Implementation of Low-Cost Mobile Robot for Rescue Challenges

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Abstract One of the biggest challenges in today's world in the field of robotics is rescue robotics. This paper aims in the design and implementation of mobile robot for the search and rescue operations in natural calamities such as earthquakes. These rescue robots reduce the response time as compared to humans and help in getting information to the rescue teams using sensors. The main issues concerned with the present rescue robots are modularity, mobility, durability, and robustness. The robot is designed considering all the required parameters in SOLIDWORKS CAD and simulated in Rviz with the control interface as Robot Operating System (ROS). The robot is designed in such a way that it can do all the mobility tasks like climbing stairs, moving on uneven terrains, step fields, sand, and gravel, as well as exploring tasks like finding the injured victims and hazardous signs.

Keywords Multi-terrain robot · Robot Operating System (ROS) · Graphical user interface (GUI) · Solidworks · Tele-operated

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1 Introduction

The first use of the rescue robots was actually during the World Trade Center (WTC) collapse in 2001 though research was going on this field in the past for many years. The main goal of these robots is to reduce the number of deaths during disasters by surveying the areas which humans are not permitted until the fire is off. Effective communication without delay and errors between the rescue team and the robot plays a key role in these situations. The rescue robot presented in this research has both wired connectivity and wireless connectivity. Robot Operating System (ROS) establishes both wired and wireless connectivities through master–slave protocol between the control system and the rescue robot. Both wired and wireless systems have its own advantage and disadvantage in rescue operations. Wired connection provides reliable connection and does not provide any interference as in wireless communication. The advantage of this is that it provides constant and faster speed compared to wireless connection because of one-to-one connection. But the disadvantage of wired connectivity is that they may not be so effective in disaster scenarios because their reliability is not so good as compared to wireless. For example, if the cables are damaged, the re-installation process would be difficult in those disaster areas. This rescue robot carries several cameras, lidar, kinect, and other sensors. Several sensors are used in this robot to know the environmental conditions of the unknown disaster area. The sensors like IMU and encoders used are for locating or identifying the robot motion. The robot is tele-operated from the controller station with a user interface and a controller.

The innovative idea of the mechanical design with the flipper mechanism and main drive mechanism is an advantage for this robot. The center of mass is well adjusted so that it does not topple while climbing stairs and any other uneven rough disaster terrain. The compactness and small size of the design allow the robot to enter small voids and collect useful information where humans cannot enter. The agility of the robot also holds an important aspect during these disaster situations where even seconds of time is valuable.

2 Related Works

The paper [1] presents the development of crawler rescue robot with two flipper arms which has the capability to move in all the four directions, i.e., not only up and down (pitching motion) but also left and right (yawning motion). The flipper arm in this robot is 2DOF. Paper [2] proposes the new design of the mobile robot which aims to perform on different types of terrains and disaster areas in a balanced way. This robot has the capability to run on any rocky and sandy area and to climb the stairs. The paper [3] discusses an exploration algorithm for the rescue robots in which it automatically maps the unknown environment while driving. Paper [4] presents the method for multi-hop communication in robots, i.e., in detail, a method by which GUI using ROS can be constructed to operate the robot is introduced. Paper [5] describes the machine learning techniques for quick training of robots for navigational tasks and facilitating remote operations. In paper [6], the authors described the design and control of the four-flipper tracked robot. They even described the control mechanisms and the multifunctionality capabilities of the robot. Paper [7] describes the fixed path algorithm and the behavior of the autonomous wheelchair using simulation technique. In paper [8], they proposed the gesture-based wheel chair and its unconventional methods of navigation which are simple and cost-effective. The two methods include Line Following Navigation (LFN) and Location Aware and Remembering Navigation (LARN). Paper [9] describes about the Interactive Remote Robot Operation (IRRO) for reducing the ambiguities and abstracting them. The authors used iterative closest points (ICP) algorithm for the results of collision detection in the reconstructed 3D map. In paper [10], the authors developed a dummy robot for the evaluation of the safety measures and features of the robot. With this testing using the dummy robot, the safety concerns that exist with the humans are removed. Paper [11] describes the study of risk assessment of the rescue robot which helps to improve the reliability of the rescue robot. The assessment is done by considering each subsection in the robot and then combining everything together. Paper [12] proposes the configuration of sensors to be used in the robot which is used to measure the environmental conditions of the disaster areas like CO_2 sensor, temperature sensor, and smoke particle density.

3 Architecture

Figure 1 gives the detailed process on how Robot Operating System (ROS) acts as the main platform to control the robot. The ROS forms the base for the architecture of our robot. Through ROS nodes and topics, the required data is exchanged. The user can control the robot from workstation wirelessly. The control station system is the master, and the robot is slave. The control is divided into different blocks.

