Robotic Pick and Place Using Two-Finger Touch Sensing

Revanth Kondaveti, Venugopal P, Shivani Rai

Abstract: ***Pick and place robots are gaining popularity in the current era due to their ability to handle objects of varying sizes and dimensions. Research to improve the efficiency and design of these manipulators is currently the need of the hour. In this, a new and novel mechanism has been introduced; it is called Blind man Mechanism that is to find the object and to find shape of it. Shape Recognition algorithm to improve the hold on the object. It involves analysis of working of the human thumb and shape of the object. The Blind man mechanism allows object to be found, even when it is not in its usual position. It includes details about the thumb analysis to find an object, which further includes shape recognition of different objects in multiple scenarios also results for whether the object has been found or not. If found so verify for a pick place robot using MATLAB results***

Index Terms: ***Blindman's Mechanism, Grasp, Object, Pick, Place, Shape.***

I. INTRODUCTION

The end effector and its effectiveness are the most important part of the robotic arm used in industries and multi fingered robots [1] [2]. Mostly, the objects are placed in a fixed position from where the manipulator picks it up and places at the desired location [3]. However, there are applications where the arm has to find the object on its own. This can be done using the proposed Blind man's mechanism, similar to a blind man looking for objects around him. Every iteration uses the thumb to look for the objects. Thumb plays a major role in detecting and grasping the object [4]. Once detected, the perfect position to grab the object is found for pick and place activity. After analysing the working of human thumb, the results are used to simulate the entire process of finding an object. This project is voice-controlled allowing the user to control the find, pick and place activity.

Many variations of the pick and place robots are available in the market and have successfully been implemented in the industries. Only drawback is that, they are designed to just pick and place the objects. They will not be able to pick them up if they are slightly misplaced. Mimicking human arm-wrist-finger behaviour is the best way to solve this issue. Robots working on Blind man's mechanism will be able to work even when objects are not placed in the desired position. Thus, unnecessary delay is reduced. Market values both quality and cost. Thus, a cheaper mechanism with better results is most desirable.

Most of the present methodologies rely on computer vision for detecting objects. Computer vision involves intensive image processing to recognize and detect the object [5]. The background may sometimes cause lot of trouble while processing. The paper "Object Detection and Recognition for a Pick and Place Robot" has described an algorithm to detect and recognize objects using feature extraction.

Once an object is detected, the next task is to pick the object [6]. "Visual grasp planning for unknown objects using a multi-fingered robotic hand" uses computer vision to analyses how to grasp any unknown object. The algorithm consists of object surface reconstruction algorithm and a local grasp planner. The photos of the object taken help reconstruct a virtual elastic covering taking the shape object. The grasp planner looks for the optimal position to pick it up. Coordinates can be specified to place the object. Deployment of robots in various environments is making it necessary to make autonomous robots [7]. They are being equipped with various capabilities to work without human interference.

The conventional methods either follow image-based or position-based pick and place. Some require prior knowledge of the object's position and shape for it to complete the task [8]. The disadvantage is that manipulators have to be designed for every object that is not the same. The manipulators are rendered useless even if there a slight change is the color or the size. Some object recognition techniques even facilitate object recognition and identification form prior knowledge [9]. Such methods focus on categorizing the objects using vision-based methods [10] [11].

The grasping capability of human hands is greater and more efficient because of the presence of thumb [12]. The opposing motion is what makes the grip perfect and efficient. This, in the robotic world, will make it simpler for the manipulators shaped just like human hands to handle objects in the industries [13]. Most of the applications rely on thumb just for its grasping capabilities. This paper uses thumb to implement the Mechanism**.** The proposed mechanism can be used without visual aids or without cameras. Object also can be found with even one touch sensor and report through communications. Object can be found using a single microphone and one touch sensor and shape recognized using two touch sensors and can be hold using two to five touch sensors.

II. METHODOLOGY

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Proposed Mechanism:

The proposed mechanism involves techniques that can be categorized as follows:

a) Object Search
b) Shape Recognition
c) Grasp
d) Pick and Place

A two touch sensors fingered approach allows the object to be found without the aid of visual sensors. This mechanism ensures that an object is found even when misplaced from its position. Recognizing the object's shape helps identify a better grasp. Point-to-point trace of the object is compared with the pre-fed shapes to call the predefined grasp function. The following section gives detailed information on the above-mentioned techniques.

I. Object Search

The proposed Blind man's mechanism for searching objects is a 3-dimensional technique. This paper focuses on the use of the thumb to search for an object. The power consumed will be less when compared to the power consumed on activating all fingers at once, considering a robotic arm. Opposable fingers help to grasp, hold and place objects collectively. On

$N = b_l \times b_r \times b^2_n$ (1)

N is the dimensional shape descriptor at scale h.

