoid Robot System with Arduino Uno controller using Embedded C Programming are as follows.

1. Initialize the controller. Initialize the wifi connection with Raspberry Pi controller.
2. Read the message received from Raspberry Pi controller.
3. If message received is 'START' message, measures the distance D from it to entered person using distance sensor, standing in-front of it.

4. Read the message received from Raspberry Pi controller.
5. If message received is 'OK' message, reads the data (H and P) sent by Raspberry Pi controller.
6. Analyze the data like H, P, h, D for its range for validity of data.
7. Deploy the motion model (Eq. 01, Eq. 02 and Eq. 03 using the analyzed data and calculate α and β angles.
8. Actuate the left arm (servo motors) of robot for motion of α angle in vertical direction and then β angle in horizontal direction.
9. Capture the multiple temperatures using thermal scanner by vibrating (vertical and horizontal direction).
10. Value with maximum frequency of measured temperatures is considered as a final measured temperature.
11. Compare the final temperature with threshold temperature (decided timely).
12. If measured final temperature is less then threshold then it actuates the Hall Gate and plays the Welcome message.
13. If measured final temperature is more than threshold then it actuates the Exit Gate and
14. Plays the instruction message to the entered person. ON the buzzer and send online SMS (through internet connectivity using SMS pack) to the authorized person.
15. Repeat the step 1) to 14) for next entry.

2.4. Hall Gate and Exit Gate Controlling System

Relay controlled motorized gates are used for entry into hall (Hall Gate) and exit by the system (Exit Gate). Arduino controller controls the relays using relay drivers. The relays are connected to the AC motors for opening and closing of the gates. Corresponding gate rod opens when the scanning is completed successfully.

3. RESULTS

Proposed system consists of three major sub-systems as Entry Gate System using Raspberry Pi controller, FRI-ML System that uses the Python programming of MTCNN algorithm deployed in to the Raspberry pi controller and 3rd system as Humanoid Robot System designed using Arduio controller. Raspberry Pi controller is interfaced with wifi dongle, 5MP Pi camera (megapixels Sony IMX219 camera sensor), PIR sensor, Ultrasonic Sensor Array and IR receiver Array as shown in Figure 14. FRI-ML algorithm identifies the rotation of entered person and the identified face area and face features for entered person is shown in Figure 15.

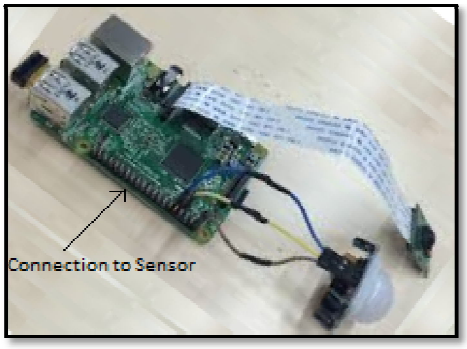

Figure 14: Raspberry Pi Controller for Entry Gate System

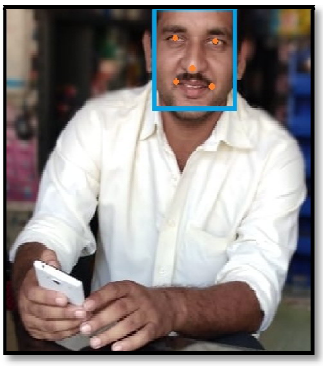

Figure 15: Identified Face Area and Face Feature Points

Raspberry Pi controller sends alert to Arduino controller by sending 'START' message. It starts its work after getting alert message. It is configured with the Distance sensor to measure distance from entered person. It is also interfaced with 12 bit servo controller to control the servo motors. Speaker system is interfaced with Arduino through MP3 controller module for sending audio instruction to entered person. ESP8266 wifi module is used to make communication with raspberry Pi controller. Arduino controller with all the interfaces is shown in Figure 17. Humanoid robot used is as shown in Figure 19. The ready entry gate (Figure 16) used for entering the person is place in-front of robot. Hall Gate and Exit Gate is place behind the entry gate (Figure 16). Low cost humanoid robot is developed with girl mannequin by connecting 2-axis Motion Control Mechanism (Figure 18) along both the shoulders and at neck position. Motions can be controlled by Arduino controller.

Same system can be implemented using face recognition systems like One Shot Learning [19] any may use the machine learning algorithms as specified in intelligent systems [20, 21].

Figure 16: Front view of Entry Gate System

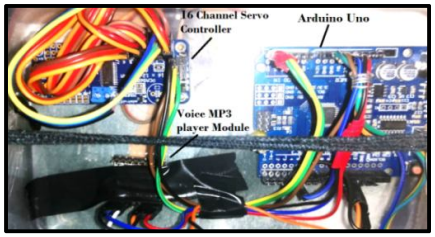

Figure 17: Arduino Controller with interfacings

Figure 18: 2-axis Motion Mechanism

Figure 19: Humanoid Robot Model for Scanning with Thermal Camera

4. CONCLUSION

During the epidemic of Covid-19, it is necessary to identify the probable patient during un-lockdown condition. Thermal scanner is the best option to identify the fever of any person from distance manner to avoid the infection to other people. In this work, we proposed autonomous humanoid robotic controlled system that identifies the entered person, identifies his/her height, his/her position, his/her face rotation and his/her distance. It deploys the motion model and calculates the robot motion parameters to control the exact scanning position of the forehead of entered person. It scans the forehead of person for temperature measurement using thermal scanner. Recorded temperature is analyzed and Hall or Exit Gate is accordingly opened. Corresponding instruction and alert is provided by the robotic system. Implemented system is working properly and useful to the entering persons for the identification of themselves health condition.

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