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Design and Control of Dual-Arm Cooperative Manipulator using Speech Commands

N. Saravanan, R. Sivaramakrishnan

Abstract: Cooperative manipulators are among the subject of interest in the scientific community for the last few years. Here an overview of the design and control of such cooperative manipulators using Speech Commands in English, Hindi, and Tamil is discussed. Here we choose two identical Robot arms from lynxmotion, and both manipulators move in conjunction with one another to achieve more payload while grasping or handling the object by the end effector. The simultaneous control of identical robot manipulators could be performed by pronouncing simple speech commands by the end user using a smartphone, which then is converted into text format using a speech recognition engine and this text fed to servo controller helps in actuating the joints of identical robot arms. Cooperative manipulators are used for handling radioactive elements and also in the field of medicine as rehabilitation aid and also in surgeries. An Android app specifically built for this purpose communicates through Bluetooth technology makes the interface for end-user simple to control both identical robot arms simultaneously.

Keywords: Cooperative manipulators; Speech Recognition and Control; Android Application; Assistive manipulators;

I. INTRODUCTION

Cooperative manipulators[1] refers to the cooperation of two serial manipulators that physically interact with an object, apply forces on it to move or perform a specific task. They were introduced to replace dirty, difficult and dangerous jobs in manufacturing. Goertz constructed a cooperative manipulator in the 1940s for handling radioactive substances.

Dual-arm manipulators were considerably improved from then, yet its control is still conventional. Such Cooperative manipulators are challenging to control and hence, we define speech-based interfaces to control two identical robot arms.

Speech Recognition is a complex problem where string of words is associated to speech in contrast to the way where human recognize speech relating to concepts. In Automatic Speech Recognition, recognition is performed seeking the string of words that best match the acoustic observations according to the available model as shown in Figure 1. All variability in speech including

- Vocal Range (pitch and formant frequencies)
- Age, gender of the speaker
- Voice Quality
- Accent
- Emotional State
- Speech Style

Should be nullified to convert speech to text form.

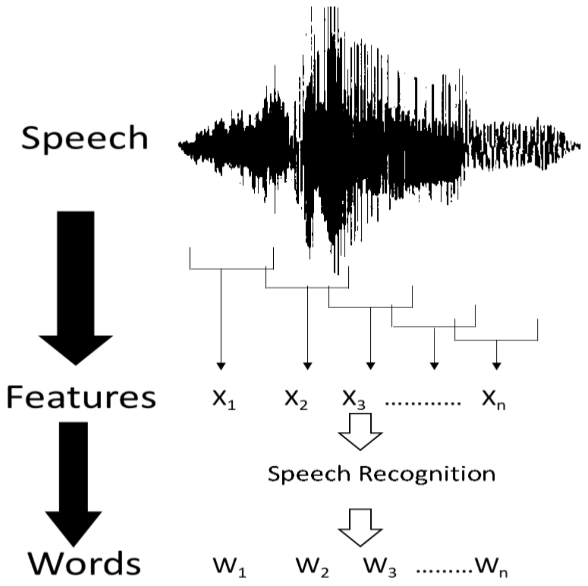

Figure 1 Conversion of Speech to text

Here, conversion of speech in Indian languages including English, Hindi and Tamil to string of words in corresponding language is done that frames in to sentences. These sentences could act as a control command for actuation of dual-arm Cooperative manipulators. The block diagram of speech-based control of two identical robot arms is as shown in Figure 2.

II. DESIGN AND SELECTION OF TWO IDENTICAL ROBOT ARMS

Any Two Robot Arms with Twisting-Revolute-Revolute with additional pitch and yaw Configuration would be applicable for cooperative operation assisting in surgical tasks or assistive rehabilitation aid[2]. Two identical robot arms from lynxmotion were selected and these assembled robot arms may be fitted into either side of a wheelchair for assistive aids or may be used in surgeries where two robot arms need to work in conjunction with one another.

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Two Kinova Jaco Spherical Robot arm can also be used for the same purpose. Kinematic Analysis of Robotic Arms[3] is done theoretically and programmatically to achieve consistency in point-to-point control of dual-arm robot arms. Such dual-arm robots could be deployed and controlled in a remote way through existing wireless technologies for handling difficult jobs like cleaning the gutter, handling materials emanating heavy radiation and many more.

Here we use Statistical based Speech Recognition Models to convert sequence of speech over time to text. CMU Sphinx API[4] built using Hidden Markov Model recognizes short vocabulary speech in English, Hindi and Tamil. Appropriate Language Models, Acoustic Models and Lexicon were generated for the above Indian languages and training using Baum-Welch Re-estimation procedures were done.

In Table 1 we describe the link lengths and base radius of both robot arms. Here in Figure 3, we present a pictorial representation of two identical robot manipulators grasping an object. Here in Figure 4, we present a CAD model of two identical robot arms acting in conjunction with one another.

