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Conception and Development of Dexto:Eka: The Humanoid Robot - Part IV

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***Abstract*—This paper elucidates the fourth phase of the development of 'Dexto:Eka: - The Humanoid Robot'. It lays special emphasis on the conception of the locomotion drive and the development of vision based system that aids navigation and tele-operation. The first three phases terminated with the completion of two robotic arms with six degrees of freedom each, structural development and the creation of a human machine interface that included an exo-frame, a control column and a graphical user interface. This phase also involved the enhancement of the exo-frame to a vision based system using a Kinect camera. The paper also focuses on the reasons behind choosing the locomotion drive and the benefits it has.**

***Index Terms*— tele-operation; mecanum wheel drive; humanoid; anthropomorphic;**

I. Introduction

When the collision courses of technology and innovation align, a path is paved for the creation of that which the ancient world would have quipped as a miracle. In his quest for forging the perfect invention man often follows a road ridden with peril. Conquering such treacherous and dicey paths often jeopardize precious lives. This is where the multi-faceted roles and applications of tele-operation begin. This was the motive that spurred the creation of 'Dexto: Eka: - The Humanoid Robot'.

Envisaged to work as a tele-operated robot, Dexto: Eka: [1] is capable of autonomous operation as well in its sovereign and semi-sovereign modes. The dependent mode is where the robot acts as a perfect master slave system, emulating every motion of the tele-operator and obeying every command. The semi-sovereign mode allows for some decision making capabilities whereas the sovereign mode permits a completely autonomous behavior with the robot being able to work at an individualistic capacity [1].

As seen in [2] the development of the robot has so far seen the completion of the upper torso, backbone and chassis. The robot can be controlled by the tele-operator using a human machine interface. A Wi-Fi channel acts as the means of communication. Two Atmega 2560 microcontrollers have been used [3] one of which act as slave at the robot's end and the other as master the tele-operator's end. These facilitate the master-slave system of Dexto:Eka:. The robot in its current stage of development is seen in Fig. 1.

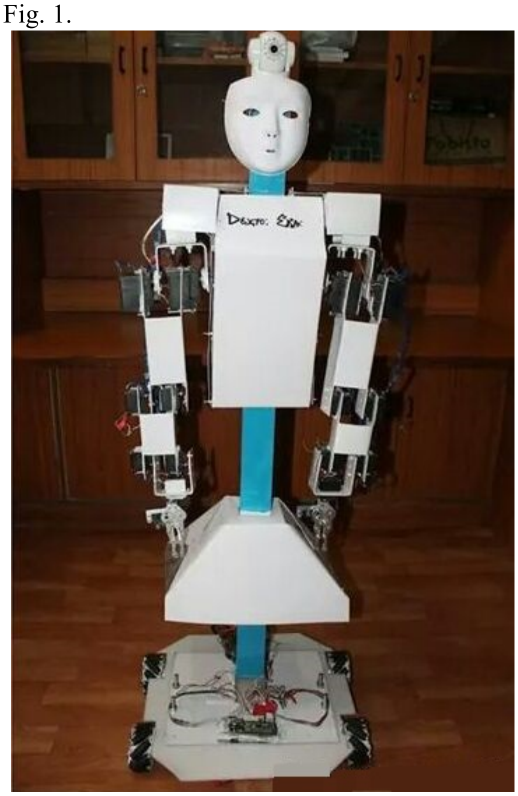

Fig. 1 Dexto:Eka: after phase IV

The trial faced in designing a suitable arm for Dexto:Eka: was the ability to emulate the fluidity and versatility of the human arm. Hence, six degrees of freedom were chosen such that they provide good flexibility and healthy amount of work volume [4]. These arms are intended to emulate the motion of a tele-operator wearing an upper limb exoskeleton as seen in Fig. 2. The exo-frame has been upgraded to a more versatile interface for tele-operation [5].

