Asian Journal of Scientific Research

ISSN 1992-1454

Asian Journal of Scientific Research 8 (3): 392-402, 2015
ISSN 1992-1454 / DOI: 10.3923/ajsr.2015.392.402

Hand Gesture Based Control of Robotic Hand using Raspberry Pi Processor

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ABSTRACT

A Novel approach has been proposed in this paper for the control of an intelligent hand which can mimic the natural movement of the human hand. Implementing such intellectual hand finds its application in humanoid as well as personal robots. In this paper vision-based interaction techniques are used to track the motion of the fingers and to extract the motion of the hand gesture accurately and promptly. Accuracy and effectiveness plays the key role for real time motion based applications. Raspberry pi processor is used to control the entire set up which has a camera module attached in it, to capture the motion. Face subtraction, skin color detections are used to characterize the hand in the video. Mean shift algorithm is used to track the motion of the finger. The mechanical structure and the ratio between number of actuators and number of Degrees Of Freedoms (DOFs) have been optimized in order to cope with the strict size and weight constraints that are typical application of artificial hands for the implication of humanoid robotics. The proposed hand has a structure similar to that of the natural hand featuring articulated fingers (every finger with 4 degree of freedom) which is controlled by DC motors.

Key words: Hand gesture, open CV, HCI, degrees of freedom

INTRODUCTION

Flexibility and accuracy of the robotic hand movement depends up on the selection of sensing mechanism, actuator and communication. A brief survey of Anthropomorphic robotic hand design is done by Melo *et al*. (2014). In the development of dexterous robotic hand there are two approaches in literature (1) Anthropomorphic approach (2) Minimalistic approach. First approach is used in this paper that is to make the hand look and function as much human-like as possible. Human Computer Interface is the computer technology that focuses on interfaces between people and computers (Jaimes and Sebe, 2007). Motion tracking is becoming one of the key technologies and it is the process of observing the movement of object. This technology is introduced in human computer interaction.

In many researches, motion tracking algorithm and extracting the hand from the video has been used. Haar feature based cascade classifier is an effective method for face subtraction to eliminate the face in the video and then Skin color detection technique is used to extract the hand region from the video (Fanwen and Zhiquan, 2013). To capture the video optical camera is used. The improvement of convexity defects and centroid of the image has been exploited by Lai and Lai

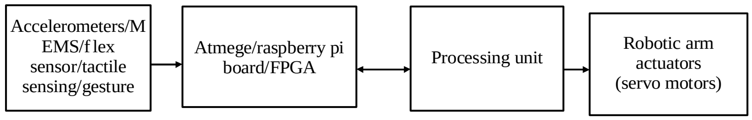

Fig. 1: Block diagram for the robotic hand control

(2014). The fingertip points are detected by Ben-Israel and Moses (2007) using starting point of the convexity defect points. It also describes the advantage of the mean-shift algorithm to track the motion of the finger. The efficient way of motion tracking using back projection method has been used by Wang *et al*. (2010). The humanoid robot is the best development of the robotic industries. This is because, the humanoid robots are expected to achieve much more performance than human hand. The design of the hand is proposed by Zollo *et al*. (2007) and Townsend (2000).

Figure 1 represent the block diagram for the control of robotic hand movement. Control signal may be produced Gesture/MEMS/Flex Sensor/Accelerometer and it in turn processed by processor/FPGA. Control word from processor is communicated to the actuator.

MATERIALS AND METHODS

Materials: Open Source Computer Vision 2.4.7, Raspberry pi b+ model, Pi-cam (Resolution 5 Mega pixel),12-kg torque DC-Servomotor, Robotic hand.

Hand detection

Face subtraction: By using Haar cascade classifier face detection is done. OpenCV contains the pre-trained classifier for face. The video sequence is converted into gray scale then by the cascade classifier we are detecting the face in the video. After detecting the face, it is eliminated from the video. Figure 2 shows that the subtracted face in the video.

