Humanoid robot for educational and assistive applications

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***Abstract*— This work presents development of custom made humanoid robot that can be used for educational and assistive applications using Robot Operating System (ROS) platform. This robot is capable of localizing itself within working vicinity and can perform different tasks such as teaching demonstration, human interaction and grasping of an object using ROS Moveit package. The development cost of the system is comparatively cheaper than the available standard international products and real scenario performance results of the system have been found satisfactory.**

***Keywords*— Humanoid, assistive robot, localization, ROS, moveit.**

I. Introduction

Ever since mankind set foot on the surface of the earth, it has induced various changes geographically or technologically. Among such fields of technology, one of the latest emerging fields is robotics. Specifically, in robotics humanoid robot is becoming an interesting domain to assist humans in multiple aspects of life. This type of robots can be used as a personal assistant, a news presenter and an informational recommender [1]. In developed countries, a number of humanoid robotic units have been developed for different applications. This work has been performed to develop indigenous and custom made humanoid robotic system for assisting in educational, commercial and domestic applications. Main objectives of the system are to produce a cheap and user-friendly robotic system which can perform multiple tasks in a developing country society comparatively having low level of technological understandings. In the developed countries, many companies specially in Japan have developed human-like robots like ASIMO (HONDA) [2], QRIO by Sony [3], NAO a small sized humanoid and Pepper by SoftBank Robotics [4], [5] and ATLAS (Boston Dynamics) [6]. The Humanoid robot can interact with its surroundings [7]. Humanoid products should provide more user-friendly and natural ways for the user to collaborate with the robot so that it can be more useful for different domains [8]. There are many ways to transfer control of a specific task between humans and robots. Domo, a humanoid robot is specifically designed to assist in daily manipulation task. It is useful in pick and place tasks and in assistive applications [9]. In this work, indigenous hardware has been made which has been controlled using Robot Operating System (ROS), an open-source robotic development platform [10]. ROS is a collection of open-source libraries available as packages which can perform multiple tasks. In the developed hardware localization, grasping, demonstration and human interaction has been accomplished using ROS packages. ROS provides support for communication between different machines, different processes and tools for visualization and many other such things. A ROS framework for the HUBO robot is an example of it [11].

Fig. 1: Developed Humanoid Robot

For the movement of arms, a popular package of ROS has been acquired named Moveit which can be used for trajectory control and grasping task. Moveit is a collection of software packages integrated within ROS. It is designed to provide mobile manipulation capabilities to the robot. A representation of the robot environment can be built using 3D environmental data. Robot motion planning considers as the problem of achieving a feasible path between start and goal position with in suitable time either in cartesian or joint space. Moveit basically takes the data of the dimensions of robot links, types of joints and objects in the environment of robot from the URDF file and assist robot in motion planning from source to destination position without any collision with other links and environmental objects that can cause damage to the robot and its environment [12]. In the forthcoming version of this research work, it is planned to use Artificial Intelligence or Machine Learning techniques to increase the efficacy of

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the system. In that case, the proposed setup will display natural intelligence while performing the required task. Presently robots made by the scientist in preponderance are for the aspiration of making them obey through commands of voice or gestures. However, scientists across the world are trying to use brain signals that can transcend mortal competence. Scrutinizing the future perspective of the robots and the applications generating by the robotics community, the proposed setup is unerringly on the direction of humongous success.

This paper has been organized as follows. In Section 2, a brief discussion of related work is presented. Section 3 describes the hardware design of the system. In Section 4, results have been shown and finally conclusions have been discussed.