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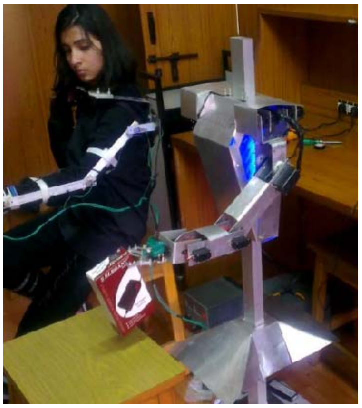

Fig. 2 Mimic Operation

The two arms are anchored to a hollow aluminium pipe which acts as the backbone holding the wires which are fed to different sections of the robot. The arms also have current sensors to prohibit the flow of excess current through them. Temperature sensors have been mounted on the gripper of each arm to ensure the robot does not pick up or go into regions of temperature that are unsuitable for its well-being. The motion of the arms can be monitored and the sensors can be monitored on the graphical user interface (GUI) [2].

II. CONCEPTION OF OMNIDIRECTIONAL DRIVE

A. Concept

The inception of the omnidirectional drive presented a variety of challenges - ability to handle the weight of the robot, balancing of upper structure, flexibility of movement and lastly it must be economical [6]. But it was also pertinent that overcoming these challenges should not hamper the smooth motion of the robot [7]. The result was the 3D design seen in [1] and is shown in Fig. 3.

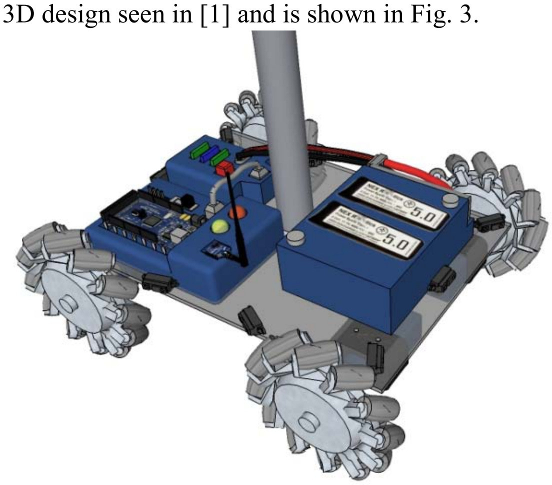

Fig. 3 3D model of Chassis and Mecanum wheel drive

The first two challenges were overcome by making the design such that the centre of mass of the robot would lie in the lower half of backbone of robot. This was achieved by placing all the heavy components such as circuitry, battery packs, motor drivers etc. on the chassis. Along with the above measures, gyroscope and accelerometers [8] were used to create a closed loop system and enhance the balancing of the robot.

The chassis of the robot had to be such that it had both the qualities of lightweight as well as that of being robust. So a polypropylene sheet sandwiched between two aluminium sheets amalgamated this requirement of features as seen in Fig. 4. The aluminium made it strong and polypropylene made it light. The chassis was further given an octagonal shape in order to accommodate a variety of sensors along the periphery.

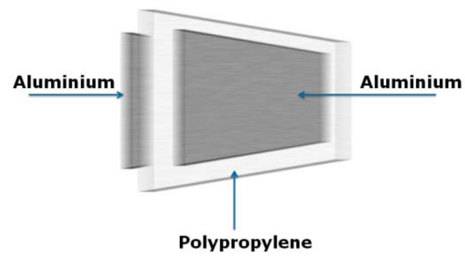

Fig. 4 Chassis of the robot

The versatility in motion was achieved using a mecanum wheel drive. Manoeuvrability has been achieved using geared DC motors. It was pertinent that the robot be able to move smoothly in every direction. So we opted for mecanum wheels instead of ordinary omni wheels. Allowing for omnidirectional motion and having a pushing force 41% higher than ordinary omni wheels, mecanum wheels were the apt choice for the robot. This can be proved as follows [9].

Consider an omni wheel and a mecanum wheel of same radius **r**. **τ** is the torque applied to the wheel. Assuming that there is no roller bearing friction, a reaction force is applied by the floor on the roller along its (roller's) axis. The magnitude of this force is **τ/r** and **τ/r** for omni and mecanum wheels respectively as seen in fig 5.