3.1 User Interface

The user interface block consists of a graphical user interface. The GUI is built on ROS plug-in RQT.

The GUI consists of two camera view blocks which give a good perception of the robot surroundings from the cameras fixed on the robot. For establishing communication between the robot and control station, the computers should be connected to an external router through ethernet cables. By running both the systems under fixed ROS_MASTER_URI with an IP address, we can establish a bridge between

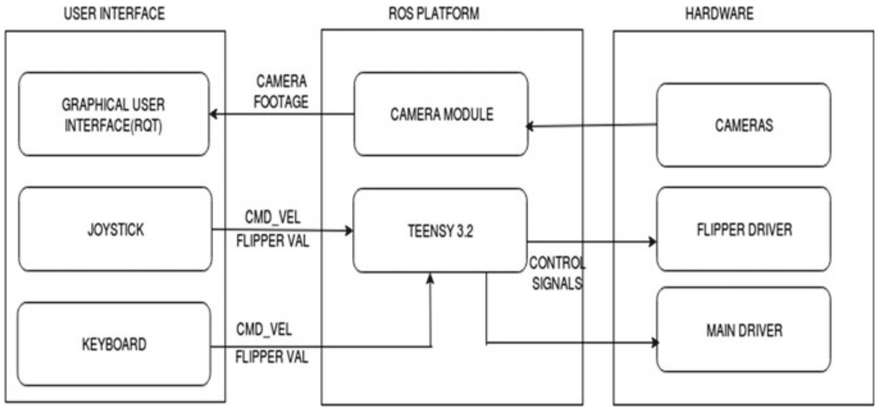


Fig. 1 Architectural diagram of the system

the control station and the robot. By this bridge, data communication takes place. A customized joystick is designed for the control of robot. The user can also control the robot through keyboard.

3.2 ROS Platform

ROS platform deals the transmission of data through nodes. Nodes are processes that perform computation. Our robot control system usually comprises many nodes. Nodes exchange data through ROS-defined messages. These messages are routed via a transport system with publish/subscribe semantics through topics. We used USB_CAM ROS package to transmit camera data. These transmitted data are seen in GUI. And the user input values through joystick are published by JOY_NODE in topic names CMD_VEL and FLIPPER_VAL. These transmitted messages are subscribed by SERIAL_NODE, and by establishing serial communication between PC and Teensy, the received data is transmitted to Teensy board. Further computation of data takes place in Teensy board which produces the corresponding PWM values and drive signals to the motor drivers and flipper drivers.

3.3 Hardware

One of the most important aspects of navigating mobile robots is perception. The robot was remotely operated with the help of cameras (logitech c310), encoders, and IMU data. We placed a camera at the front end of the robot with a rotary base made of servo to get a 180° view, +90° to the right and −90° to the left, while the robot is in motion. We had one camera each at the corner end, at the back placed horizontally, mounted over a moving servo base with possible rotation of 90° (45° to each side). This arrangement covers all the possible views around all the sides of the robots, and most importantly, we can also view the positioning of the flippers. The camera live feed was streamed back to the operating station with the help of ROS nodes and ROS usb_cam package. Since the bandwidth required for the data was huge, there was a delay in the communication network so we had to compress the video data to reduce the video latency. The video data was compressed by a node written in C++ which dropped some of the unnecessary features of the images of each frame in a way that the video quality is maintained to a standard.

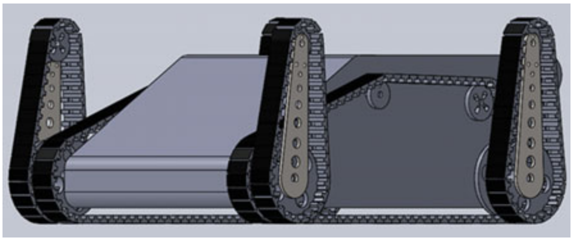
The encoder data and IMU were used to keep track of the motion and the distance moved by the robot in the GUI. The IMU data was used to measure if we have a rolling on a inclined surface. The encoder data also helped to maintain our differential drive of the main drive without any error. The data was transmitted from the Teensy 3.2 through a topic/odom to the GUI node to keep a note of the sensor (IMU, encoders) readings.

The flippers were designed to perform a movement of 360° around the center position of the main drive motor shaft. To enable an easy control of the flippers, they were assigned with some poses. The first pose consists of all the four flippers pointing vertically up and 90° from the ground. This pose was used to move it quickly through the plane surfaces since the area of contact is minimum in this pose. The second pose was where the front two flippers were vertically inclined at an angle 45° from the ground, and others were vertically 90° from the ground. This position was mostly used for climbing up inclined surfaces. The third position was where all the flippers laid horizontally to the ground making an angle of zero degree. This position was fully stretched position of the robot.