II. RELATED WORK

Globally, with the advancement in robotics and automation, such robots are developed that can be used in our homes and possibly in the near future the type of machines will help and assist us in our daily lives, and these can also be used as research tools. Humanoid robots are very helpful in research work and they could contribute in different type of work like neuroscience studies [13]. Socially interactive humanoid robots are also being developed and they can be used in many ways like to interact with autistic children and to identify the children with social defects and teach them to interact in more human-like ways [14]. SONY have introduced a highly sophisticated humanoid robot for entertainment purpose in the 2000s. It is capable of walking, dancing, speaking, listening (using microphones) and it also has capabilities to detect and identify objects around it using a stereo camera [15]. Human-Robot Interaction (HRI) is a research field, it is the study of interaction between robots and humans and the safety issues related to this interaction. In industries robots are used for many applications like welding, drilling, painting or assembly. HRI evaluation implies a risk assessment for robots in industries in terms of safety requirements [16], [17]. WENDY is a human-like robot consisting of a head, two human-like arms and torso. It is designed to work and interact with humans. It has fingers and finger nails as well that help it to pick up difficult objects and it can even pick a small or flat object using it. It can be used for accomplishing different tasks such as grasping very small objects like coins and in chopping vegetables [18]. Humanoid robots are also very important in medical and health care field. They can be used to assist patients with cerebral palsy [19] and pediatric cancer [20]. The crucial responsibilities of the robot in clinical healthcare domain are distress minimization[21], remote monitoring, and interacting with the patients [22], [23]. “Face Pain Scale-Revised” is an approach that was used to measure the effect of humanoid robots in pain and distress minimization during the vaccination of children. The pain level during vaccination was measured using muscle tension or crying behavior and facial expressions. It was observed that child felt less pain in the presence of robot [21]. This level of achievement set an example and standard for the development of advanced and highly sophisticated human-like robots. Many developed countries have started working on humanoid robotic using ROS technology and its moveit package for movement to go to the place where the item must be located and to grasp the object in the location.

In this work, a preliminary humanoid design has been constructed and tested with real experiments and found satisfactory results for localization, teaching demonstration, grasping and assistive applications.

III. HARDWARE DESIGN OF THE SYSTEM

A. Mechanical Model

The mechanical model of the robot is consisting of a base, main body of the robot and two arms as shown in fig. 2.

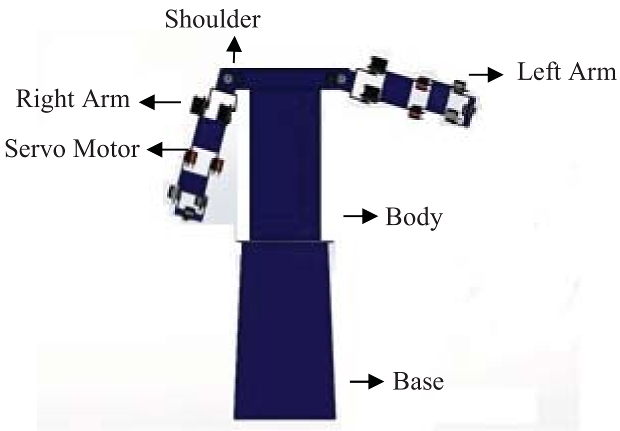

Fig. 2: Robot design on SOLIDWORKS

The base has been designed using welded L-shaped iron pieces along two stage wood plates for placing electronic components. Two 36V hover board BLDC motors along 6.5-inch diameter tyres coupled with the base. The base is then joined with the main body using nuts and bolts. The main body of the robot is made up of four 2mm thickness square shaped hollow aluminum rods which are supporting front and back wooden sheets and all this setup is resting on a circular acrylic plate of thickness 5mm. The shoulder and both arms of the robot are made up of aluminum sheets of thickness 2mm and are joined with the main body using nuts and bolts attached to the hollow aluminum rods of main body. All the parts of the arms and shoulders have been cut into the required shapes and measurements using shearing machine and grinder. Then holes for the servo motors and other joints have been made using drilling machine. Each arm has 6 degrees of freedom as shown in fig. 3. Servo motors of required torques have been used for the movement of joints.

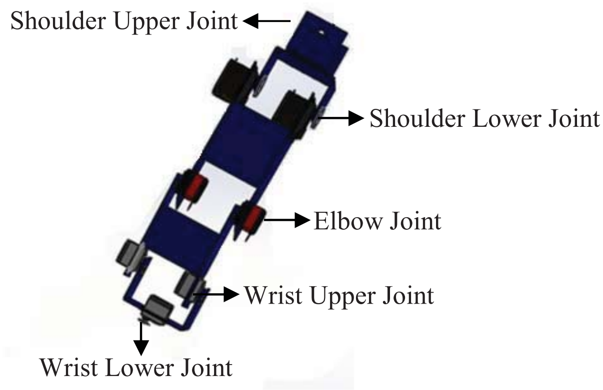

Fig. 3: Arm design on SOLIDWORKS

Each joint (DOF) has two servo motors, starting from the shoulder upper joint containing two PDI-2060MG servo motors capable to rotate arm along X-axis. For shoulder lower joint, two CYS-8218 servo motors have been integrated and capable to rotate arm along Y-axis. Two PDI-6221MG servo motors have been connected at elbow joint, after that two MG-996 servo motors for the next joint, then it has an MG-996 servo motor for the movement of wrist and in the last it has a claw and its movement is controlled by MG-996 servo motor. So, in a single arm it has a total of ten servo motors that makes a total of six degrees of freedom as shown in fig. 3 and fig. 4.