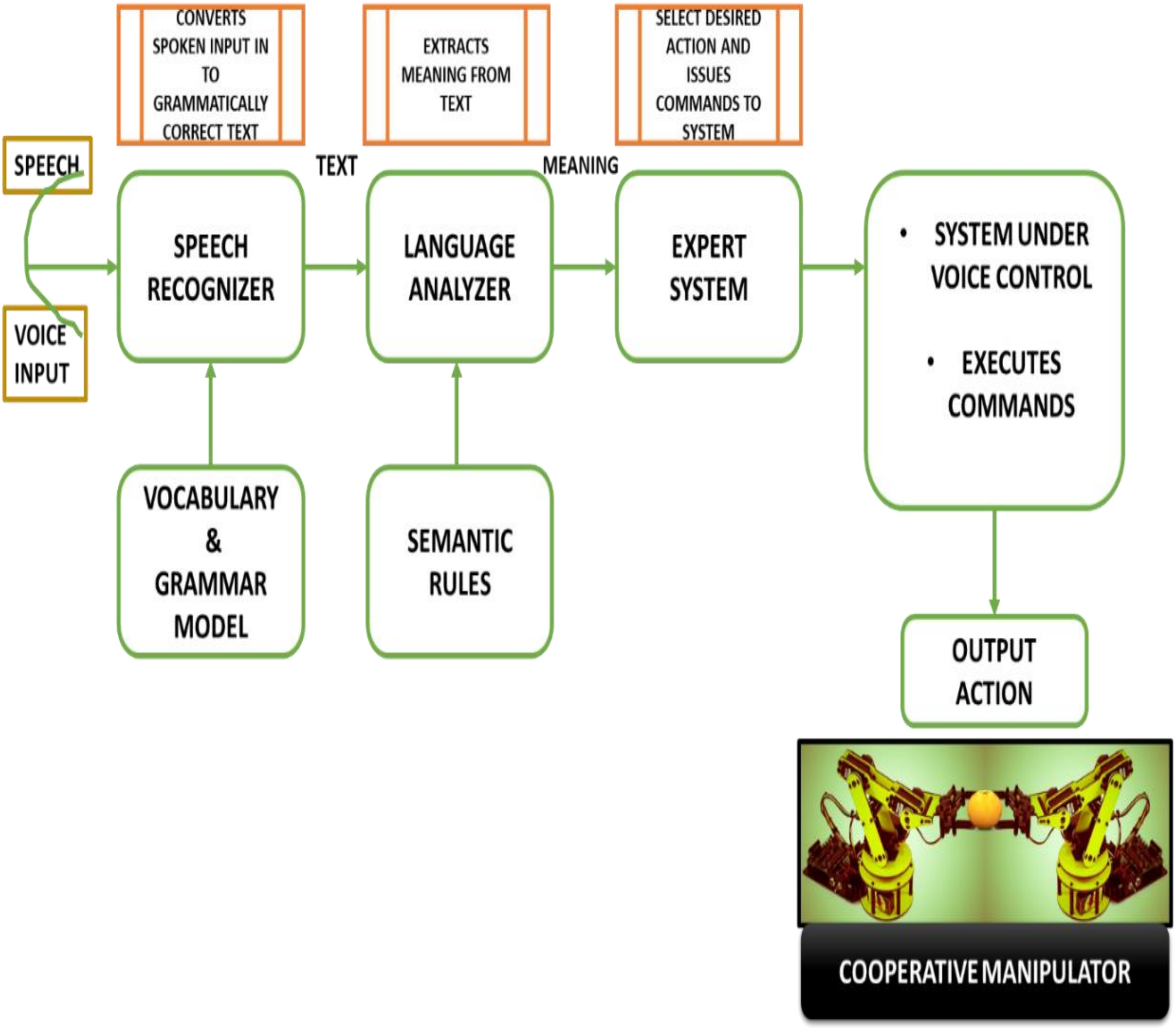

Figure 2 Block diagram of speech-based control of two identical robot arms

Table 1 Link lengths and base radius of both robot arms

ROBOT-A	Inch	Cm		**ROBOT-B**	Inch	Cm
Base Radius	1.94	4.928		Base Radius	1.94	4.928
Base height	3.11	7.899		Base height	3.11	7.899
Forearm Length	4.75	12.065		Forearm Length	4.75	12.065
Arm Length	4.75	12.065		Arm Length	4.75	12.065
Hand Length	5.61	14.249		Hand Length	5.61	14.249