Lengths L_{AB} are binned in b_l bins in log space.

Normal angles are binned in b_n angles.

Chord orientation in b_r bins.

$N_a = N'_a - \phi_{ab}$ (2)

$N_b = N'_b - \phi_{ab}$ (3)

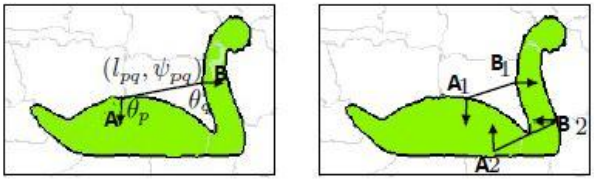

Figure 1: (a) Chord Features, (b) Normal of two chords

Once chord is detected then the using the segment detection where outside the object is considered to be one and inside the object is zero. When the chord distance is zero it, it is the boundary point of an object. In general, the object is held through maximum chord distance [17] [18].

Where **N_a and N_b are normals at the points a and b on the object, and ϕ_{ab} is the orientation of the chord.**

Thus, the features on the chord (F_{ab}) is written as

$F_{ab} = (L_{ab}, \phi_{ab}, N_a, N_b)^T$ **(4)**

Where L_{ab} is the length.

To find the difference between two shapes we can use any type of metric between the chordiogram extracted from the shapes. In the experiments conducted further, we need to use L1 distance between L1-normalized chordiograms, which we will call chordiogram distance:

D (u, v) = ||u/||u||1 − v/||v||1||1

(for two chordiograms u and v) **(5)**

comparing the fingers in the human hand individually, we find that the thumb has the ability to cover a larger area because; the anatomy of human hand restricts the free motion of other four fingers as compared to the thumb.

The fingertips have a capacitive sensor to detect the contact with the object. The process iterates until the object is found. The search for an object stops when the thumb senses its presence. The whole mechanism mimics the way a blind person looks for an object, thus the name.

II. Shape Recognition

A point-to-point approach is employed to trace the shape of the object found [14]. The thumb randomly chooses a fixed point on the object, making it the reference point. The other fingers work to trace the object, till they make it back the reference point. After constructing the traced image, it is compared with the pre-defined shapes to choose the perfect grasp. The process of correlation is used to compare the shapes. The shapes considered here are circle/ellipse and square/rectangle. Chorogram is process that performs the same process but in K-dimensional scale [15] [16]. It is used for grip of an object while holding the object.

III. GRASP

Recognition is used for understanding the shape of object. Grasp is used for finding the object based on human finger grasping the object.

The process of grasp [19] is necessary to ensure the object safely held, neither too loose, nor too tight. This process may require all the capacitive sensors to be activated or may depend on the type of grasp coded into the machine based on the shape detected. On grasping, the proximity of the conducting plates varies causing changes in capacitance and change in current.

$$\text{Capacitance} = \frac{\text{Dielectric constant X Area}}{\text{Distance}} \quad (6)$$

The box-based approximation can also be used for detecting the type of object [20]. Which identifies object using simple box. Wraps the object with

Once the object is found, the origin is assumed to locate the points based on edge of object detected [9].

Algorithm

In the Algorithm [20], Shape based Object Detection via Boundary Structure Segmentation recognizes shape using camera and visual aid. The object detected using taken a photograph. Using this algorithm we don't need a camera.

Az≤d **(7)**

Where, z is represents the vertices of the polyhedron, A is a (4x3) matrix with rows being the transpose of the normal unit vectors, d is a (4 x1) vector whose elements define uniquely the positions of the planes in the space[20][15].

Once all the vertices $Z_v = [Z_{vx}\ Z_{vy}\ Z_{vx}]^T$ of the polyhedron P are found out, the central moments can be found with the help of the following,

$\mu_{i,j,k}=\sum_{z_v \in P}(z_{v_x} - \overline{z_{v_x}})^i + (z_{v_z} - \overline{z_{v_z}})^k$ **(8)**

Where,

$$\overline{z_v} = [\overline{z_{v_x}}\ \overline{z_{v_y}}\ \ \overline{z_{v_z}}]^T = \frac{1}{n_v}\sum_{i=1}^{n_v} z_{v_i}$$

(9)

The pseudo inertia tensor of the polyhedron is defined as

$$I=\begin{bmatrix} \mu_{2,0,0} & \mu_{1,1,0} & \mu_{1,0,1} \\ \mu_{1,1,0} & \mu_{0,2,0} & \mu_{0,1,1} \\ \mu_{1,0,1} & \mu_{0,1,1} & \mu_{0,0,2} \end{bmatrix} \quad (10)$$

Where the eigenvalues and eigenvectors specify the principal axes of inertia of an ellipsoid, enlarged to guard object wrapping, which is made the initial shape of the reconstruction surface.