The complete structure of the robot is consisted of twenty servo motors, two hoverboard BLDC motors and fifteen degrees of freedom as shown in fig. 4. All the mechanical structure of the robot has been designed on SOLIDWORKS then after examining the actual hardware has been made in accordance with the model designed.

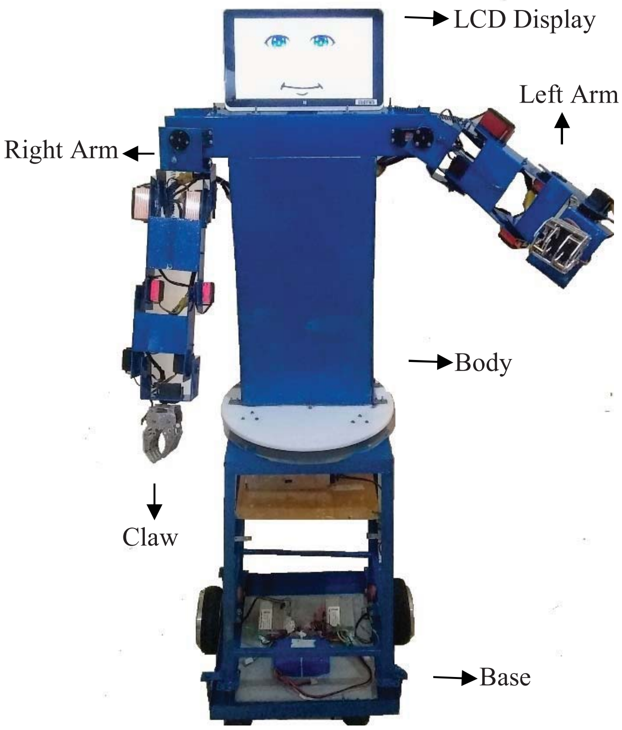

Fig. 4: Actual Hardware of robot

B. *Electronic Hardware Design*

Designing of instrumentation circuitry comprises of interfacing of multiple actuators with ROS running on laptop as shown in fig. 5. Raspberry Pi (3B+) has been used as a main controller and three Arduino microcontrollers used as slaves to make a distributed architecture. Raspberry pi takes the user defined data from ROS (laptop) and transmits it to other controllers to control the actuators for the desired movement of joint. In humanoid robot multiple controllers have been required for joint movement and localization, so here three Arduino Mega 2560 have been used. One Arduino controls the actuators (servo motors) of left arm, second one has been used to control the actuators (servo motors) of right arm and third one has been used for the localization of robot. Use of multiple Arduino controllers increases reliability of the system and any unforeseen error in a single controller will not affect operation of others. Each Arduino has not been connected directly to the servo motors; but through PCA-9685 servo drivers to reduce complexity of circuit. PCA-9685 servo driver is an excellent solution for projects which require large numbers of servo motors to operate simultaneously. This servo driver uses an I^2C (inter-integrated circuit) communication protocol, capable of hooking up to 16 servo motors with only I^2C communication pins i.e. SDA and SCL. The basic principle of operation of the driver is based on a master-slave communication between the Arduino and the servo driver. For the localization of robot, two 6.5 inch, 36V hover board BLDC motors have been used and controlled by intelligent brushless motor controllers used in E-bike. The built-in encoders of hover board BLDC motors have been used to calculate the rpm of the wheels which has been utilized to calculate the total distance travelled by the humanoid robot and this data has been used as a feedback to ROS. The actual humanoid robot has been simulated in ROS and Moveit package has been applied to control the arm movements. All calculations work has been done in ROS running on laptop and this data is transmitted wirelessly to the Raspberry pi 3B+ (also running ROS). Then three Arduino Mega 2560 have been connected to the Raspberry pi through serial communication to control the joint movement and localization and all data have been recorded through ROS which is a reliable data collection platform. Since sensors have not been used here to identify any object in the vicinity of robot therefore to pick an object the coordinates of the object to be picked have been provided as an input in ROS then Moveit package has been applied to the arms of the Humanoid Robot to grasp the object properly and place the object at the required place. Moveit is a motion-planning tool for ROS. It is very useful and easy to use tool for motion-planning and to find a collision free trajectory between a start and a goal state. It is complicated but unlike some ROS libraries it has user-friendly GUI Wizard to get started [12].

