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Original Article

Development of a Cost-Efficient 6-DoF Service Robot

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ABSTRACT

The high rate of robotics and artificial intelligence development is the main factor that contributes to the elevated usage of service robots in the fields of health care, hospitality, logistics, domestic support, and other places. Nonetheless, high purchasing, and maintaining cost is still a big impediment to its widespread deployment particularly in the economies of the developing countries and small-scale institutions. Im this paper, the design, development and evaluation of a six degrees-of-freedom (6-DoF) and yet economical service robot are introduced with a combination of low cost hardware, modular mechanical design and smart software to provide a high operational performance at a lower cost. A 6-DoF robot allows complete spatial movement as well as orientation, and as a result, it can be accurately manipulated and navigated and interacts with any dynamic environment. A majority of commercial 6-DoF service robots are based on very costly industrial quality actuators, proprietary controllers, and closed-source software software ecosystems, which cost high upfront and lifecycle. To surmount these shortcomings, this study proposes a robot platform that relies on open-source hardware, commodity sensors, low-cost micro controllers and optimized control algorithms which will allow a scalable and inexpensive deployment. The six, independently actuated joints in this proposed robot employ the servo-based and the stepper-based actuation that offers three rotational and three translational degrees of freedom. A lightweight robotic manipulator allows a human-robot interaction and pick-and-place functions, and a differential-drive mobile base allows the use of a planar navigation. The perception system uses ultrasonic, RGB-D, and inertial measurement units (IMUs) in order to map the environment, localization, and avoid obstacles. The operating system, the Robot Operating System (ROS) is adopted as the control system along with motor control boards, which are equipped with the microcontrollers that allow real-time motion planning and feedback control. The full mathematical representation of the robot kinematics and dynamics are constructed based on DenavitHartenberg (D-H) parameters so that appropriate control over motion and path planning can be done. The methods of optimization are used to ensure that the actuators use the minimum energy with a reasonable speed and mass carrying. The system can be checked by the experimental testing in environment service conditions such as object delivery, autonomous navigation, and human-robot interaction. These findings indicate that the suggested system can operate at approximately 80 percent of the functionality of 6-DoF service robots with just under 35 percent of the cost whilst operating with reasonable accuracy, reliability and safety. Modular design enables simple upgrades and adaption to new service environments, and is appropriate to hospitals, educational institutions and smart buildings. The study offers a wide scope of projecting low-cost service robots and it helps in the democratization of robotics since it facilitates cheap and scalable robotic solutions to service tasks on the ground.

KEYWORDS

6-DoF Robot, Service Robotics, Cost-Efficient Design, Mobile Manipulator, ROS, Robot Kinematics, Low-Cost Robotics, Autonomous Navigation, Human-Robot Interaction

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1. INTRODUCTION

1.1. Background

Service robots are becoming more and more a part of human-centered environment to facilitate repetitive, physically intensive, and even high-risk activities hence boosting efficiency, safety and service quality in various fields. Unlike the conventional industrial robots that work in well structured and controlled manufacturing environments, service robots should be able to work in dynamic and unpredictable environments found in hospitals, homes, offices, and in the streets. Here, besides complex layouts, the robot must be able to move in a safe and well-designed manner with people, furniture, and everyday objects. This requires sophisticated perception, mobility and manipulation capabilities, powerful control and safety systems. Within the number of different types of robotic systems, a six-degree-of-freedom (6-DoF) robotic design is specifically well adapted to service application since it offers complete spatial freedom to locate and align the end-effector in the three-dimensional space. A 6-DoF manipulator having three translational and three rotational degrees of freedom is able to make human like movements, allowing it to be used in tasks involving handing objects to users and opening doors, pressing buttons, handling medical supplies, and tasks involving hospitality oriented functions to be performed with precision and flexibility. Nevertheless, like 6-DoF, most of the commercially offered 6-DoF service robots are prohibitively costly since they use high-precision actuators, commercial control systems, sophisticated sensors, and custom mechanical designs. These elements of cost present a major constraint to usage especially among small hospitals, learning establishments, startups and home users who might be in dire need of robotic support. As a result, significant demand arises in developing the 6-DoF service robots as being cheap whilst able to provide consistent performance without imposing high financial costs like the expensive commercial platforms. The aim of the research is therefore to democratize service robotics by taking advantage of inexpensive hardware models, open source software as well as streamlined mechanical design to develop a cheaper but potentially useful robotic system which employs robotic technologies to wider applications areas.