Basic forces can be written as,

$$b\dot{z}_{I,j} + k(z_{i,j} - z_{i-1,j}) + k(z_{i,j} - z_{i+1,j}) + k(z_{i,j} - z_{i,j+1}) + k(z_{i,j} - z_{i,j-1}) = f_{i,j}(z_{i,j}) \quad (11)$$

For i = 1, . . . , n_m and j = 1, . . . , n_p , where $z_{i,j}$ is the position of the sampling point at the intersection of the ith meridian with the jth parallel. Vector $f_{i,j}$ is the external force acting on the point $z_{i,j}$, repulsive with respect to the border of the visual hull V and is different from zero only when $z_{i,j}$ comes into V

$$f_{i,j}(z_{i,j}) = \begin{cases} \alpha_{i,j} F_a n_{i,j} & x_{i,j} \in V \\ 0 & otherwise \end{cases}$$

(12)

Where $n_{i,j}$ is the unit vector normal to the surface at $z_{i,j}$, protruding from the object, and $\alpha_{i,j}F_a$ is the amplitude of the force. In detail, F_a is the maximum force module and $\alpha_{i,j} \in (0, 1]$ is a strictly decreasing sequence of scale factors defined as

$\alpha_{i,j}(k + 1) = \varepsilon\alpha_{i,j}(k)$ (13)

$\alpha_{i,j}(0) = 1$ (14)

where $\varepsilon \in (0, 1)$ and a new value of the sequence is computed every time point $z_{i,j}$ comes out from V.

Collecting some terms in the previous dynamic equation of the system, a more compact expression is

$$b\dot{z}_{I,j} + k(4\ z_{i,j} - c(z_{i,j})) = f_{i,j}(z_{i,j})$$

(15)

Where, in the expressions, the points with subscript coincides with those with subscripts, respectively.

$$c(i,j) = z_{i-1,j} + z_{i,j+1} + z_{i+1,j} + z_{i,j-1}$$

(16)

$$i-1 = j-1 = 0 (i+1 = n_m + 1\ and\ j+1 = n_p + 1)$$

$$i-1 = n_m\ and\ j-1 = n_p (i+1 = j+1 = 1)$$

The two poles have to be treated distinctly, due to topological differences,

$$b\dot{z}_{np} + k\left(n_m z_{np} - \sum_{j=1}^{n_m} z_{1,j}\right) = f_{np}(z_{np})$$

(17)

For the north pole (np), and

$$b\dot{z}_{sp} + k\left(n_m z_{sp} - \sum_{j=1}^{n_m} z_{np,j}\right) = f_{sp}(z_{sp})$$

(18)

For the south pole (sp),

$$f_i' = f_i - (f_i^T v_i) v_i \quad (19)$$

Where, f_i is the force vector, f_i' is the projection of force f_i, and v_i is the normal unit vector to the surface at point p_i.

During the action of grasp, the contact points do not always belong to the same plane. The plane Π which minimizes the distance from all the points contact is taken into accpunt and used to compute the projection p^{Π}_i of contact point p_i on Π , with i = 1, . . . , n_f , being n_f the number of fingers of the hand. Moreover, let c_m denote the center of mass that is estimated of the current shape of the object (assuming uniform mass distribution) and let c^{Π}_m be the projection of c_m on Π.

To account for the different quality indices, the (virtual) force vector f_i at contact point p_i is computed as the sum of a number of (virtual) force contributions:

$$f_i = f_{\pi i} + f_{ei} + f_{ai} + f_{c_m} + f_{bi}$$

(20)

Where,

1) $f_{\pi i} = k_\pi (p_i^\Pi - p_i)$ is the virtual force which moves p_i to p_i^Π, so that all the contact points belong to same grasp plane.

2) $f_{ei} = k_e(\theta_i - 2\pi/n_f)t_i$ is the virtual tangential force in charge of producing an equilateral grasp configuration, where θ_i is the angle between vectors $p_i^\Pi - c_m^\Pi$ and $p_j^\Pi - c_m^\Pi$ with $j = i + 1$ for $i = 1, \ldots, n_f - 1$, and $j = 1$ for $i = n_f$, and t_i is the tangential unit vector normal to $c_m^\Pi - p_i^\Pi$ and pointing toward p_j^Π.

3) $f_{ai} = k_a(p_i^\Pi - c_m^\Pi)/\| p_i^\Pi - c_m^\Pi)\|$ is the virtual force which tends to enlarge the area of the grasp polygon.