4 Design and Implementation

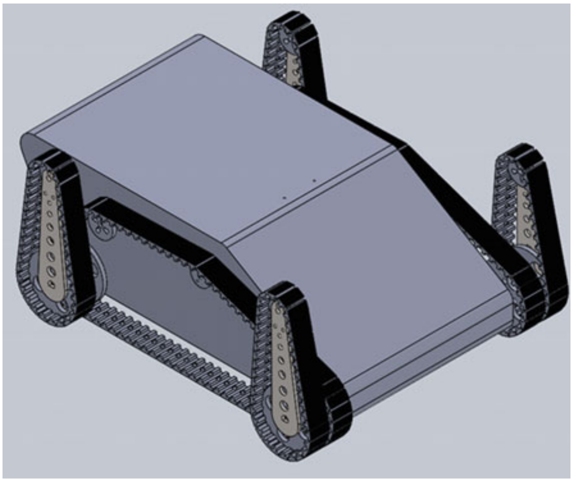
Body as shown in Figs. 2 and 3 was designed on SOLIDWORKS platform with two drive wheels and four flippers, and mild steel was the material used in manufacturing the robot. Chain sprocket power transmission mechanism is followed in robot mobility where electrical power of the motor was converted into momentum which was essential for the body movement. The dimensions of the robot body are 60 ×

Fig. 2 Left corner view



30 × 25 cm (length × width × height); the electronics for the body are placed from opening designed to and fro of the robot. The center of the mass of the body was sustained with care to avoiding the toppling of the robot; two E-bike motors with 24 V input supply and 350 W power help to drive the body. The shaft of the E-bike motors was replaced with 10-mm shaft which was further coupled with 50-mm pitch circle sprocket (Fig. 4). Worm-geared window motors (Fig. 5) with 12 V voltage supply were used for the flipper movement, and 12-mm shaft was passed through these motors which is coupled to 5 mm thickness and 150-mm-long flipper plate. Two sprockets of 100 mm pitch circle diameter are coupled through welding concentrically to maintain common axis of rotation around the shaft that has been passed through the center for the flipping mechanism. One sprocket was mated with main drive chain where the other was mated for flipper chain. Main sprocket is parallel to two more sprockets; one of them was attached to drive sprocket which was coupled to E-bike motor, and the other sprocket was coupled to rotary encoder. The side plate of body which was manufactured with 5 mm MS had the PCD of the E-bike and encoder to couple. Sprocket-to-sprocket distance for the center chain was 54 cm, and the length of the flipper was 15 cm (distance between main sprocket and dummy sprocket of flipper). Flipper adjusting mechanism is taken care by the flipper plate which was designed and manufactured with the PCD for the center shaft and 50-mm pitch circle flipper dummy sprocket axis. Lidar placement and mountings for pan and tilt for camera were taken care during the manufacturing. 1-mm metal sheet was used for body cover of the robot, 3 cm ground clearance for the robot, and the 380 cm × 320 cm area for placements of components (camera, lidar) above the body.