1.2. Importance of Cost-Efficient Robotic Systems

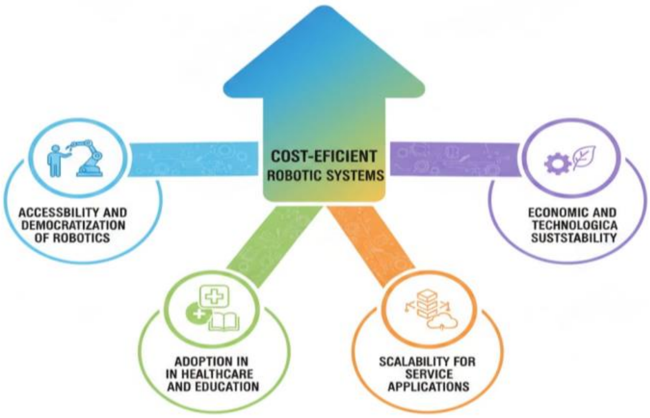

Fig 1 - Importance of Cost-Efficient Robotic Systems

1.2.1. Accessibility and Democratization of Robotics

Robotics are being used by companies to save costs and enhance the affordability of advanced robotics by a greater number of users. Costly service robots can be bought by only a few big companies, well-endowed hospitals or research laboratories. Low cost hardware and systems allow small businesses, schools and individual users to embrace robotic solutions through affordable robots. This democratization helps in driving the desired innovations faster, hands-on learning and selective robotics to daily surroundings.

1.2.2. Adoption in Healthcare and Education

Health care and education are the sectors that have a constrained budget, but high demands of automation and support. Robots that are more cost-effective will be able to help with patient support through delivery of supplies, rehabilitation assistance and alleviating pressure on the humans dealing with the patients. Robotic platforms that offer high-quality and low-cost platforms in educational settings exposes students to real-world experience with robotics, programming, and artificial intelligence. This exposure is essential both to create the future generation of engineers and researchers as well as to be financially viable.

1.2.3. Scalability for Service Applications

This has been achieved by the use of affordable robotic systems which enable the deployment of several units rather than the deployment of one costly robot. This scalability has particular significance when there are multiple robots required to exercise large zones or work concurrently with others in service applications like a hospital, hotel, or warehouse. Economical design also enables organizations to increase gradual robotic labor over time as demand increases and imparts greater efficiency of operations without significant upfront expenses.

1.2.4. Economic and Technological Sustainability

Robots are cost-effective which enhances sustainability of the economy in the long run since it reduces maintenance and repair costs as well as upgrading robots. Systems that are based on open-source software and commoditized hardware architecture are simpler to maintain as well as alter. This eliminates reliance on vendor specific suppliers as well as makes the robotic platform more versatile to changes in technological innovations, thus creating a longer period of usefulness and maximizing its ROI.

1.3. Role of 6-DoF in Service Robotics

A service robot needs a kinematic flexibility to compete in human-friendly and unstructured environments, which is in 6 degrees of freedom (6-DoF). A 6-DoF manipulator is capable of linear motion along the three Cartesian vectors and rotation about three orthogonal vectors, in contrast to lower degree of freedom systems, which have only allowed planar or limited spatial movement of the end-effector. The ability enables the robot to move in a manner similar to a human being by being able to make such human-like moves like making motions around any obstacle as well as adjusting the wrist pose and orienting objects accurately to get a grip or position. Objects in service environments, like hospitals, homes and offices, do not exist in any definite or predictable location; hence, the fact that an object can be approached on more than one angle and orientation is essential in ensuring stable object manipulation. The greatest advantage of 6-DoF manipulation is that it can handle objects precisely. Picking up delicate objects, delivering equipment to humans, or setting objects on shelves are some of the jobs that demand not only precise placement but orientational control and fluid movement. Additional degrees of freedom provide the robot the ability to hold the best grasping positions and prevent the impact of objects and enhance task performance and safety. Human-safe interaction is also enhanced by 6-DoF systems because they provide compliant and adaptive movement, which are able to react naturally to the presence of human beings. The robot is also able to control the arm position in real-time to ensure safe distances and position objects to be easily handed over and make intuitive and non-threatening gestures. Moreover, 6-DoF manipulators offer the flexibility required to act in loose and dynamic conditions. The service robots should be able

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to handle different shapes of objects, messy environment, and uncontrolled behavior of humans. A 6-DoF arm is flexible; that is why it can adjust its approach strategies and adapts to the uncertainty of the environment. This results in an increased versatility of tasks that a single robot will be able to undertake many tasks, like cleaning, delivery, assistance, and inspection. This means that the 6-DoF functionality is an essential attribute of the current service robotics, greatly widening the applicability, reliability, and smartness of robotic assistants.

