RoboCup Rescue 2023 Team Description Paper ATR_Kent Team

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Info

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https://www.atr.cs.kent.edu/projects/robocup-2023/rescue/
Team Video:
https://www.youtube.com/watch?v=tV9nKRRgIb4

***Abstract*—This paper presents the TeleBot-3R, a semi-autonomous humanoid telepresence robot specially designed for search and rescue applications. The TeleBot-3R was developed by the ATR_Kent team of the Advanced Telerobotics Research (ATR) Laboratory under three central design principles: (1) employing an intuitive and familiar method of control (2) leveraging artificial intelligence (AI) algorithms to realize semi-autonomous capabilities and greater operational independence, and (3) using a transformable physical structure to navigate rough terrain and provide flexibility in constrained environments. In this paper, we outline the overall architecture of the TeleBot-3R and specify the advanced approaches our team employs for execution of RoboCup Rescue tasks. In addition, we introduce the organization of our team including the roles and contributions of individual members.**

***Index Terms*—RoboCup Rescue, Team Description Paper, Teleoperation, Supervised Autonomy, Virtual Reality**

I. Introduction

In the wake of disasters, such as the Fukushima nuclear disaster or the recent earthquakes in Turkey and Syria, extensive human and ecological harm are at risk if response teams are unable to quickly react. Unfortunately, the vicinity of such disasters may often be too hazardous for humans to safely navigate, posing a substantial barrier to an effective response. Robotic systems present a powerful solution to this issue. A human agent can teleoperate a robot from a distance to accomplish a number of imperative tasks in such hazardous environments, without putting themselves at risk to those inherent hazards.

Despite this, several barriers lie in the way of the widespread adoption of telerobotics in disaster response scenarios. Such systems, for instance, are often very complex and challenging to control. As such, it can take months to develop proficiency in their operation. This excessive timeline may limit their adoption by the first responders responsible for their operation. Furthermore, methods of control which rely completely on teleoperation in real-time are unfeasible in the presence of significant bandwidth constraints. These challenges can be addressed through the deployment of intuitive, familiar interfaces and supervised autonomy which collectively lessen operational dependency on the human controller.

All team contributors are members of the ATR lab at Kent State University, Ohio, U.S.A, e-mail: jkim72@kent.edu .

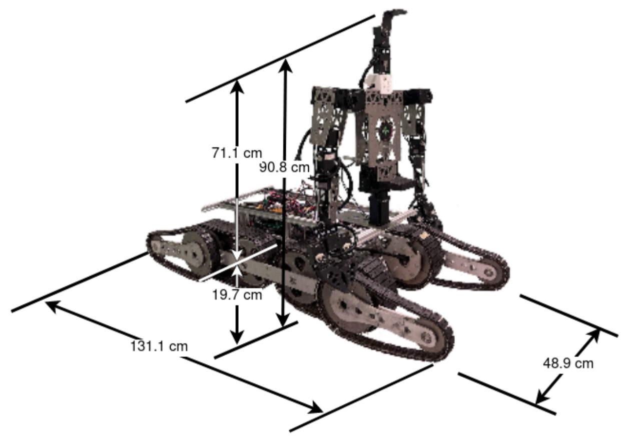

Fig. 1: Dimensioned image of fully-assembled TeleBot-3R

In this paper, we present the TeleBot-3R, a semi-autonomous humanoid telepresence robot that integrates these two aforementioned factors to offer a highly intuitive tool for rescue and disaster response scenarios. The TeleBot-3R, shown in Fig. 1, builds upon our previous work in [1] [2]. The integral characteristics of our robotic system are fourfold: (1) using a Virtual Reality (VR) control system, which provides the user with a familiar and intuitive interface compared to the complex button-axis joystick alternatives (2) having a transformable structure, thereby allowing it to navigate rough terrain and adapt its shape to the constraints of its surroundings, (3) affording intelligent navigation, manipulation, and perception capabilities through Artificial Intelligence (AI) algorithms, and (4) being developed upon a robust robotics software structure, ensuring its adeptness in the wide variety of situations encountered in real-life scenarios.

II. System Description

A. Hardware

The TeleBot-3R's structure consists of a dynamic upper body and lower body structure. The upper body is designed to mimic a humanoid torso with two arms. The lower body, the "mobile base," is made of four independently-driven treads, each with a flipper on the end for improved maneuverability across a variety of terrains. This structure allows for the robot to take three distinct forms: “compact”, “tall”, and “extended”. The dimensions of each form is shown in Table I.

TABLE I: Robot dimensions

Dimensions	Compact Phase	Tall Phase	Extended Phase
Length	90.17 cm	90.17 cm	130.81 cm
Width	48.26 cm	48.26 cm	155.58 cm
Height	40.64 cm	106.68 cm	87.63 cm

The “tall” form features the arms fully extending upwards and the flippers pointing towards the ground, elevating the robot. In this form, the robot has an enhanced reach and can also easily descend from higher to lower elevations. When the TeleBot enters its “compact” form, the upper body condenses onto the lower body and the flippers point upward. In this form, the robot reduces its frame to fit into tighter spaces. Lastly is the “extended” form, in which the TeleBot’s flippers extend outwards in a horizontal manner and the arms reach fully out to the side. This form allows the robot to navigate uneven terrain and interact with distant objects. The operator can use combinations of these forms to enhance the TeleBot’s ability to perform in varying environments.