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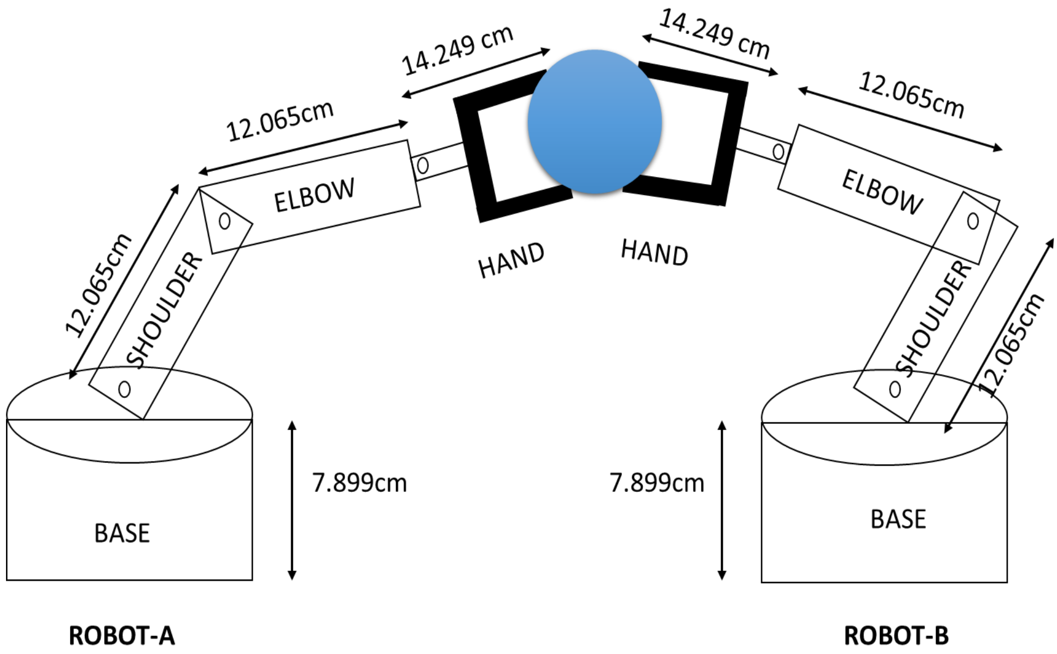

Figure 3 Two identical robot manipulators are grasping an object

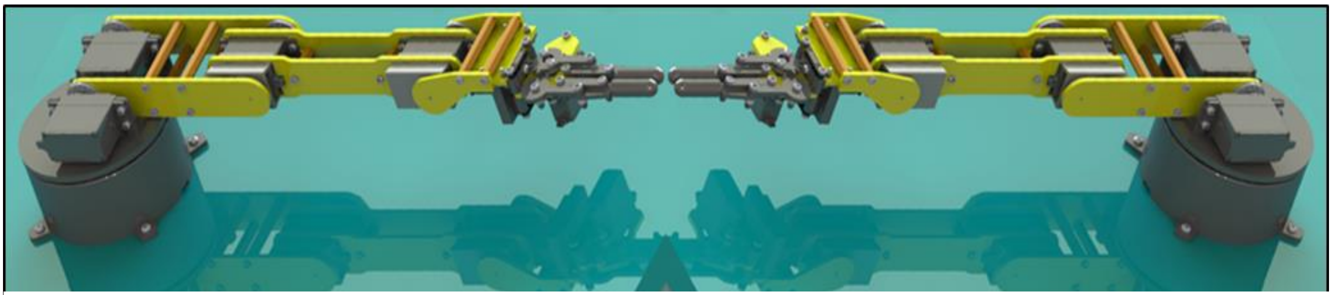

Figure 4 CAD model of two identical robot arms

III. KINEMATIC ANALYSIS OF T-R-R CONFIGURATION ROBOT ARMS

Kinematics[3] is the examination of the motion of robots. It can be Forward Kinematics, wherein Cartesian coordinates are found using Joint angles and Inverse Kinematics, wherein Joint space coordinates are found using Cartesian Coordinates.

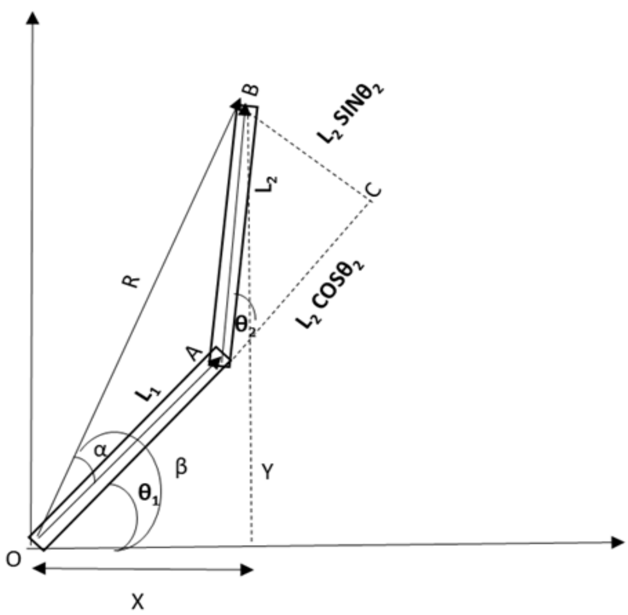

Figure 5. Schematic Representation of two degrees of Freedom R-R Planar Robot

A. FORWARD KINEMATICS

A. FORWARD KINEMATICS:

Forward Kinematic Equations are as shown in Table 2.