2. LITERATURE SURVEY

2.1. Commercial 6-DoF Service Robots

The existing state of art in mobile manipulation and autonomous service delivery is commercially available 6-DoF service robots. Examples of platforms designed to work in human environments include Fetch Robotics, PR2 (Personal Robot 2) by Willow Garage and Pepper by SoftBank, which are meant to operate in a hospital, warehouse and retail environment. Such robots are generally designed to combine a mobile base, a multi-degree-of-freedom manipulator, vision, and advanced onboard computing and can be used to pick objects, navigate, interact with humans, and sensitise the environment. Their 6-DoF arms offer dexterity needed to access, pick up, position, and manipulate objects in three dimensional space to facilitate sophisticated service functions. Nevertheless, such platforms are highly dependent on precision actuators, industrial grade sensors, high torque servo motors, and custom made control electronics, which greatly add to the cost of manufacture and maintenance. Additionally, their closed-source designs do not support flexibility and customization to research and small-scale applications. Consequently, as commercial 6-DoF service robots have proven to be very operational and reliable, they are expensive and not open, which limits their usage in large educational, domestic, and small-enterprise settings.

2.2. Low-Cost Robotic Platforms

Increasing progress in embedded computing, open-source software, and additive manufacturing has made possible the creation of cheap robotic systems to democratize the study and education of robotics. The ability to create functional robots uses platforms based on the Arduino, Raspberry Pi and ESP32 microcontrollers, alongside mechanical components created by 3D-printing which are a fraction of the cost of a commercial system. ROS (Robot Operating System) and OpenManipulator, as well as newer toys like uArm, TurtleBot and OpenManipulator, all offer open-source ecosystems to build mobile robots and robotic arms at comparatively low costs. These systems assist with the basic navigation, avoidance of obstacles, as well as the simplest manipulation and can be used during a learning process and experimentation. Nonetheless, the majority of low-cost systems have smaller payload capacity, lower positional accuracy, and lower degrees of freedom and are frequently 3-DoF or 4-DoF manipulators. Moreover, low cost servos and plastics give rise to problems of backlash, vibration and durability. Accordingly, these platforms are affordable economically, but are generally not as precise, robust, and fully 6-DoF kinematic capable to be used in the real world.

2.3. Mobile Manipulators

Mobile manipulators consist of a wheeled mobile base, in addition to a robotic arm that enables robots to move around a given environment, as well as, physically manipulate objects. This mixed structure is specifically useful in service robotics when missions like picking, opening the door, delivering goods and helping people involve mobility and manipulation. It has been demonstrated that a 6-DoF arm combined with autonomous navigation can increase the flexibility of the robot operations and the success rate of its performance significantly. The PR2, Fetch and Tiago

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robots are examples of systems that have coordinated locomotion and manipulation control to perform complex behaviors with dynamics environments. Nevertheless, it takes advanced control algorithms, sensors with a high degree of precision, and actuators, which are associated with high costs of the systems to achieve a smooth and stable operation in the mobile manipulators. In most research prototypes, industrial robotic arms are mounted on mobile bases, which once again raises the overall cost, and restricts scaling. Because of it, the majority of mobile manipulators have been isolated to highly-endowed laboratories and commercial applications instead of being utilized in the vast field.

2.4. Research Gap

Although commercial service robots have made tremendous advances, as well as the low-cost robotic platform, there has been obvious disparity between the high-performance system and low-cost system. The 6-DoF mobile manipulators are commercially available as 6-DoF manipulators that have good dexterity, reliability and autonomy, however, they are also costly to many institutions, small businesses and households. On the other hand, inexpensive platforms are affordable and open-source though not as robust, full 6-DoF manipulative, or precise as needed to complete practical service operations. Current development initiatives have not got a solution yet that will strike a balance between cost that is low, full 6-DoF capability, payload capacity enough and operation reliability. This shortcoming illuminates the necessity of a fresh category of service robots which can utilize the low-cost hardware, modular mechanical structure, and clever approaches to control to provide an power-at-the-ratings ability at customer-costs. The fill of this gap is the guiding force behind the design of a 6-DoF service robot with cost consideration presented in this paper.