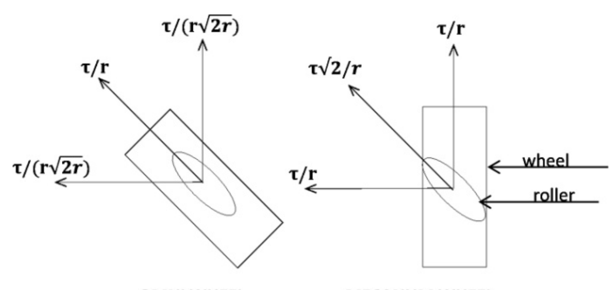

Fig. 5 Vectors representation of force acting on mecanum wheel

$\boldsymbol{\tau_A}$ is torque applied to left front and right rear wheel and $\boldsymbol{\tau_B}$ is torque applied to right front and left rear wheels which produce force vectors as shown in Fig. 6. The force

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vectors seen are then added to give cumulative force acting at an angle **θ** which remain identical for both wheels as long as torque is same.

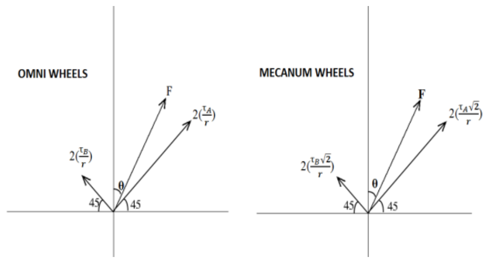

Fig. 6 Comparison of mecanum and Omni wheels

For Omni wheels:

$$F\cos\theta = \frac{\sqrt{2}}{r}(\tau_A + \tau_B)$$
$$F\sin\theta = \frac{\sqrt{2}}{r}(\tau_A - \tau_B)$$
$$\theta = \tan^{-1}\frac{(\tau_A+\tau_B)}{(\tau_A-\tau_B)}$$
$$F = \frac{\sqrt{2}(\tau_A+\tau_B)}{r\cos\theta}$$

For Mecanum Wheels:

$$F\cos\theta = \frac{2}{r}(\tau_A + \tau_B)$$
$$F\sin\theta = \frac{2}{r}(\tau_A - \tau_B)$$
$$\theta = \tan^{-1}\frac{(\tau_A-\tau_B)}{(\tau_A+\tau_B)}$$
$$F = \frac{2(\tau_A+\tau_B)}{r\cos\theta}$$

Thus it can be clearly seen that the magnitude of force **F** for a mecanum wheel exceeds that of the omni wheel by $\sqrt{2}$.

B. Navigation

As stated in [2] navigation system of Dexto:Eka: is dependent on ultrasonic and IR sensors installed along the chassis[10]. In the current phase we have taken one more step towards the automation of the navigation system. In this phase we have combined it with image processing techniques to make a map of environment and detect of objects which are in range of 5 meters of the robot.

Balancing and position sensing of the robot is done with the help of a combination of gyroscope and accelerometer modules [11]. These are placed on the top of the robot which makes it easy for the gyroscope to easily judge any deviation in the stationary position of the robot. While gyroscopes only provide directional information, accelerometers provide the information of forces acting on or experienced by the robot. The accelerometer sensor consists of a metal beam which changes the capacitance and the change in the capacitance value determines the acceleration of the robot. This acceleration is used to calculate the force which enables the gyroscope tells the direction of deviation. The change in the orientation and the force calculated is been sent to the microcontroller and then it performs the control action accordingly.

III. Visual Perception and Processing

The robot has an IP (internet protocol) camera mounted on its head. This continuously provides live feed [12] to the tele-operator, thus creating the perception and semblance of tele-presence. The IP camera has been chosen such that it provides a multitude of features. It has 11 infra-red LED providing for good quality night vision, two way audio communication to enable communication with tele-operator from remote location, 300 degree pan and 120 degree tilt, hence providing a wide range of visibility of surroundings. The tele-operator has clear view of the current remote environment the robot is present in.