4) $f_{c_m} = k_{c_m}(c_m - c_m^\Pi)$ is the virtual force, equal for all the contact points, which attracts the grasp plane Π to the center of mass c_m.

5) f_{bi} is the virtual barrier force, that avoids the motion of the fingers along directions that cause the reaching of joint limits, joint or hand singularities, and the collision with either fingers or with the palm.

Parameters k_π, k_{c_m}, k_e, k_a are positive constant coefficients, selected to weigh the single force contributions.

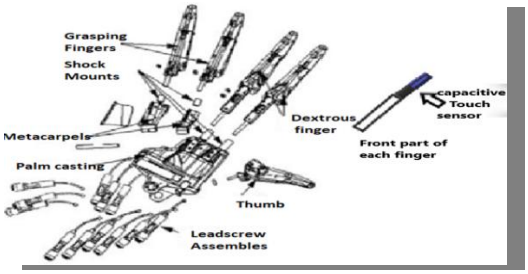

Figure 2: Grasping shape of Robonautica arm for commonly used shapes [21].

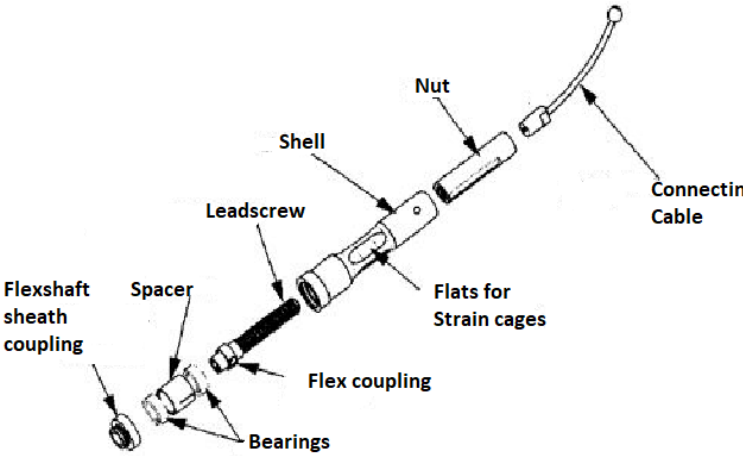

Figure 3: The mechanism of finger without capacitive touch sensor.

IV. PICK AND PLACE

Depending on the application, the arm picks up the grasped object and places it in the required position. The pick-place mechanism made voice-controlled as an add-on feature. Correlating the input voice with the reference voice will guide the arm accordingly. If the input voice signal and the reference signal have a correlation value greater than or equal to 90, the command is executed.

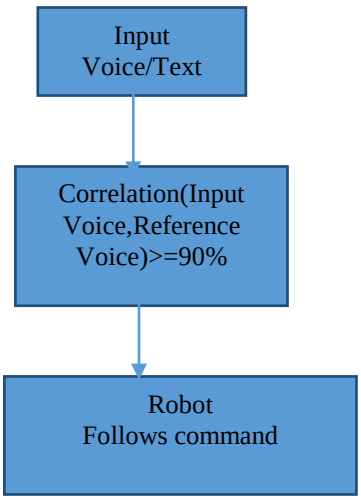

Figure 4: Voice input processing

Correlation need not be greater than 90%. Considering correlation greater than 90% accuracy of voice given by the controlled person.