Global skin color detection: Skin color detection is the process of finding skin colored pixels in an image. By detecting regions of skin, one can find the presence of faces, arms, hands and gestures. Camera module in the raspberry pi is used to capture the video. To extract the skin color from the video we need to set the threshold value for skin color. Then we need to convert it in YCBCR color space. The condition for YCBCR is:

- CR should be in the range between 135-183
- CB should be in the range between 120-154

Then morphological operation has been done for enhancement process**.** We apply Dilation on the probability image with a 9×9 rectangular mask. After that, Erosion is applied with a small rectangular mask of size 5×5. Figure 3 shows that skin color alone with face subtraction in the video.

Contour detection: Contour is a curve joining all the continuous points, having same color or same intensity. Contour is a useful tool for object detection and recognition**.** In OpenCV, finding contours are like finding white object from black background. Objects to be found, should be white and background should be black. Figure 4 shows the contour of the hand.

Fig. 2: Face subtraction

Fig. 3: Skin color detection

Fig. 4: Contour detection of the hand

Centroid of the hand (Fig. 5): To find the centroid of the hand we are using image moments function. Image moment will give the average of the image pixels intensities. For the 2D continuous function f (x, y) the moment is given by:

$$M_{pq} = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} x^p y^q f(x, y)\, dx\, dy \quad (1)$$

Centroid is given by the relations C_x = M10/M00 and C_y = M01/M00. This can be done as follows:

$$C_x = \text{Int}\left(\frac{M['m10']}{M['m00']}\right)$$

$$C_y = \text{Int}\left(\frac{M['m10']}{M['m00']}\right)$$

Convexity defects and convexity hull: The space between the contour line and the actual object is known as convexity defects. When camera is focusing our hand, four points are described in our hand as:

- Point of the contour where the defect begins
- Point of the contour where the defect ends
- The farthest from the convex hull point within the defect
- Distance between the farthest point and the convex hull

Convexity hull: Convex hull of a finite point is derived from all possible convex combination of its points. Each point in the convex combination is denoted by weight, such that the co-efficient are positive and these weights are used to estimate the weighted mean of the points. Figure 6 shows that the convexity hull and the convexity defect points of the hand.

Mean shift algorithm: A non parametric Estimator method is involved in mean shift algorithm which is proposed by Fukunaga and Hostetler (1975). The algorithm has less computation and it is useful for tracking the motion of target area. The target areas are selected manually by Duan *et al*. (2011). In this article, the target area is applied in the starting point of the convexity

Fig. 5: Centroid of the hand

Fig. 6: Hull points and defects points of the hand

defect points. Totally five windows are chosen. Mean shift is the scheme implemented in OpenCV, which is having the following steps:

- This algorithm calculates the histogram value of the object in the first frame of the video
- Back-projection technique is applied. This technique will apply the initial histogram into every new frame from the video
- It will search the high intensity region which corresponds to the area where the object tracked in first frame

Mean shift calculation: In real time application there will be more background texture and less foreground data. So it will be difficult to calculate foreground accurately hence it is better to consider foreground data approximately as α (ratio).

By following the above procedure and applying the below equation we can evaluate foreground and background which are the essential part of an intellectual hand:

$$q^T = \alpha q^F + (1-\alpha) q^B \Rightarrow q^F = \frac{q^T - (1-\alpha) q^B}{\alpha} (0 < \alpha < 1) \quad (2)$$

where, q^T→Target region, q^F→Foreground region, q^B→ background datas

Tracking algorithm: Three basic steps in tracking are:

- Approximation of foreground data α
- Background data estimation
- Next probable position can be obtained through mean shift algorithm

Figure 7 shows the target region of the foreground region.