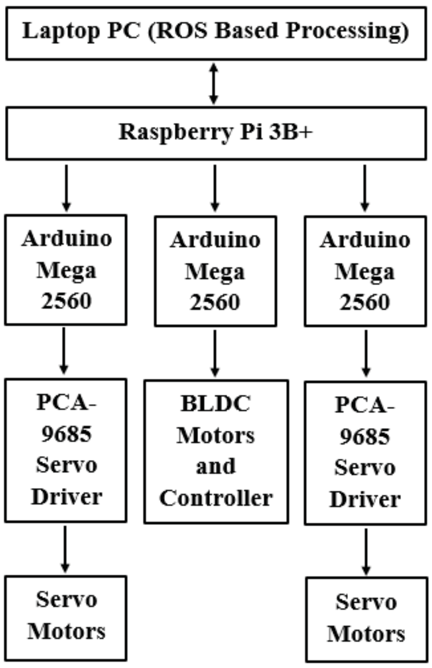

Fig. 5: Block diagram of electronic system

IV. MATHEMATICAL EQUATIONS

All the movements are based on translational and rotational motion. Standard kinematic equations for translational and rotational motion described in [24] have been used here for transformation from body reference frame (denoted by X_1,Y_1,Z_1) to shoulder frame (denoted by X_2,Y_2,Z_2) as shown in fig. 6.

$$Pxyz = Trans\,(l1, l2, l3) Rot\,(x, \alpha) Pnoa \qquad (1)$$

Here Pxyz is the point related to body frame while Pnoa point is related to shoulder frame. Further for local hand (end effector) to shoulder transformation has been made using DH parameterization [24].

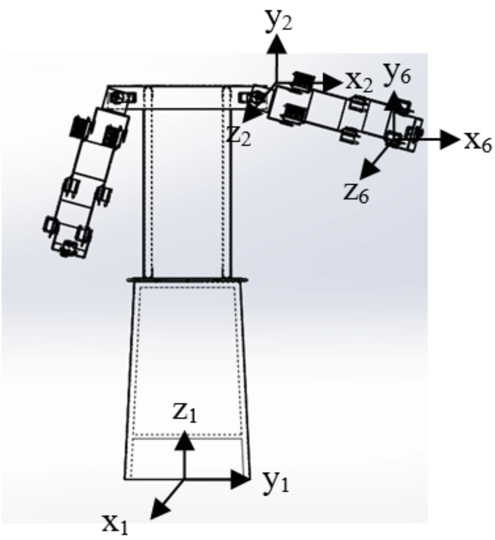

Fig. 6: Showing the coordinates of different joints

For localization, standard equations have been used. Differential drive is a mechanism that is used in many mobile robots. It has two wheels attached to a common axis and each wheel can move independently in either forward or reverse direction by varying the velocities for the forward, reverse and rotating motion of the robot. Instantaneous Centre of Curvature (ICC) is a point that the robot rotates about and lies along the axis that is common in left and right wheel as shown in fig. 7 [25].

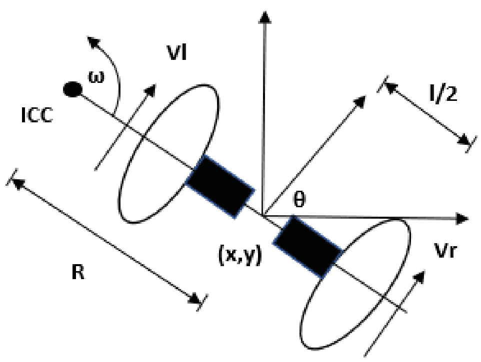

Fig. 7: Differential drive components

The motion of the robot can be controlled by varying the velocities of the two wheels and for the rate of rotation ω, equations can be written as:

$$\omega\,(R + l/2) = Vr \qquad (2)$$

$$\omega\,(R - l/2) = Vl \qquad (3)$$

here, R is the distance between the midpoint of the wheels and the ICC, V_r, V_l are the velocities of right and left wheels and l is the distance between the two wheels as shown in Fig. 7. For any instant of time the value of R and ω is given by:

$$R = (l/2)\{(Vl + Vr)/(Vr - Vl)\} \qquad (4)$$

$$\omega = (Vr - Vl)/l \qquad (5)$$

In fig. 7, consider the robot is at any point (x, y), moving in a direction and makes an angle θ with the x-axis. Assume the robot is centered at a point midway along the wheel axle. By controlling the parameters V_l and V_r robot can be proceeded to different positions.