Table 2 Forward Kinematic Equations of T-R-R Configuration Robots

FORWARD KINEMATICS
ROBOT-A
$X = [L_{A1}COS\theta_1 + L_{A2}COS(\theta_1+\theta_2)]COS\emptyset$ $Y = [L_{A1}SIN\theta_1 + L_{A2}SIN(\theta_1+\theta_2)]$ $Z = [L_{A1}COS\theta_1 + L_{A2}COS(\theta_1+\theta_2)]SIN\emptyset$
ROBOT-B
$X = [L_{B1}COS\theta_1 + L_{B2}COS(\theta_1+\theta_2)]COS\emptyset$ $Y = [L_{B1}SIN\theta_1 + L_{B2}SIN(\theta_1+\theta_2)]$ $Z = [L_{B1}COS\theta_1 + L_{B2}COS(\theta_1+\theta_2)]SIN\emptyset$

B. INVERSE KINEMATICS:

To find the joint angles of T-R-R configuration manipulator, we perform inverse kinematics of two degrees of freedom R-R planar manipulator, since the manipulators we use are of the configuration R-R with twisting base.

C. INVERSE KINEMATICS OF TWO DEGREE OF FREEDOM R-R PLANAR ROBOT:

Here we consider Cartesian Coordinates (r1 = [X1, Y1], r2 = [X2, Y2]) are known along with the Link Lengths. Here, we follow a geometric approach instead of D-H (Denavit – Hartenberg) matrix approach. Finally, we arrive at all angles including θ_1, θ_2 (Joint angles) and φ (rotation angle).

$BC = L_2SIN\theta_2$ (1)

$OC = L_1 + L_2COS\,\theta_2$ (2)

$AC = L_2COS\,\theta_2$ (3)

$$\tan\alpha = \frac{BC}{OC} = \frac{\text{L2 SIN}\theta 2}{\text{L1 + L2 COS}\theta 2} \quad (4)$$

$$\tan\beta = \frac{Y}{X} \quad (5)$$

$r_1 = [X_1, Y_1] = [L_1COS\,\theta_1, L_1SIN\,\theta_1]$ (6)

$$r_2 = [X_2, Y_2] = \begin{bmatrix} L_2COS\,(\theta_1+\theta_2), \\ L_2SIN\,(\theta_1+\theta_2) \end{bmatrix} \quad (7)$$

$X = L_1COS\,\theta_1 + L_2COS\,(\theta_1+\theta_2)$ (8)

$Y = L_1SIN\,\theta_1 + L_2SIN\,(\theta_1+\theta_2)$ (9)

$X^2+Y^2 = L_1^2COS^2\theta_1 + L_2^2COS^2\,(\theta_1+\theta_2)$
$+2L_1L_2COS\,\theta_1\,COS\,(\theta_1+\theta_2)$
$+ L_1^2SIN^2\theta_1 + L_2^2SIN^2\,(\theta_1+\theta_2) +$
$2L_1L_2SIN\,\theta_1\,SIN\,(\theta_1+\theta_2)$ (10)

$X^2+Y^2 = L_1^2 + L_2^2 +$
$2L_1L_2\,COS\,(\theta_1-\theta_1-\theta_2)$ (11)

Since,

$COS^2\,\theta + SIN^2\theta = 1$

and

$COS(A-B) = COS(A)COS(B) + SIN(A)SIN(B)$

$X^2+Y^2 = L_1^2 + L_2^2 + 2L_1L_2\,COS\,(\theta_2)$ (12)

Since

$COS(-X) = COS(X)$

$$COS\,\theta_2 = \frac{X^2+Y^2-L_1^2-L_2^2}{2\,L_1L_2} \quad (13)$$

$\theta_2 = atan2(SIN\,\theta_2, COS\theta_2)$ (14)

$\theta_2 = atan2\left(\pm\sqrt{1-COS^2\theta_2}, COS\,\theta_2\right)$ (15)

The final equation for θ_2 is

$$\theta_2 = atan2\left(\pm\sqrt{1-\left(\frac{X^2+Y^2-L_1^2-L_2^2}{2\,L_1L_2}\right)^2}, \frac{X^2+Y^2-L_1^2-L_2^2}{2\,L_1L_2}\right)$$

Also,

$\beta - \alpha = \theta_1$ (16)

$$\tan(\beta-\alpha) = \tan\theta_1 \quad (17)$$

$$\tan\theta_1 = \frac{\tan\beta - \tan\alpha}{1+\tan\beta\,\tan\alpha} \quad (18)$$

$$\tan\theta_1 = \frac{\frac{Y}{X} - \frac{L_2SIN\,\theta_2}{L_1+L_2COS\theta_2}}{1+\frac{Y}{X} * \frac{L_2SIN\,\theta_2}{L_1+L_2COS\theta_2}} \quad (19)$$

$$\tan\theta_1 = \frac{Y[L_1+L_2COS\,\theta_2] - X[L_2SIN\theta_2]}{X[L_1+L_2COS\,\theta_2] + Y[L_2SIN\theta_2]} \quad (20)$$

The final equation for θ_1 is

$$\theta_1 = atan2(y, x) - atan2(Z_2, Z_1)$$

Where,

$Z_1 = L_1 + L_2COS\,\theta_2$ (21)

$Z_2 = L_2SIN\,\theta_2$ (22)

D. INVERSE KINEMATICS OF LYNXMOTION ROBOT ARM:

Now, Robotic ARM can be represented as a 2R manipulator with a rotating base.