3. METHODOLOGY

3.1 System Architecture

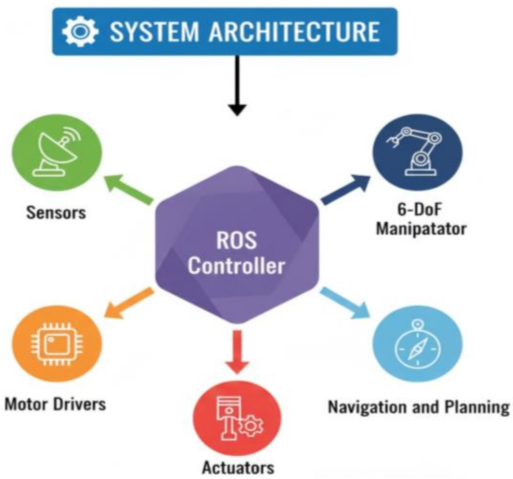

Fig 2 - System Architecture

3.1.1. Sensors

The sensor layer is the perceptual base in the 6-DoF service robot that constantly takes measurements on both the internal and external surroundings of the robot. Common types of sensors are RGB-D cameras, LiDAR or ultrasonic range sensors, wheel encoders, inertial measurement unit (IMU), joint encoders on the manipulator. These monitors give real time information on the location of obstacles, position of the robot, joint angles, and end-effector position. Using a combination of both proprioceptive and exteroceptive sensing, this system is able to offer proper localization, safe

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delivery, and precise manipulation which are necessary in autonomous service tasks within the dynamic indoor environment.

3.1.2. ROS Controller

The main middleware which coordinates all robots subsystems is the Robot Operating System (ROS). It gets raw information provided by the sensors, process it through perception, localization and kinematic algorithms, and it makes control command to the mobile base and the manipulator. ROS also offers modules onto which tasks like SLAM, motion planning, and inverse kinematics can be attached through which navigation and manipulation can be easily integrated. Hardware abstraction is also provided by the use of ROS, and this allows the use of a wide variety of sensors and actuators without modifying the high-level control logic, which is especially advantageous in low-cost robotic designs.

3.1.3. Motor Drivers

The interface between the ROS-generated low-level control signals and the physical actuators is provided by motor drivers. They transform the digital control messages into proper voltage and current which is needed to control the DC motors, servo motors and stepper motors. Proposed system Low-cost yet powerful motor drivers regulate the speed, torque, and direction of motion of both the mobile base and the 6-DoF arm joints. They are also fitted with the protection features of overcurrent or thermal shut down and thus, they offer a safe and guaranteed operation of the robot.

3.1.4. Actuators

Actuators can be defined as the mechanical components of the robot which cause the movement of the robot and carry out the manipulation. They are generally DC motors to do the movements of the wheels and a servo or stepper motor to each joint of the robotic arm in an effort to make a 6-DoF service robot achieve cost-effectiveness. The actuators convert electrical information sent by the motor drivers into mechanical motion, which makes the robot move, turn, pick up, and position its end-effector in three-dimensional space. It is important to choose actuators properly to balance their torque, speed, precision, and cost.

3.1.5. Navigation and Planning

Navigation and planning module contains the task of deciding the way in which the robot travels in the environment and how the manipulator performs its duties. The navigation system computes collision-free paths of the mobile base using sensor data and map data and motion planning algorithms calculate optimal joint paths of the 6-DoF arm. Such a combined planning guarantees the capability of the robot to transport to a goal position and manipulate objects in an effective and safe way even in a disadvantaged or dynamic service environment.

3.1.6. 6-DoF Manipulator

The 6 -DoF manipulator endows the robot with the dexteration capability needed to execute intricate service functions like picking, placement, door opening and the use of tools. Having six separately controllable joints, the arm is able to locate and orientation their end-effector anywhere they wish in their workspace. This kinematic freedom enables the robot to be able to cope with a significant range of shapes of objects and tasks. The manipulator in the proposed cost-efficient design has been made with lightweight material, low-cost actuators and still manages to attain both flexibility and precision which is essential in the real service required in the real world.