Motion calculation: The centroid of the hand is considered as the base point. The five windows are considered as sub points. The following method is used to identify, which finger is having motion in action (Fig. 8):

Fig. 7: Image for mean shift algorithm

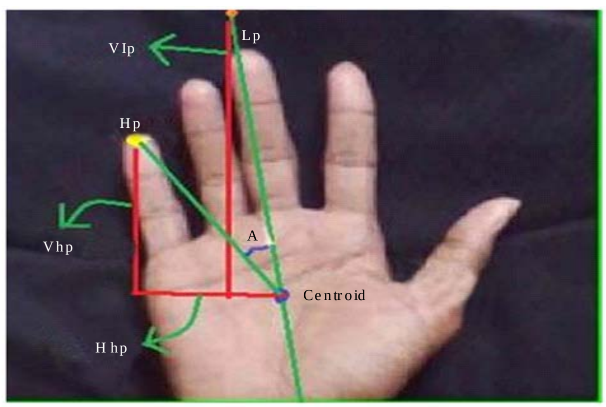

Fig. 8: Geometric relation finger tip and centroid

- (xc, yc)-centroid point
- (x0, y0)-line of intersection(lp) of principle axis and (0, y) line (implies)→(0, y0)
- (x, y)-Hull point (hp)

Vertical distances:

$$Vhp = xc-x$$

$$Vlp = xc-x0, \text{ since, } x0 = 0, Vlp = xc$$

Horizontal distances:

$$Hhp = yc-y$$

$$Hlp = yc-y0$$

Angle between principle axis and line joining Hull point (finger tip) and centroid of the palm, if Hlp and Vlp are negative or positive:

$$A = PI\text{-atan}\left(\frac{Vhp}{Hhp}\right)\text{-atan}\left(\frac{Vlp}{Hlp}\right)\text{radians}$$

(Hlp and Vlp having opposite signs):

$$A = \frac{PI}{2}\text{-atan}\left(\frac{Vhp}{Hhp}\right)\text{radians}$$

So, now we can find angle for five fingers. Now assemble the five angles in ascending order. Then we can able to identify the each finger separately.

The distance between the base point and the sub point is used to control the servo motor. If we use maximum distance between them, then the servo motor will not rotate. If we use minimum distance between them, then the servo motor will rotate to 90 degrees and then single tension cable connected with robotic finger will pull the finger to fold (Fig. 9).

Robotic hand: The challenging task is to develop anthropomorphic dexterous multi-finger robot hand. Various methods has been proposed in literature to get the precise and accurate grasp of the robot hand by Butterfab *et al*. (2001), Ramos *et al*. (1999) and Akazawa *et al*. (1996). It mimics the versatility and sensitivity of the human hand. The most important aspects to be considered are their stability, reliability and cost. Main parts of a characteristic of robot hand are not the same as human. Robot hand mechanism totally related to the cost. Simplifying the robot mechanism with less cost which is similar to human is most challenging task. In our paper the finger having four degree of freedom (up, down, forward, backward). Each finger is controlled by a DC servo motor (Fig. 10a-c).

Based on experimental analysis, we found, best design for the hand is that the single cable tension design proposal with three independently actuated joints. Therefore we used this method to mimic the movement of the finger (Fig. 11, 12 and 13).

RESULTS AND DISCUSSION

The major difference between the robot hand and human hand is the number of degrees of freedom. Different Methods are used for communication between robotic hand and human using