Procedure Horizontal-Track
1: Initialize servo values
    move = **GetVariable**("move")
2: Get the size of the bounding box(COG):
  size = **GetVariable**("COG_BOX_SIZE")
3: **if size** = null ;
  Display no object detected
4: Calculate centre of gravity:
  if size != null;
5: Get the horizontal center of gravity:
  cogX = **GetVariable**("COG_X")
6: Move left
  move=1;
  if cogX<300;
  end if.
7: Move right:
  move =2;
  if cogX>340;
  end if.
8: Be stationary/Stop action:
  if cogX<340 && cogX>300;
  end if.
9: Reset value of move to initial values of servo.
10: Count the number of faces:
 facescount=GetVariable("FACES_COUNT");
11: Again stop action/be stationary:
  if FACES_COUNT=0;
12: Again reset the value of move to initial values of servo.
13: Wi-Fi_Transmit(move);
14: **End Procedure**

Fig. 7 Horizontal Face Tracking Algorithm

The feed from the IP camera has been coupled with image processing technique and data from distance sensors [13] to enable autonomous navigation and environment mapping. Edge detection techniques have been used to detect obstacles in the path of the robot and enable the

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robot to move away or avoid the hindrance. The robot is also able to detect and track faces.

A camera placed at the control end allows for teleoperated panning and tilting of IP camera at robot end. This is achieved by first detecting the face and then tracking the centre of gravity of the image. The values determined by the face tracking done at tele-operator's end determine the direction of pan of pan and tilt of the IP camera. These movement variables are then transmitted via Wi-Fi to the slave microcontroller which then causes the IP camera at the remote location to move in that direction. The algorithm employed for horizontal and vertical tracking is seen in Fig. 7 and Fig. 8.

```
Procedure Vertical-Track
1:  Initialize servo values
            move = GetVariable("move")
2: Get the size of the bounding box(COG):
  size = GetVariable("COG_BOX_SIZE")
3: if size = null ;
  Display no object detected
4: Calculate centre of gravity:
  if size != null;
5: Get the vertical center of gravity:
  cogY = GetVariable("COG_Y")
6: Tilt down:
 move=3;
  if cogY<220;
  end if.
7: Tilt Up:
 move=4;
  if cogY>300;
  end if.
8: Be stationary/Stop action:
  if cogY<220 && cogY>300;
  end if.
9: Reset value of move to initial values of servo.
10: Count the number of faces:
   facescount=GetVariable("FACES_COUNT");
11: Again stop action/be stationary:
  if FACES_COUNT=0;
12: Again reset the value of move to initial values of servo.
13: Wi-Fi_Transmit(move);
14: End Procedure
```

Fig. 8. Vertical Face Tracking Algorithm

IV. HUMAN MACHINE INTERFACE

The tele-operation control system for the robotic arms was a very crucial aspect. The tele-haptic system seen in [14] relies on force feedback between user and robot. The electro-tactile system enables control using a wireless data glove and a tracking system. It allows the user to feel the feedback using electrodes placed on the arm. The vision based system in [15] makes use of several stereo cameras placed at user end and at robot end in order to achieve mimicking motion of robot manipulator.

Human machine interface consisting of hardware (control column and exo-frame) and software (GUI) were developed for control of Dexto:Eka:.

A. Upper Limb Tele-operation Interface

A Kinect camera has been introduced as replacement of Exo-frame [3]. This was done in order to overcome the constraints posed by the exo-frame. Kinect is a combination of IR projectors and camera which can sense gestures and track movements in three dimensions. The exo-frame was tailored to fit a single individual. Any modifications demanded a complete change in structure of the system [3]. Kinect overcomes this challenge by making the system universal and enables it to be operated by anyone. Kinect is used to sense the motion of joints (shoulder, elbow, wrist and palm) of human arm and then robotic arm is made to mimic those motions. Replacement of exo-frame with Kinect [11] will help to get rid of a suit which was required to be worn every time by the teleoperator and no longer hampers movement.

A basic block diagram of working of Kinect is shown in Fig. 9.