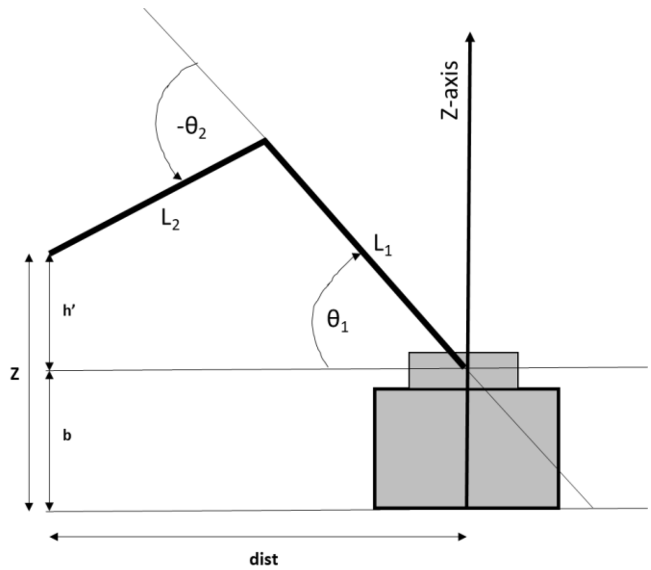

Figure 6 Side view of a TRR robot arm without the gripper

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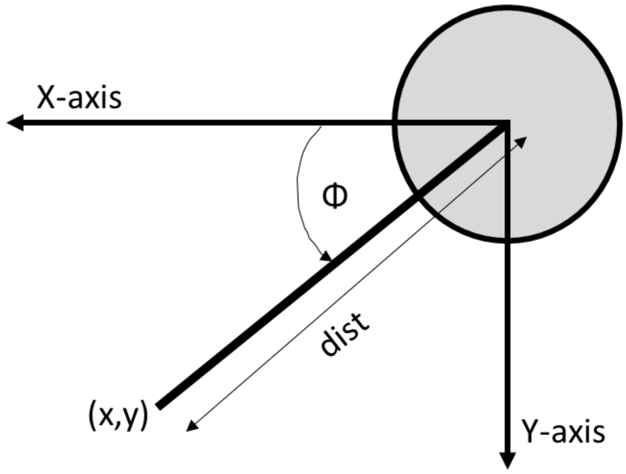

We can calculate the angles φ,θ_1, θ_2 from the position (x, y, z) of the wrist.

$$\varphi = \mathrm{atan2}(y, x)$$

To calculate angles θ_1 and θ_2, we first find the distance dist of the point (x, y) from origin o and we also determine the height above the shoulder joint.

$$dist = \sqrt{x^2 + y^2} \quad (23)$$

$$h' = Z - b \quad (24)$$

Now, substitute x=dist and y=h' in the equations where we find θ_2 and θ_1 for R-R planar manipulator. Kinematic Equations helped in determining the current state of the lynxmotion robot arm. However, our project aims in high level control interface using Speech commands.

IV. DESIGN OF SPEECH-BASED INTERFACE FOR CONTROL OF DUAL-ARM MANIPULATORS

The text and speech corpora for control of dual-arm manipulators was created in Indic languages naming English, Hindi, and Tamil[4]. Here we use an offline speech recognition engine[5] so that control could be made wirelessly through smartphone and also doesn't require an active internet connection. The following Figure 10 shows Text and speech corpora created for control of cooperative manipulator. Language model, Acoustic model, and dictionary were created for languages English, Hindi, and Tamil so that end-user comfortable in these languages will be able to control two identical robot arms simultaneously. Hidden Markov Model forms the basis of my Recognition Engine where in The Forward Algorithm is used for Scoring, Viterbi Algorithm for Matching and Baum-Welch Learning algorithm for training. Speech recognition engine developed converts the above commands to text form, fed to servo controller for appropriate actuation of the robot[6].

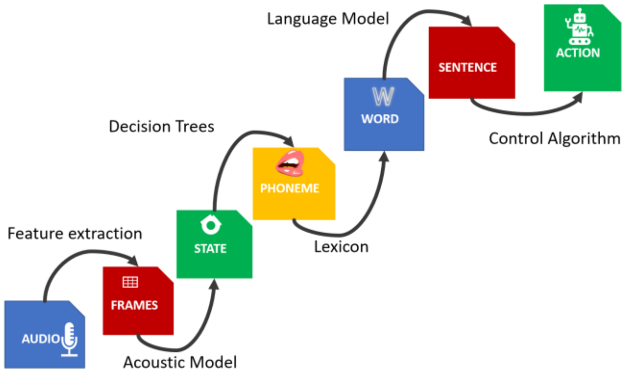

Figure 8 Speech to dual-arm robot actuation

```
private void setupRecognizer(File assetDir) throws IOException {
    langSelected=langSpinner.getSelectedItem().toString();
    recognizer = SpeechRecognizerSetup.defaultSetup()
            .setAcousticModel(new File(assetDir, langSelected+"/acoustic-model"))
            .setDictionary(new File(assetDir, langSelected+"/pronounciation-dictionary.dic"))

            .setRawLogDir(assetDir)

            .getRecognizer();
    recognizer.addListener(this);
    File languageModel = new File(assetDir, langSelected+"/language-model.lm");
    recognizer.addNgramSearch(tamSearch,languageModel);
}
```