Fig. 9: Distance between the centroid and base points

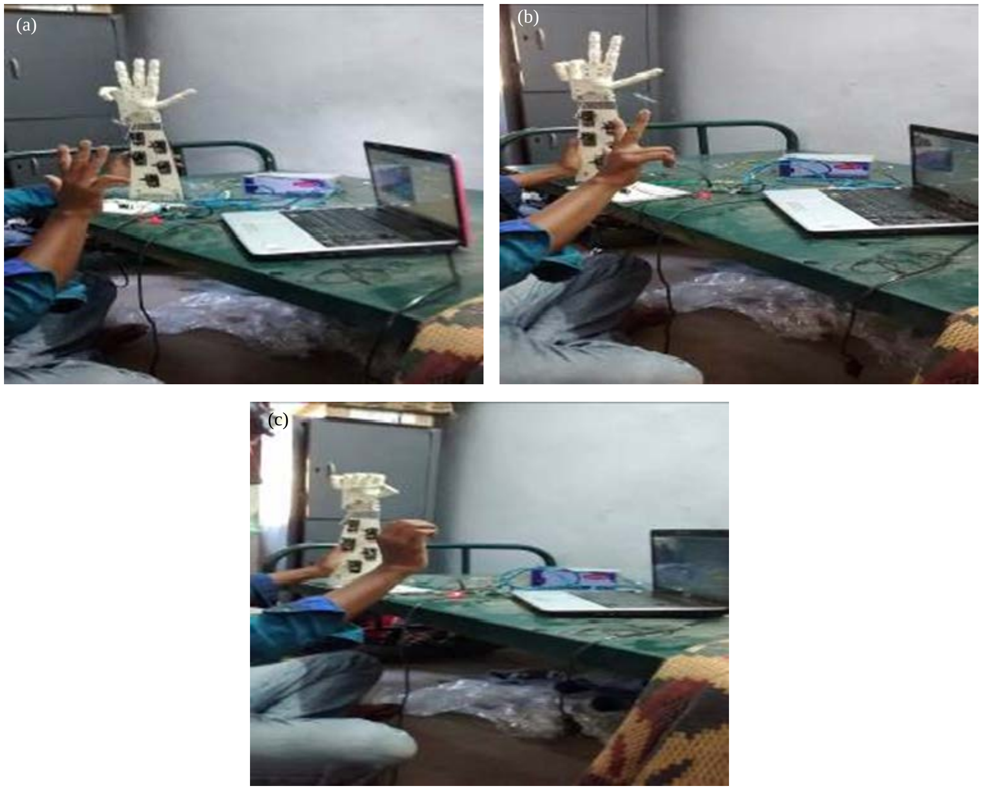

Fig. 10(a-c): Robotic arm that mimics the movement of the human hand finger, (a, b) Up and (c) Down

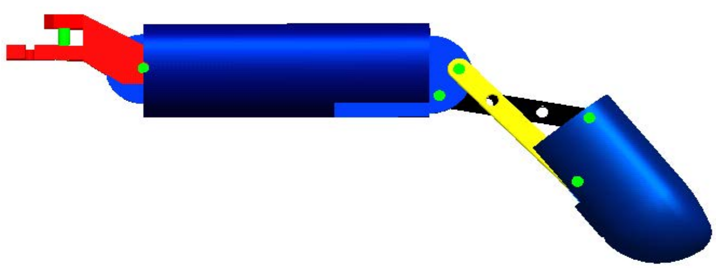

Fig. 11: Four bar linkage design approach to the robotic finger

flux sensor/Micro Electro Mechanical System (MEMS-accelerometer sensor)/gesture/accelerometer. Sensing output has to be properly interpreted and in turn actuators have to be operated accordingly.

Over the past decades the control of robotic arm movement has been controlled by using various sensors like flex sensor, MEMS, IR sensor, Tactile sensor and bio signals. Flex sensor based robotic arm is controlled by the resistance value (Syed *et al*., 2012). In the flex sensor the carbon resistive elements are placed in the flexible substrate. Flex sensor is placed in each finger. The resistance values will be changed due to the amount of bend in the flex sensor. According to the change in resistance value the robotic arm is controlled (Fig. 12). Gesture and angular position is determined