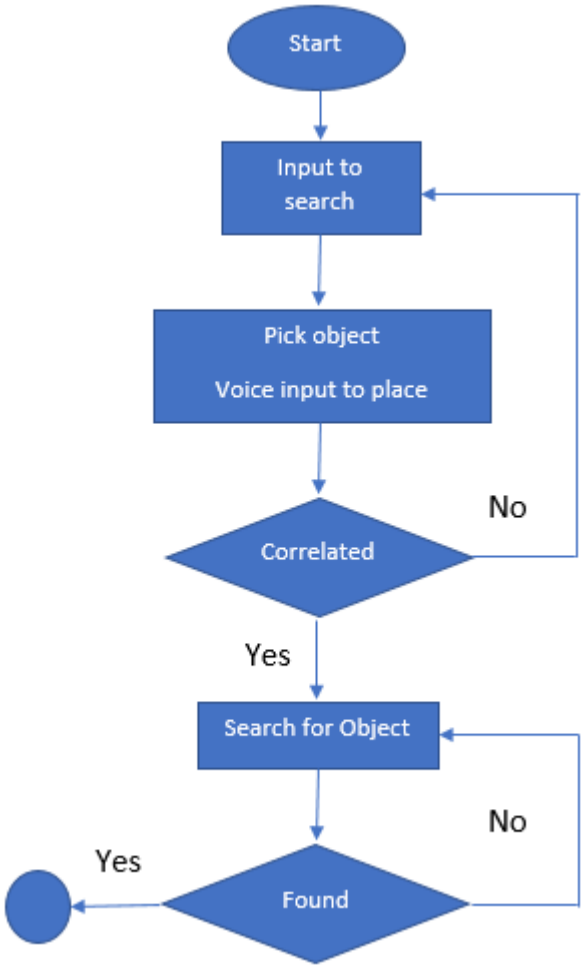

Figure 5a: Flow chart of the mechanism

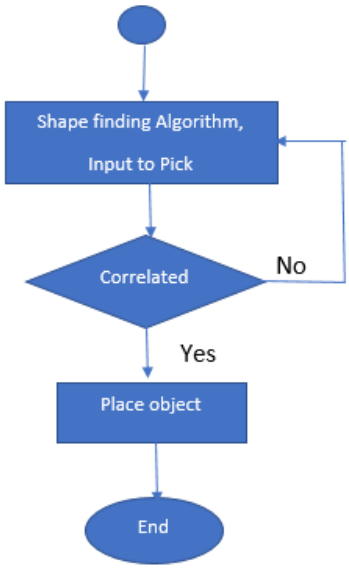

Figure 5b: Flow chart mechanism

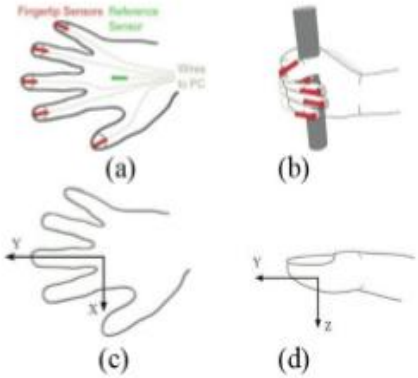

Figure 6: Description of the setup of the sensors. (a) Position of the sensors on the fingers (red) and of the reference sensor on the dorsum (green). (b) Example of grasp posture. (c) and (d) Coordinate system used in the analysis

Results:

Human thumb movement was analysed to understand the area that covered by its rotational motion. The result of the thumb movement analysis given at Figure 6,7,8,9. Figure 6,7,8,9 represents the area covered during through a point in an iteration for searching the object.

Finding an object followed by pick-place:

Object 1: A stone has been simulated and fed in a 3D digital space with a certain distance. While thumb is used for searching the object, where the position of placing an object is not disclosed and results for algorithm as follows. In this object is recognized.

Figure 7, 8 understands about the finger movement in a 3D space with total iterations; which helps determining whether object has been found or not and also shows where it has been checking for the object. Figure 8 helps to understand total area covered while searching for object. Figure 10 understand how many iterations took to find the object. It is also similar representation in 2-Dimension.Once the object is found, Origin is the first point where it contacted the object in Figure 11. Here in Figure 12 and Figure 13 the boundary of object is recognized using chordiogram technique. Where normal and chords are used to determine the boundary.

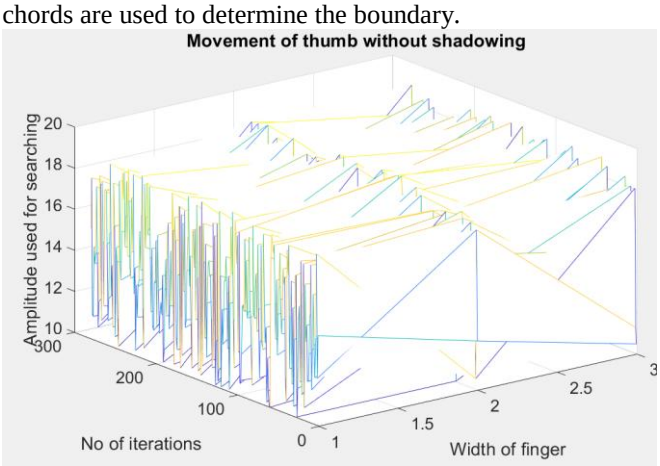

Figure 7: Movement of fingertip for searching the object in all the directions.