Figure 9 Code to set the Decoder

SPEECH COMMANDS TO CONTROL COOPERATIVE MANIPULATOR

	ENGLISH	TAMIL	HINDI
file_1	MOVE SHOULDER UP	தோளை உயர்த்து	कंधे को ऊपर करें।
file_2	MOVE SHOULDER DOWN	தோளை இறக்கு	कंधे को नीचे करें।
file_3	MOVE ELBOW UP	முழங்கை உயர்த்து	कोहनी को ऊपर करें।
file_4	MOVE ELBOW DOWN	முழங்கை இறக்கு	कोहनी को नीचे करें।
file_5	MOVE WRIST UP	மணிகட்டை உயர்த்து	कलाई को ऊपर करें।
file_6	MOVE WRIST DOWN	மணிகட்டை இறக்கு	कलाई को नीचे करें।
file_7	OPEN GRIPPER	விரலை திற	उंगली खोलें।
file_8	CLOSE GRIPPER	விரலை மூடு	उंगली बंद करें।
file_9	ROTATE BASE	அடித்தலத்தை சுற்று	बेस घुमाएँ।

Figure 10 Speech Commands to Control Cooperative Manipulator

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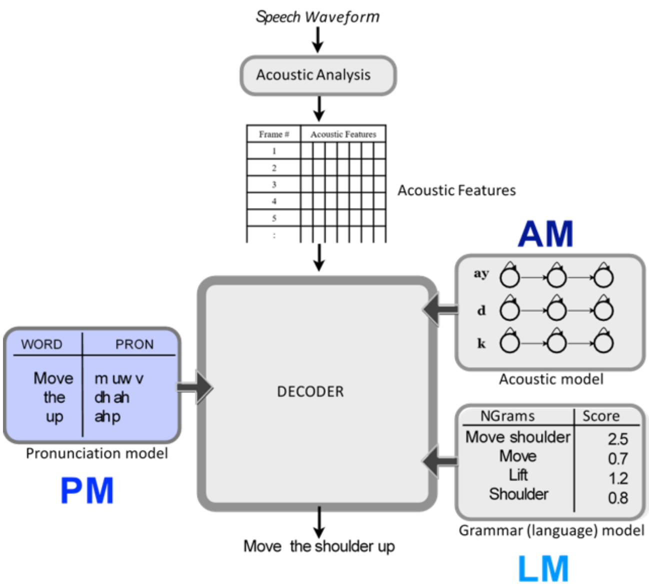

Figure 11 Block Diagram of Decoder

V. IMPLEMENTATION OF CONTROL USING ANDROID APPLICATION

We develop an android application[7] using HC-05 Bluetooth technology coupled with Arduino UNO and servo controller. Two identical serial arms can be controlled through speech commands said through the microphone of a smartphone which is then converted into text form through the mobile app and after processing the language, the mobile app sends appropriate commands serially to Arduino board, which then sends signals to motor controller for simultaneous actuation of servo motors. The joints of ROBOT-A are connected to the channels 1 through 4 and the joints of ROBOT-B is connected to the channels 26 through 30.

```
private class ConnectBT extends AsyncTask<Void, Void, Void>  // UI thread
{
    private boolean ConnectSuccess = true; //if it's here, it's almost connected

    @Override
    protected void onPreExecute()
    {
        progress = ProgressDialog.show(MainActivity.this, "Connecting...", "Please wait!!!");  //show a progress dialog
    }

    @Override
    protected Void doInBackground(Void... devices) //while the progress dialog is shown, the connection is done in background
    {
        try
        {
            if (btSocket == null || !isBtConnected)
            {
                myBluetooth = BluetoothAdapter.getDefaultAdapter();//get the mobile bluetooth device
                BluetoothDevice dispositivo = myBluetooth.getRemoteDevice(address);//connects to the device's address and checks
                btSocket = dispositivo.createInsecureRfcommSocketToServiceRecord(myUUID);//create a RFCOMM (SPP) connection
                BluetoothAdapter.getDefaultAdapter().cancelDiscovery();
                btSocket.connect();//start connection
            }
        }
        catch (IOException e)
        {
            ConnectSuccess = false;//if the try failed, you can check the exception here
        }
        return null;
    }
    @Override
    protected void onPostExecute(Void result) //after the doInBackground, it checks if everything went fine
    {
        super.onPostExecute(result);

        if (!ConnectSuccess)
        {
            msg("Connection Failed. Is it a SPP Bluetooth? Try again.");
            finish();
        }
        else
        {
            msg("Connected.");
            isBtConnected = true;
        }
        progress.dismiss();
    }
}
```