Fig. 3 Right-top corner view



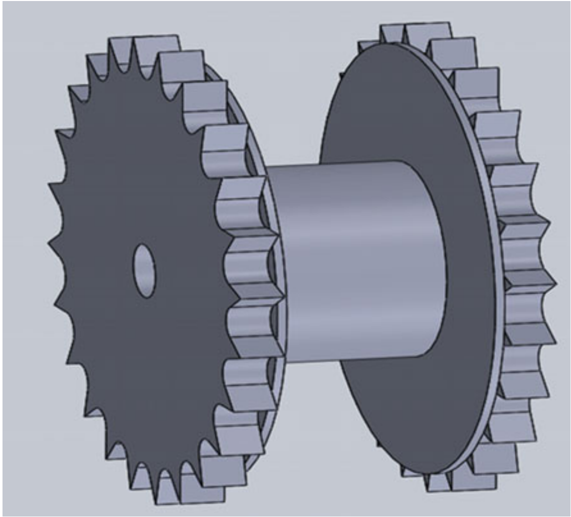


Fig. 4 Coupled sprockets

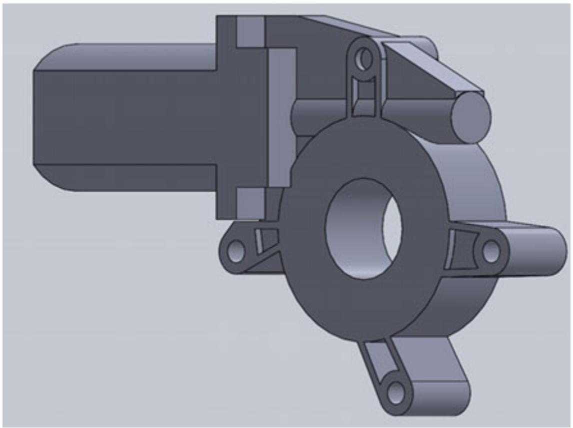


Fig. 5 Worm-geared window motor

5 Experiments and Results

The robot was tested in an arena which resembles the real-world scenario. The operator controls the robot using a customized joystick board. The operator controlled wirelessly through the video visual from the cameras fixed on the robot. The design and solid metallic body gave extra stability. To inspect the feasibility of the proposed design, we tested the robot under different terrain scenarios, A. 25° ramps, B. uneven terrain, C. 45° steep terrain, and D. parallel rail bars.

Fig. 6 Robot tested on rail bars

5.1 25° Ramps

This test scenario contains 25° continuous ramps. According to the tested results, the robot was able to drive freely as shown in Fig. 6. The flipper mechanism gave extra support to modify the pose to the altered terrain environments.

5.2 Uneven Terrains

This test scenario consists of varied angles and dimensions of ramps on the trot continuously. Despite these harsh terrains, the robot drives freely.

5.3 45° Steep Terrain

The arena consists of a 45° steep track. With the high torque E-bike motor and the flipper mechanism, it will be to go up the 45° steep track.

5.4 Parallel Rail Bars

This test consists of two parallel rail bars of breath equal to the dimension of the main track width of the robot. With the PID control, speed parameter of the robot is controlled by which we were able to drive the robot on the parallel rails without deviating its path as shown in Fig. 7.

These scenarios will test the robustness and flexibility of the robot in harsh environments.

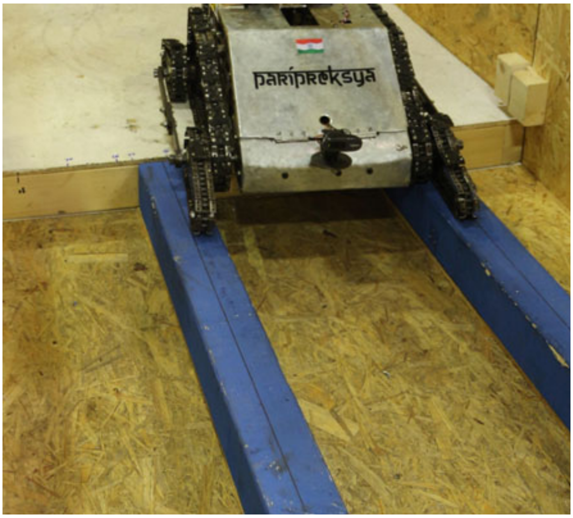


Fig. 7 Robot tested on ramps

6 Future Works

Robot flipper mechanism needs to be modified so it adds more stability to reach steepy terrains too. Gearbox should be redesigned to meet the required torque for flipper. The drive chain mechanism needs to be modified since axial motion of the main sprockets causing the chain to slip from the sprocket. This problem can be restrained by installing cross-roller bearing mechanism. Efficiency of power transmission through sprocket chain mechanism is way less than direct coupling of the motor to sprocket so it is necessary to avoid chain drive mechanism. Chassis material needs to be fabricated with aluminum to diminish the weight issues. Track belt needs to be installed with nylon pulley instead of direct chain and sprocket since robot is lacking friction in few situations. This also reduces the weight of the robot. As the robot runs many modules, processor speed of the microprocessor needs to be improved to decrease delay in transmission of camera footage. Communication range of the robot also needs to be improved for extending the exploration limits of the robot, needs to extend research on autonomous navigation which maps the surrounding and navigate itself, and needs to include image-processing module for detecting hazard signs and victims.

7 Conclusion

Although there is an enormous amount of research in the field of search and inspection robotics, this paper provides the working and design of a low-cost mobile robot which can be used for search and inspection in disaster-hit areas. The mobility of the robot through rough terrains or through debris left in the disaster hit areas is impactful and considerable because of its flipper mechanism. The body design developed is very suitable for disaster sites because of its rigidity and durability. The power consumption of the robot is also less compared to other robots used for exploration purposes. The paper also acknowledges the fact that during disaster situation, we need a reliable communication network between the operator and the robot. Thus, the Ubiquiti antenna deployed near the controller station provides strong and reliable connection between the master and slave interface. The Wi-Fi adapter used is configured with an operating bandwidth of 5 GHz so that we do face a transmission delay in the network. We also focus on the setup time for the robot which is considerably small in our case. Setup time needs to be very small for these rescue robots.

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