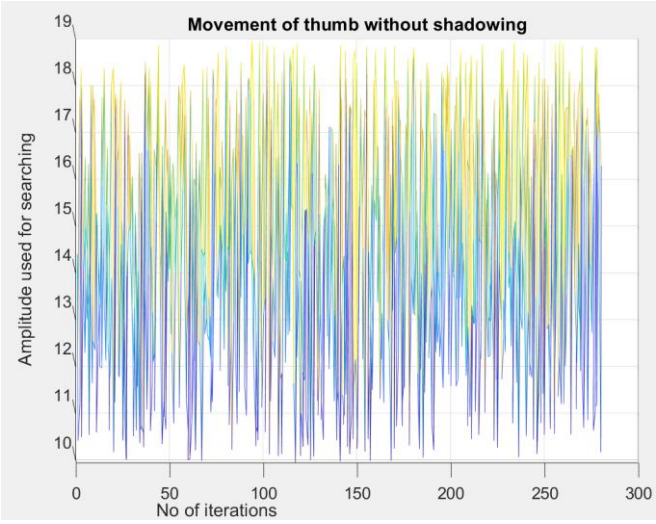

Figure 8: Movement of axis thumb till object is found.

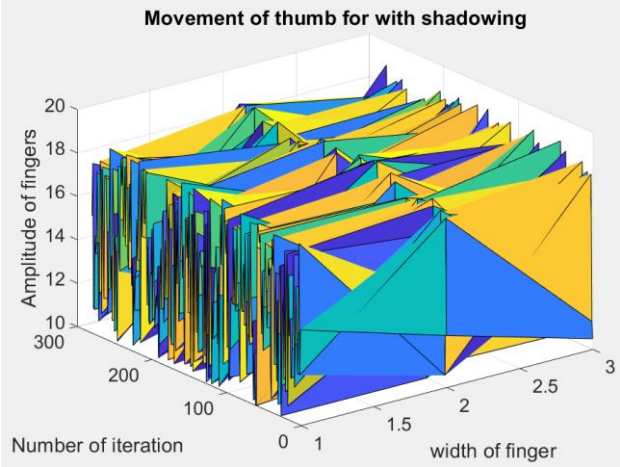

Figure 9: Movement of fingertip for searching the object in all the directions and the area covered while searching

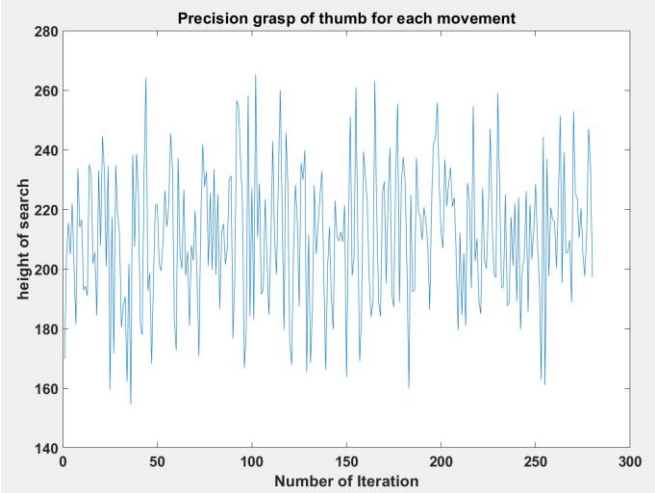

Figure 10: Precision grasp of a finger to find an object

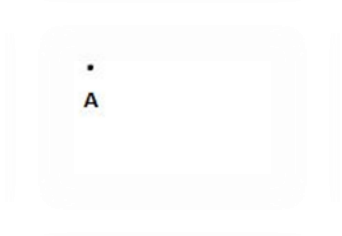

Figure 11: Assumption of origin to find an object

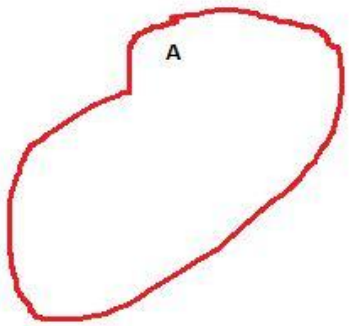

Figure 12: Object placed and shape of the object shown

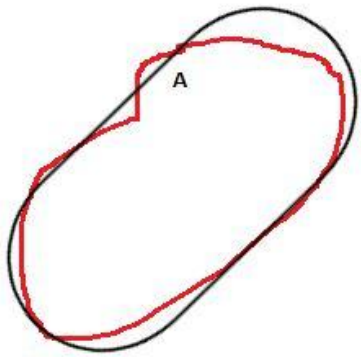

Figure 13: Object whose shape is recognised

Object 2: A mobile phone has been simulated and fed in a 3D digital space with a certain distance. While thumb used for searching the object, where the position of placing an object is not disclosed and results for algorithm as follows. In this case, object found using box-based method [19]. Figure 14, 15 understands about the finger movement in a 3D space with total iterations; which helps determining whether object has been found or not and also shows where it has been checking for the object. Figure 16 helps total area covered while searching for object. Figure 17 understand how many iterations took to find the object. It is also similar representation in 2-Dimension.Once the object is found, Origin is the first point where it contacted the object in Figure 18. In Figure 19 Object shape determined by chordiogram method. Figure 20 shape recognized.