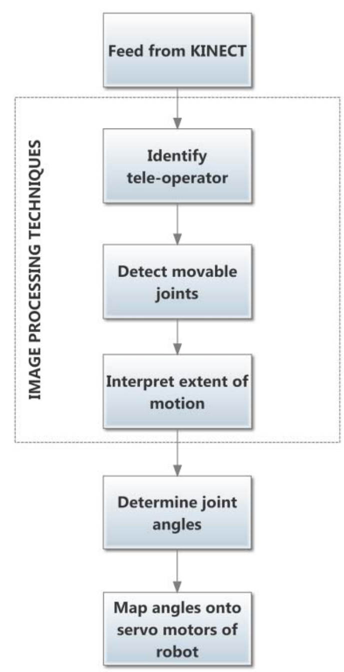

Fig. 9 Block Diagram of Arm Control using Kinect

B. Graphical User Interface (GUI)

The very ergonomic GUI seen in [2] continues to be used in the system with little modifications. The system has been updated to work along with the Kinect rather than the exo-frame. An interface for the joystick has been added

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in the GUI.

C. *Control Column*

The locomotion drive is governed using a control column which comprises a joystick like device and a button interface mounted on the master microcontroller. The analog values from potentiometers of the control column are mapped onto the locomotion drive for enabling movement in the required direction.

V. Experimental Results

The face detection and tracking algorithm employed at the tele-operator's end determines the direction the direction in which the IP camera is to pan or tilt. The output of the algorithm at the user end can be seen in Fig. 10. From the left the first image shows a detected face, followed by left detection, right, down and finally in the up direction. The control column and the GUI's joystick interface for controlling the locomotion drive was tested. The joystick interface can be seen in Fig.11. The controlling was done with an error of less than 1%.

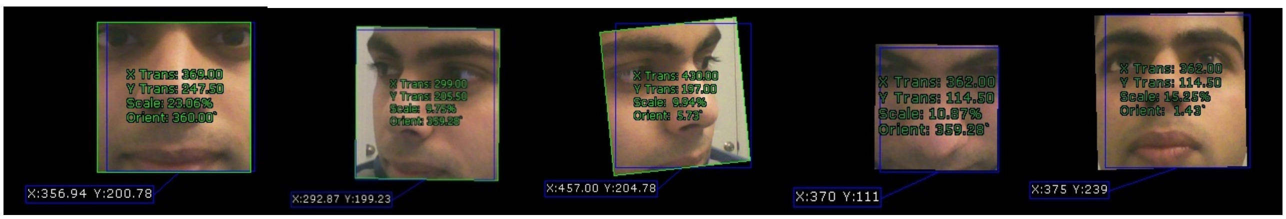

Fig. 10. Face Detection and Tracking

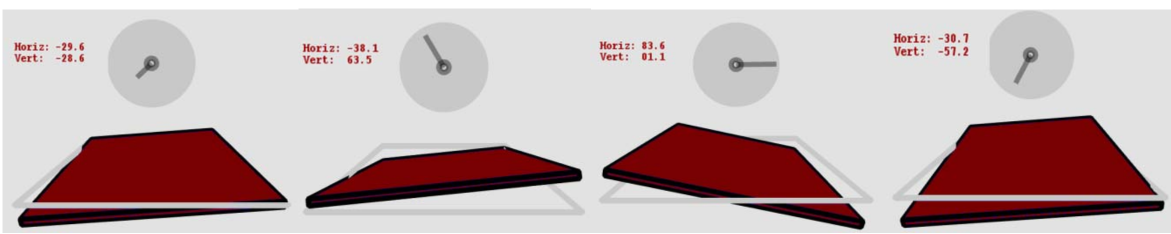

Fig. 11. Joystick Interface in GUI

VI. Conclusions and Future Work

Thus the fourth phase of tele-operated humanoid robot was completed with conception of an efficient omnidirectional mecanum wheel drive. Experiments performed on the robot returned optimistic results with few errors in automatic mode. Future work includes the development of an advanced control mechanism of robotic arms using the vision based system implemented through Kinect as stated above and enhancement of object detection and navigation techniques and error minimization in movements of mecanum wheel drive and and finally the development of fully automated navigation system using image processing techniques.

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