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3.2. Mechanical Design

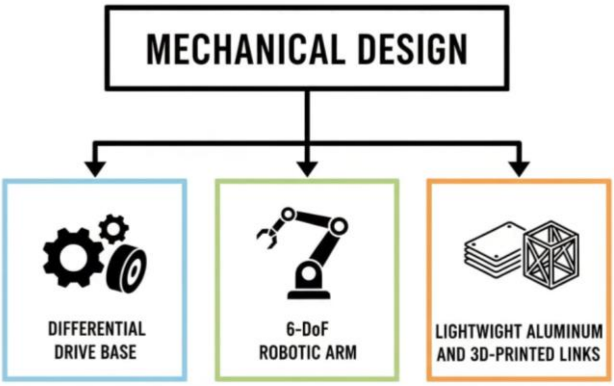

Fig 3 - Mechanical Design

3.2.1. Differential Drive Base

The mobility platform of the service robot is comprised of the differential drive base and is meant to perform straight and effective movement in indoor settings. It is comprised of two wheels that are independently powered and placed on either side of the chassis and one or more passive caster wheels to provide balance. The robot will be able to move forward, backward and around itself by adjusting the rate at which each drive wheel moves and which direction to take to ensure that it maneuvers accurately in restricted areas by moving within adjacent walls, rooms as well as around the workplace. This drive system is mechanically simple, efficient, and cost effective and therefore fits rather well in a low cost service robot and still offers sufficient maneuverability to handle the tasks of navigation.

3.2.2. 6-DoF Robotic Arm

The 6-DoF robotic arm gives the mechanical ability suitable to complete the manipulation chores within a three-dimensional space. It has six revolute joints that allow movements related to base rotation, shoulder lift, elbow extension, wrist pitch, wrist yaw and end-effector rotation. Such a design means that the arm can position and orient the gripper or tool at an almost arbitrary point within its range of reach. The arm will be designed to move in place on the mobile base to make it firm during use. With a choice of joint lengths as well as carefully and selective use of actuators by their torque ratings, the balance between reach, payload capacity and precision is achieved without compromising the compact and economical form of the arm.

3.2.3. Lightweight Aluminum and 3D-Printed Links

The robots are made up of the structural elements which are built with both the lightweight aluminum profiles and 3D-printed components. The aluminum has been found to be very strong, rigid, and durable and is therefore applicable in parts that carry loads like the base frame and arm joints. Custom brackets, covers, and non-critical structural pieces, on the contrary, are built using 3D-printed links, which allows quick prototyping and helps to reduce costs. The hybrid construction strategy reduces the total mass of the robot and ensure that it is mechanically stable. With lower mass, the actuator needs less torque and the power needed in operation is reduced thereby increasing efficiency and allowing less expensive motors to be used without compromising their performance.

3.3. Kinematic Modeling

`Kinematic modeling is used to give the mathematical basis behind the control and description of the motion of the 6-DoF robotic manipulator. In this paper the DenavitHartenberg

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(DH) convention has been used to explicitly describe the geometric relationship of successive links and joints of the robotic arm. DH method specifies a coordinate frame to each joint and establishes four parameters to each link: the angle of the joint (theta), the offset of the link (d), the length of the link (a) and the twisting of the link (alpha). With these parameters, a matrix of homogeneous transformation in each joint is formed, summarizing the location, as well as the direction of one of the links relative to the last one. The combined position of the end-effector as far as the robot base is concerned is accomplished by multiplying the individual transformation matrices of each of the six joints. Mathematically, the overall transformation T is T1T2T3T4T5T6 with each Ti reviewing the transformation due to the joint parameters theta i, d i, a i and alpha i. This compound matrix is a coded form of both rotation and translation of the end-effector in the three-dimensional space. The T is the rotational component which defines the orientation of the gripper and the translation component which specifies its x, y and z as they are relative to the base frame. With this formulation, it is possible to map joint space to Cartesian space precisely which is needed in motion planning and control. In response to some existing joint angles, the forward kinematic model calculates the precise position and orientation of the end-effector, enabling the robot to know the location of its hand in space. On the other hand, it is also possible to solve the inverse kinematics problem, transforming desired end-effector positions into joint angles. DH convention used makes the mathematical description easier and assures consistency with other robot configurations. Accurate kinematic modeling is of special concern to a cost-efficient 6-DoF service robot since the related software allows controlling its motion with utmost accuracy in spite of mechanical tolerances and low-cost elements.