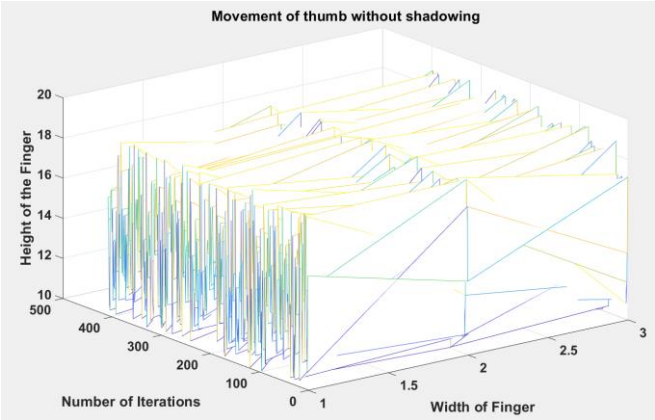

Figure 14: Movement of fingertip for searching the object in all the directions.

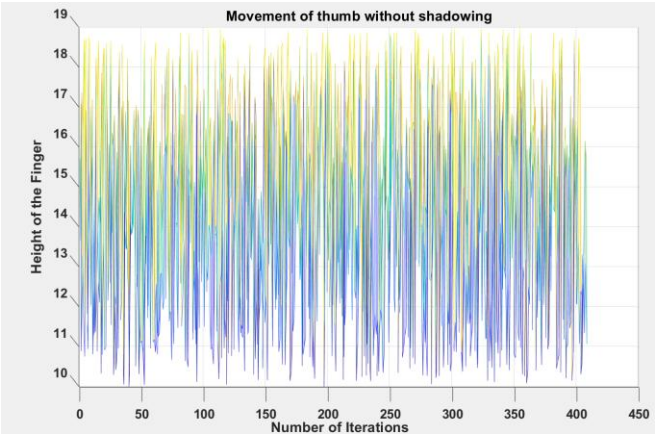

Figure 15: Movement of axis thumb until object found.

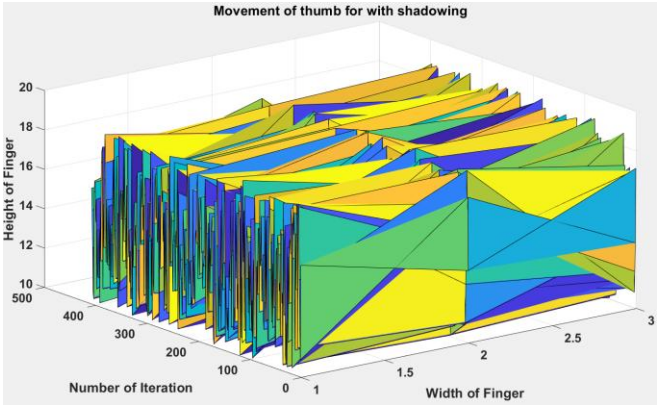

Figure 16: Movement of fingertip for searching the object in all the directions and the area covered while searching

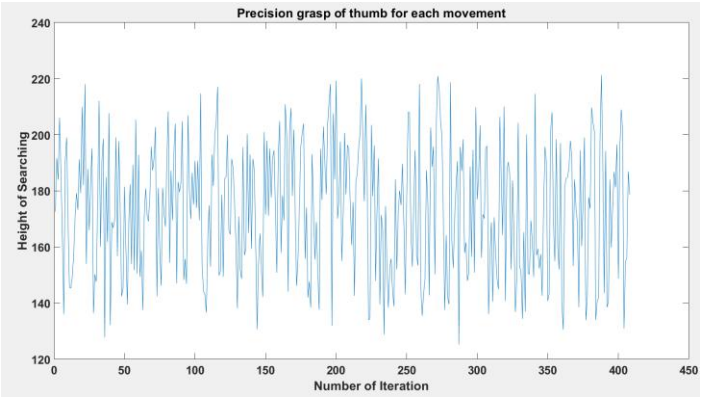

Figure 17: Represents the precision grasps. It also represents the height of searching and amplitude of searching

ss

Figure 18: Assumption origin on the object

Figure 19: Object placed and shape of the object shown

Figure 20: Object whose shape is recognized

Analysis of outputs obtained from MATLAB:

Object 3: No object has been simulated or fed in a 3D digital space. While thumb used for searching the object, where the position of placing an object is not disclosed and results for algorithm as follows. Figure 21 understands about the finger movement in a 3D space with total iterations; which helps determining whether object has been found or not and also shows where it has been checking for the object. Figure 22 helps total area covered while searching for object. Figure 23 understand how many iterations took to find the object. It is also similar representation in 2-Dimension.As the object has not been found, there will not be any Shape determination and recognition.