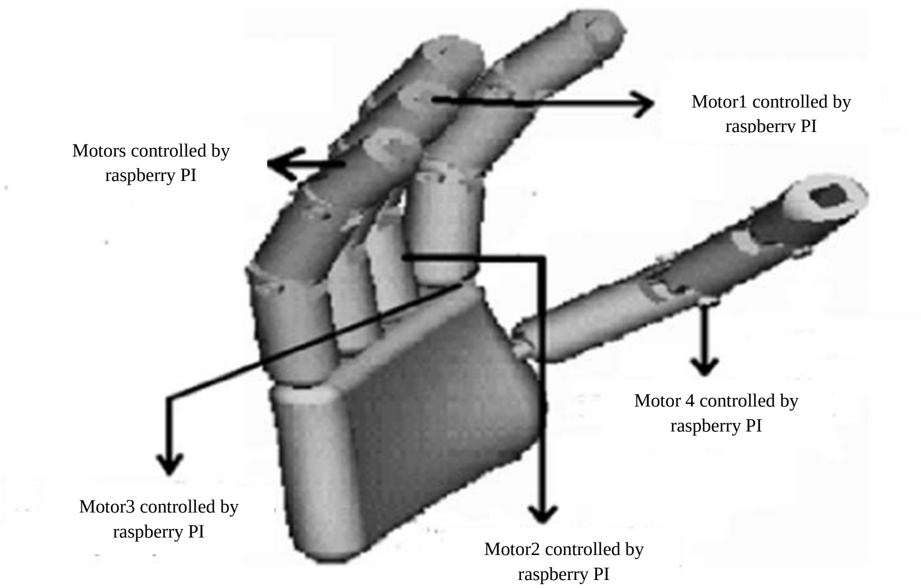

Fig. 12: Robotic hand

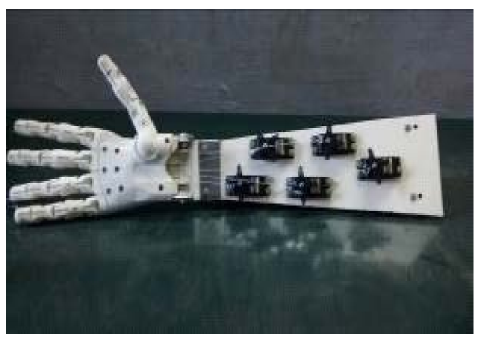

Fig. 13: Robotic fingers connected with servo motors

by 3-axis accelerometer and 3-axis gyrometer (Bhuyan and Mallick, 2014). The hand motion is controlled by the data of three different analog voltages (x, y and z) in three dimensional motion. Gifu Hand-II developed with distributed tactile sensor has a high potential to do dexterous object manipulation (Kawasaki *et al*., 2002). Hand gesture recognition using data glove and accelerometer is proposed by Dharaskar *et al*. (2012). The data glove capture hand motion using accelerometer sensor. Biological signals Electroencephalogram (EEG), Electromyogram (EMG), Electrocculogram (EOG), Electrocorticography (ECoG) are also used for controlling the robotic hand. Brain activated mobile robot is reported by Del R. Millan *et al*. (2003). The EMG based high level human robot interaction is proposed by Rani and Sarkar (2005). The EMG based real time high level online control system for robotic arm is proposed by Shenoy *et al*. (2008). Control of robot hand using Electrocculogram and voice recognition is proposed by Martinez *et al*. (2013). In this study, vision based control is used to overcome the cost of sensor and the complexity of the hardware designing like, user must wear the hardware device which reduces the user convenience. This method does not need any specific hardware device like gloves, etc. Biological signal controlled robotic hand is highly desirable for the disabled persons. Further for dexterous object manipulation rigorous training with different gestures is needed. The drawback of proposed method compared to sensors are that, it will work only under good lighting condition.

CONCLUSION

In order to extract the finger motion instantaneously and accurately, mean shift algorithm is used for tracking. Five windows are declared for five fingertips to detect the motion of the fingers. The windows are declared in the starting point of the defect point. Motions are calculated using mathematical operation. The centroid was found and it is taken as base point and the windows are considered as sub points. Using the difference between the base point and the sub point the motion is detected. Based on the distance values the each servo motor is rotated. A single tension cable is attached with these motors to control the hand. This approach leads to high robustness in real time application. Further, refinement is needed to solve the problem in motion tracking speed and to improve the accuracy.

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