Figure 12 Android code to connect to Bluetooth

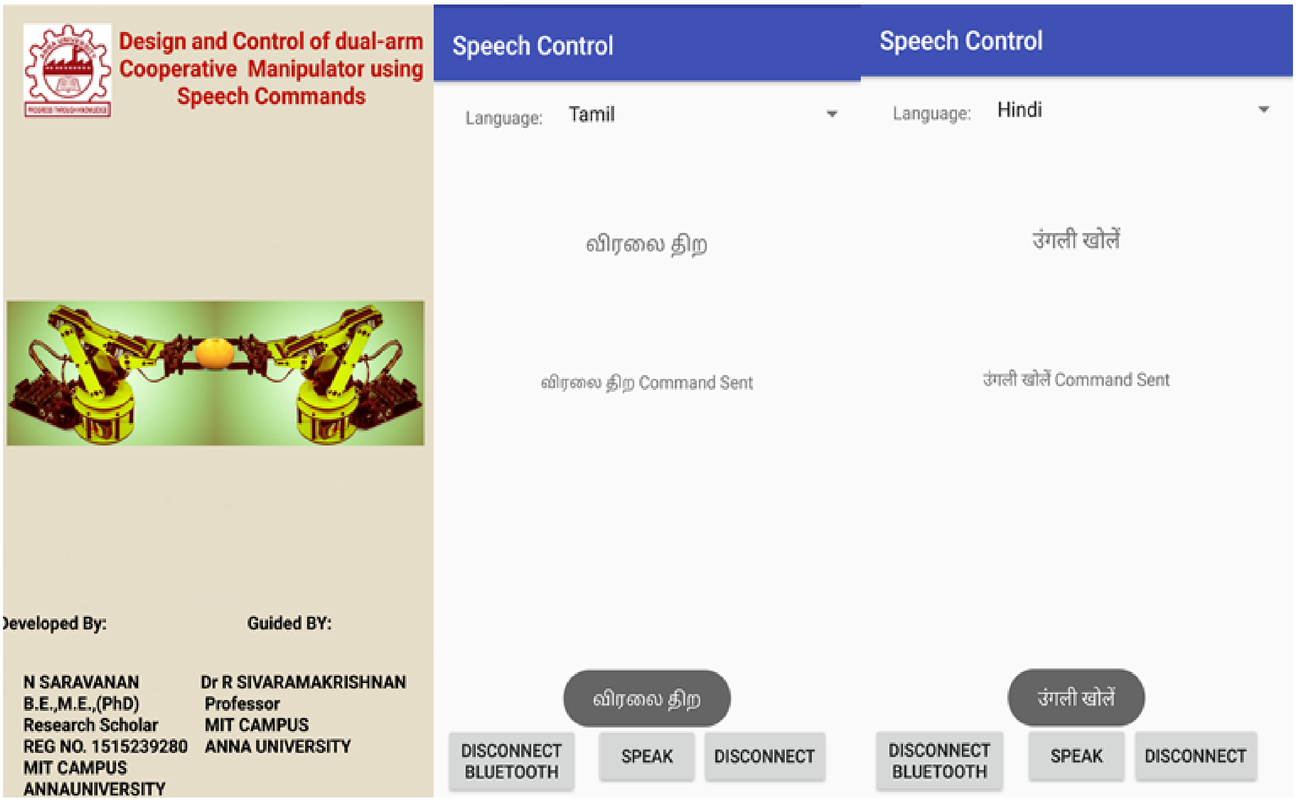

Figure 13. Sample Android Application for control of dual arm manipulators through speech