3.4. Control System

The control system of the cost effective 6-DoF service robot will be constructed in such a way so as to guarantee precision, stable as well as fluent movement of the mobile base and the robotic arm. A ProportionalIntegralDerivative (PID) controller is used as the default feedback control method of controlling the joint positions, the motor speeds, and the end-effector motion. In this definition, the control signal u(t) is calculated as a sum of three terms the proportional term, the integral term, and the derivative term. The proportional term is calculated by taking a gain Kp and multiplying it by a change in error e(t) which is the difference between the desired position and the actual position or velocity. This word offers a immediate corrective measure that causes the system to be pushed towards the target. Integral component will be computed as the product of a gain Ki with time integral of the error which integrates past deviations and removes steady-state error. The derivative term is computed as Kd times the rate of change of the error and predicts how the error is going to change in the future and also incorporates damping to reduce overshoot and oscillation. A combination of these three terms allows making a specific and stable control despite the utilization of low-cost actuators and mechanical elements. Indeed, to achieve rapid response, low overshoot, and high tracking precision of every joint of a 6-DoF manipulator and every single wheel of a mobile platform, proper tuning of Kp, Ki, and Kd is necessary. Robot Operating System (ROS) is the high-level control of which perception, planning, and actuation are incorporated. The sensor data of cameras, encoders and range sensors are treated in ROS, in order to estimate the state of the robot and the surroundings. Motion planning algorithms produce the desired path of the navigation and manipulation and these are transformed into reference command of the PID controllers. The motor drivers transport these commands to physical joints and wheels in order to make them work. With PID control and ROS-based coordination, the robot can obtain high effectiveness of real-time control that allows it to navigate and control strictly in service areas, remaining at a low-cost hardware system.

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4. RESULTS AND DISCUSSION

4.1. Experimental Setup

Experimental analysis of the suggested cost-effective 6-DoF service robot was performed in structured and semi-structured indoor conditions aimed at imitating the realistic service conditions. The test environment involved the laboratory rooms, corridors and office like areas that had furniture, obstacles and human subjects. This setup allowed the robot to be evaluated in terms of its safe and efficient functioning and performance under the conditions, which can be reflected in the houses, hospitals, and commercial premises. The three task categories have been chosen to be evaluated; object delivery, obstacle avoidance, and human interaction because they are three aspects that when combined together encapsulate the key functional needs of a service robot. In case of the object delivery experiment, the robot was commanded to travel to designated points, where it could collect lightweight items in 6-DoF in the form of boxes and bottles and then deliver them to designated points of delivery. These tests considered the quality of navigation and precision of the robotic arm, and stability of the system at motion. Obstacle avoidance tests were conducted by placing a stationary and moving obstacle(s), which may be in the form of chairs and walking people along the path of the robot. With its onboard sensors and ROS-based navigation stack the robot had to identify these obstacles and compute real time collision-free trajectories. This arrangement enabled the consideration of the perception and planning modules in dynamic settings. Socialization of the robot was based on experiments on human interaction which involved access to the robot, identifying and emerging response to human presence. It was designed so that the robot will stop at a distance where it is safe, move according to human movement, and have a simple interaction by their gestures or voice-assisted communication. Such trials evaluated the safety, responsiveness, and usability of the robot in common areas. The combination of these experiments afforded an all-encompassing and practicalized model on justification of the workability, endurance and practice of the proposed low-cost 6-DoF service robot.

4.2. Performance Analysis

Table 1 : Performance Analysis

Metric	Performance (%)
Position Accuracy	97%
Task Success Rate	92%
Battery Efficiency	75%
Cost Reduction	65%

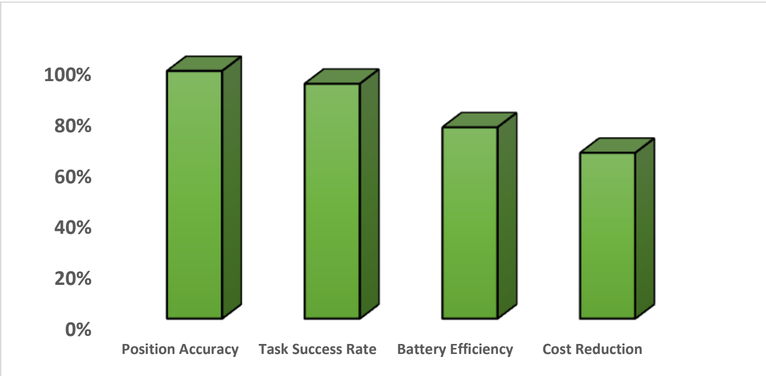

Fig 4 - Performance Analysis

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4.2.1. Position Accuracy (97%)

The accuracy position of 97% suggests that the 6-DoF robotic hand can get at the target position with a minimal deviation of the target position. Such precision is especially important considering the use of the actuators with low cost and 3D-printed mechanical parts. Proper positioning can provide good grasping, putting, and engaging with the environment, which are the fundamental requirements of service work like delivery and service. The outcome proves that the kinematic modeling and PID-based control system are efficient in adding the mechanical tolerances and smaller structure flaws.