The ICC can be found using V_l, V_r and equations mentioned above, the *ICC* location is given by,

$$ICC = [\,x - R\sin(\theta), y + R\cos(\theta)\,] \qquad (6)$$

and at time $t + \delta t$ the robot's pose can be calculated by,

$$x' = (x - ICC_x)\cos(\omega\delta t) - (y - ICC_y)\sin(\omega\delta t) + ICC_x \qquad (7)$$

$$y' = (x - ICC_x)\sin(\omega\delta t) + (y - ICC_y)\cos(\omega\delta t) + ICC_y \qquad (8)$$

$$\theta' = \theta + \omega\delta t \qquad (9)$$

These equations simply describe the motion of a robot rotating a distance R about its *ICC* with an angular velocity of ω.

V. RESULTS

The humanoid robot has been tested for localization, demonstration and grasping as presented below.

A. Localization test:

The robot has been used for localization. For this purpose, the built-in encoders of BLDC motors have been used. The pulses from the encoder have been used to calculate the RPM and distance travelled by the robot which is transmitted by the Arduino to the Raspberry pi and then transmitted wirelessly to the main server i.e. ROS running on laptop and used as a feedback.

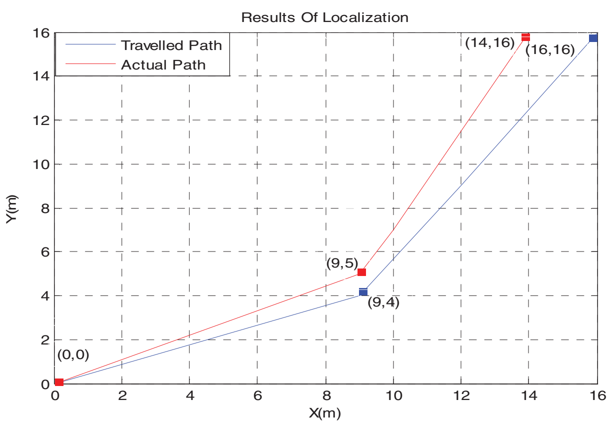

Fig. 8: Graph representing the error in localization

Satisfactory result has been found for localization as shown in fig. 8 and in following table. Translational error has been less than 35 cm and rotational error has been less than 5 degree.

TABLE I: LOCALIZATION RESULTS

No. of tests	Translational error	Rotational error
1	20cm	8º
2	15cm	12º
3	35cm	10º

B. Teaching assistant test:

The robot has been used and tested as a teaching assistant for pre-primary, primary and secondary classes as shown in fig. 9. In one of such demonstrations, the robot was explaining the map of Pakistan and the details of each provinces and after the demonstration the students had been asked with a questionnaire to check the output and feedback from the student that how much they have gained from the demonstration and whether it can be useful or not as a teaching assistant in our society.

TABLE II: TEACHING DEMONSTRATION RESULTS

No. of students	Categories of students	Knowledge before presentation	Knowledge after presentation
10	Pre-primary	20%	35%
10	Primary	43%	65%
10	Secondary	39%	54%

During this test, knowledge gain has been observed as shown in Table II. Data set has been collected from ten students of each categories (pre-primary, primary and secondary). Fig. 9 is showing a picture of students during the demonstration of map of Pakistan.

Fig. 9: Demonstration test

C. Grasping test:

The robot has also been tested for grasping or picking an object from a predefined location and placing it to another location fig. 10. Since camera or sensor has not been used here for locating an object in the vicinity, so the coordinate of the object to be picked has been provided as an input to the robot. The actuators have been used here do not have any feedback mechanism so there are some errors in the desired goal position achieved by the robot.

TABLE III: GRASPING TEST RESULTS

No. of test performed	Error in achieving the goal position
1	4cm
2	3cm

Two different grasping tests has been performed and satisfactory result has been found with maximum error of 4 cm.

Fig. 10: Grasping test

VI. CONCLUSION

The hardware of the robot has been developed and multiple tests such as localization, teaching assistant and grasping have been performed and satisfactory results have been achieved as shown above. There are errors present in different tests performed that can be reduced using feedback sensors and camera that can help in localizing the system correctly. Further improvements in the current system are under process and in future Artificial intelligence and image processing can also be applied. This humanoid is relatively cheaper, custom made and can be used for multiple applications and it can impose a positive impact in the educational system and can increase the technological awareness of the society.

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