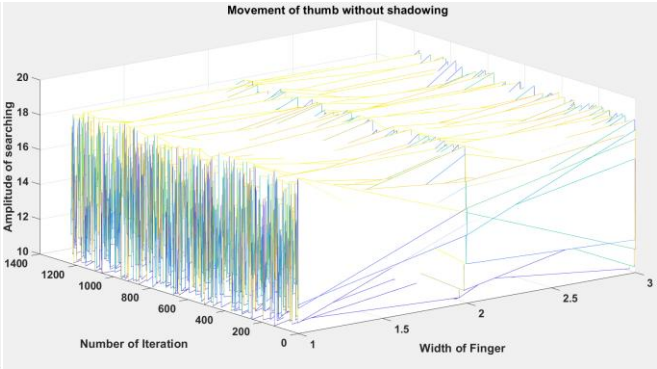

Figure 21: Movement of fingertip for searching the object in all the directions.

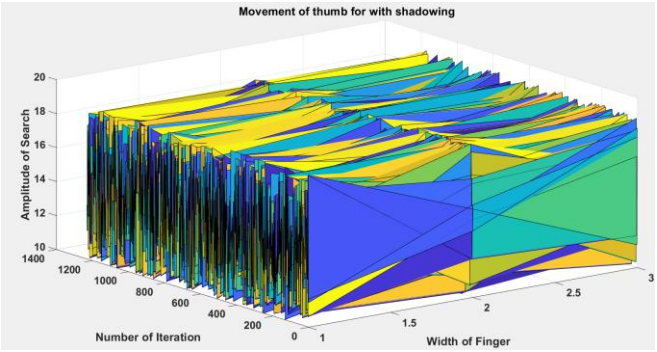

Figure 22: Movement of fingertip for searching the object in all the directions and the area covered while searching

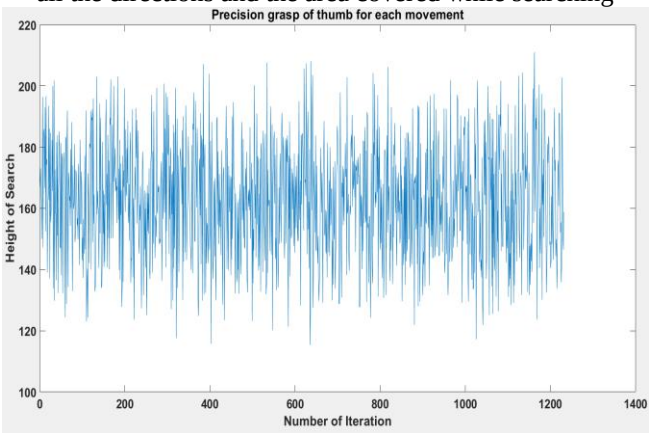

Figure 23: Precision grasp to find an object

In this situation, object is not placed. Thus, the output showed that the object not found within the maximum iteration search number.

Table 1: Objects tested with (Summary)

Serial number	Object placed	Number of iterations	Object found for iteration
1	Stone	500	237
2	Mobile Phone	1000	810
3	None	1250	object not found

Table 2: Results for Object Pick, Hold, Place

Object	Object Found	Object Held	Object Placed
Object 1 (Stone)	✓	✓	✓
Object 2 (Mobile Phone)	✓	✓	✓
Object 3 (None)	×	×	×

Table 1 represents the object that has been found for Number of iterations. Table 2 represents whether the object has been found or not or if found it is held or not or if it is placed or not.

Conclusion:

To implement Pick Place algorithm where shape plays a priority for an unknown object. Considering three different scenarios, firstly a stone placed in an imaginary three-dimensional space. In which object is found using thumb grasp. Once the object found, it undergoes shape determination using chordiogram. Shape of object is determined using either of box-based method or of ellipsoid method. If the object is the required object it undergoes pick place algorithm to pick and place an object by a robot. Similarly, it undergoes same procedure for scenario 2 to implement algorithm. Whereas in scenario 3 the object is not found because object is not placed. As, the object is not found process terminates and does not go undergo either shape recognition, shape determination or Pick place algorithm. Thus, Using Blind Man's mechanism robot has successfully implemented Pick place algorithm

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Future scope

In real time, fingers of robot can include with touch sensors such as, capacitive or inductive. Better wrist, shoulder and finger movement gives much better performance in finding the object and determining the shape of it.

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