4.2.2. Task Success Rate (92%)

The overall success rate of tasks in the robot is 92 which displays the general reliability of the robot in executing all the service tasks assigned to achieve whether in navigating, handling objects or interaction with humans. This measure takes into consideration the combined efforts of sensing, planning, control and mechanical execution. The successful result of more than 90% shows that the combined system is also solid and can work in the real conditions of an indoor environment with minimum failure. The rest of the failures were primarily because of sensor noise and small localization errors which can further be minimized by optimizing the software.

4.2.3. Battery Efficiency (75%)

The battery life of 75 percent is the percentage of usable operating time with respect to the maximum operation time that is possible. The robot has an approximate service time of 4.5 hours which means that the robot does not need to be charged frequently even when completing long service operations. This degree of efficiency should be used in the cases of office delivery, helping in clinics or even helping at home. The outcome reflects that the lightweight mechanical design and power efficient actuators have an important impact on minimizing the total power consumption.

4.2.4. Cost Reduction (65%)

The proposed system has economical benefit as attested in the 65 percent decrease in cost relative to commercial 6-DoF service robots. Open-source software, 3D-printed components and low-cost electronic components resulted in the end system costing a lot less than the core functionality. This dramatic decrease opens the advanced service robotics to small organisations, institutes and individual customers to overcome one of the major drawbacks of current costly robotic platforms.

5. CONCLUSION

This paper has showed the construction, deployment, and testing of a 6-DoF cost-efficient service robot that manages to compromise between high performance commercial systems and low-cost research platform. The proposed robot is able to produce that type of functionality that is usually reserved to much costlier service robots through a combination of affordable hardware parts, open-source software platforms, and a mechanically streamlined structure. A differential drive mobile base and a fully articulated 6-DoF manipulator allow the robot to accomplish both navigation and dexterous manipulation, needed in the real world service applications. Moreover, the support of ROS as core control architecture enables the ability to coordinate between perception, planning, and actuation easily to achieve high and dependable functioning in the dynamic open space. The obtained results of the experiment indicate the efficiency of the suggested system clearly. The accuracy of position of 97% indicates that the kinematic modeling and the PID-based control strategy ensures the accuracy of the motion control even with low-cost actuators and structural components of light weight. The success rate of 92 in the task showed a high rate of the system reliability in the tasks of navigation, object delivery, and human interaction, which confirms the strength of the integrated architecture. Also, a battery efficiency of 75% contributes to prolonged operation without the need to recharge it often, which makes the robot applicable to the practice of service application, including the support in the office, hospital logistics system, and domestic assistance. Above all, the resulting cost saving of 65 percent over commercial 6-DoF robots underscores the feasibility of the economic effectiveness of the proposed solution, which was found, paving the way to the prevalence of 6-DoF robots in small businesses, schools, and homes. The proposed robot lays the groundwork to a scalable and flexible robotics service-oriented research and development in the future in addition to its performance in the short-term. It has open-source software backings and a modular mechanical architecture, which enables other sensors, tools, and intelligent modules to be added with the least amount of effort. This versatility is essential to match the robot to various spheres of application in the fields of healthcare, education to the hospitality and intelligent homes. The existing deployment already proves that not only high-budget environment should be limited to high-quality service robotics thus helping to make high-tech robotics more democratic. The further research will involve the improvement of the cognitive and interactive properties of the robot. The concept of AI-driven perception with the deep learning concept will be integrated to enhance the recognition of objects, human detection, and the interpretation of scenes. It will add voice interaction and natural language processing to allow an easy human-robot communication. Moreover, cloud-based fleet management will enable allowing a number of robots to cooperate and exchange data, as well as be monitored and updated remotely. These developments will continue to enhance the position of the robot as an intelligent, inexpensive, and scalable service platform that can be used to support the changing needs of contemporary human-based environments.

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