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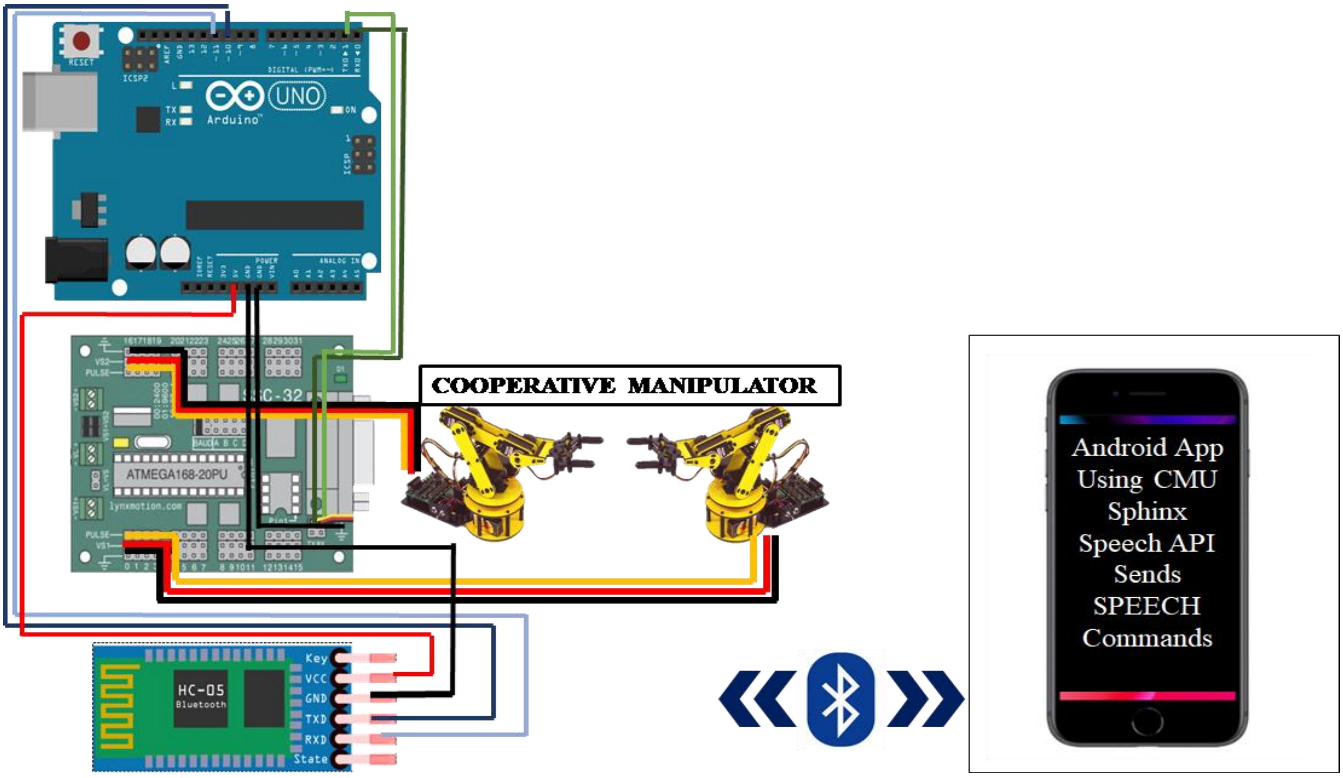

Figure 14 Circuit Schematic of controlling cooperative manipulator using Android Application

Figure 15 Sample Experimental Setup of Dual arm Cooperative Manipulator

Table 3 Experimental Results- Speech-Based Control of Cooperative Manipulator

Gender	Total Number of Robot Commands Spoken (184)			Total Number of Robot Commands Recognized by Robot-A and Robot-B (178)			Total Number of Robot Commands went Unrecognized by Robot-A and Robot-B (6)		
	English	Hindi	Tamil	English	Hindi	Tamil	English	Hindi	Tamil
Male	40	40	42	39	39	42	1	1	0
Female	20	20	22	19	19	20	1	1	2

VI. RESULT AND DISCUSSION

The designed Cooperative Manipulator[8] was checked for its movements for individual robot commands for Point-To-Point Control through Speech. Candidates from both genders were allowed to speak and actuation of cooperative manipulator was monitored. Usually, Cooperative manipulators are controlled through Teach Pendant or require a complex mechanism. Here we just provide a smartphone to the end-user who just speaks to control and thus that could be an assistive aid if both robots were deployed on either side of the wheel chair. The prototype was tested and had an accuracy of 96.73%. The following figure shows the criterion tested for Actuation of Robot-A and Robot-B.

Criterion	Recognition of Robot Command	Actuation of Robot-A and Robot-B
True Positives	Correctly Recognized	Correctly Actuated
True Negatives	Correctly Recognized	But Incorrectly Actuated or Actuation NOT DONE
False Positives	Incorrectly Recognized	But Actuation Done
False Negatives	Incorrectly Recognized	And Actuation NOT DONE

Figure 16 Criterion Tested based on Recognition and Actuation

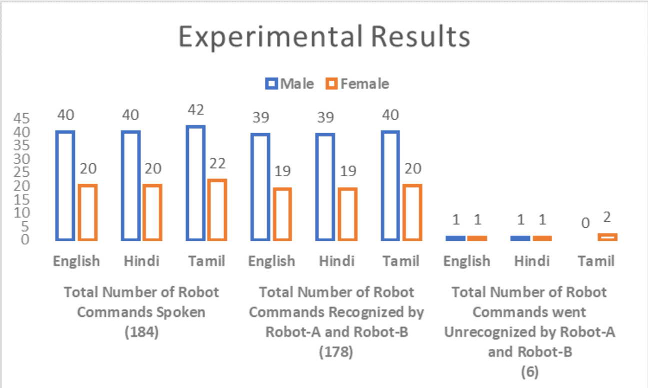

Figure 17 Experimental Results-Actuation on Recognition

VII. CONCLUSION

There were no or minimal False Positives and True Negatives concluding our control of cooperative manipulator to be more robust. The Training Mode of Speech Recognition[9] had the following Phases and it listed only minimal word error rate encouraging us to develop a robust system for control of two identical lynxmotion robot arms. Cooperative manipulators[6] designed and controlled through speech could be deployed in assisting Surgeries[2], or manipulating radioactive elements simultaneously or combinedly operating on the object twice its payload for pick-and-place[10].

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