1) Electric Circuit: In order to facilitate safe and consistent operation of the TeleBot-3R, the team has designed several custom printed circuit boards. The Power Distribution Board (PDB) is responsible for relaying power throughout the system. This board also provides a wireless Bluetooth kill switch to remotely disable power to the motors in the case of an emergency. Another board designed by the team is the microcontroller board, which houses an Arduino Uno as well as a display screen and buttons to control aspects of the robot for testing purposes.

2) Leveling System: We installed two inertial measurement units (IMUs) on the TeleBot to assist with the leveling of the robot. The first is installed on the lower body of the robot, providing both roll and pitch information. This feedback is used to keep the robot balanced on the most uneven of terrains. This information is also valuable if weight on the robot becomes unevenly distributed. The other IMU, which is installed on the head of the robot, allows the head of the robot to remain level. This is crucial for the video feed to remain stable and avoid motion sickness of the operator.

3) Mobile Base: The mobile base, shown in Fig. 2, is at the heart of the TeleBot-3R’s operation. It houses all main computing aspects of the robot including a small desktop computer, motor controllers, batteries, and the bulk of the custom circuitry. The desktop computer is responsible for running the software related to controlling the robot, such as mapping, localization, and path planning. The desktop is also responsible for communication with the operator station and interpreting any commands from the operator. Structurally, the mobile base is designed with four flippers located at the front and back of the robot. These can be used to vertically scale terrain such as staircases, ledges, or ramps. An Intel Depth Camera, attached to the front of the robot, is used to generate 3D point clouds and 2D maps for navigation.

Fig. 2: TeleBot-3R Mobile Base

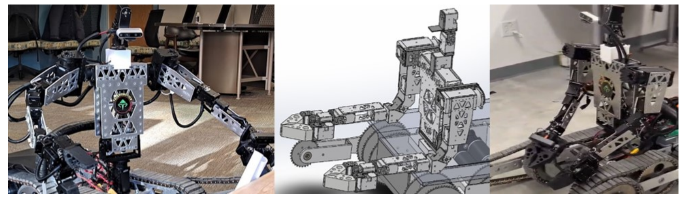

Fig. 3: TeleBot-3R Upper Body

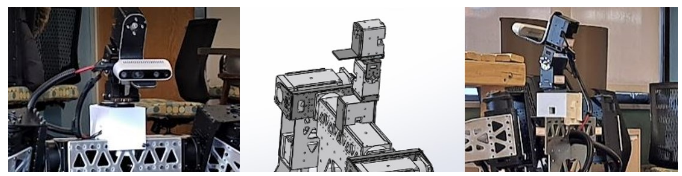

Fig. 4: TeleBot-3R Head

4) Upper Body: The upper body, shown in Fig. 3 of the TeleBot is designed to mimic a human torso, with a head and two arms. The arms are built using a combination of Dynamixel Pro and Dynamixel XM540-W270 motors, resulting in 9 degrees of freedom (DOF). Two more Dynamixel Pro motors are used as a waist to support the upper body and allow for more complex motions. When controlling the TeleBot, the human-like structure provides the user with a more precise and immersive experience. This supports a wide variety of intuitive control schemes and operation methods. We have also mounted several cameras on the upper body to provide the operator with a more comprehensive view of the robot’s surroundings.

5) Head: The head (Fig. 4) of the robot includes two cameras which provide additional data to the operator. The first camera is a low-latency 4K resolution camera which acts as the main perspective for operators. By leveraging the second camera, another Intel Depth Camera, we can also generate a second point cloud to further improve our mapping and navigational data.

B. Software

The following section demonstrates the components of our software structure, including perception, navigation, and control.The Robot Operating System (ROS), a robotics middleware designed for heterogeneous computer clusters, serves as the foundation of this system.

1) Driving: The driving system is based on the Turtlebot 3 [3] control system with added flipper control capabilities. By default, it can drive itself using differential driving, yet this ability is customizable to suit the needs of the operators. An operator can also watch the surrounding environment through multiple cameras on the robot.

2) Navigation: The navigation system implements rtabmap [4], a ROS package for navigation, which creates a 3D point cloud of the surrounding environment and a 2D occupancy grid map using the depth camera from the robot base and robot head. Moreover, in cases of uneven terrain, the base driver uses the Turtlebot3 navigation driver with additional flipper control and path planning algorithms.

3) Object Recognition: For computer vision and object detection, we employ a variety of algorithms and strategies to recognize objects and extract information from surroundings. This includes the ”You Only Look Once” (YOLO) [5] object detection algorithm. We have leveraged YOLO in the past in the development of our vision-based gauge detection system [6]. This gauge detection system has been extended to recognize critical objects in disaster response scenarios. Furthermore, this prior experience has allowed us to develop perception algorithms to track moving objects for position updates and to identify nearby items or victims.

C. Communication

Our system uses a Dual-Band Mesh WiFi 6 connection powered by Linksys Intelligent Mesh technology. It is capable of a speed of 6 Gbps and is compliant with IEEE 802.11ax to provide a consistent flow of data between all agents in the system. The TeleBot-3R is capable of two distinct communication modes. The first mode is the high-bandwidth mode, which occurs while the speed exceeds 50Mbps. In this mode, all data including camera feed, mapping data, and robot control commands are transmitted actively across the network. If the connection speed drops below 50 Mbps, the TeleBot enters limited bandwidth mode. In this mode, the TeleBot operates semi-autonomously to reduce the amount of data transferred. Additionally, video resolution and framerate is significantly reduced and mapping data is not transmitted. These two modes allow the TeleBot to operate under a variety of network conditions.

D. Human-Robot Interface

As important as it is to have a sturdy and reliable rescue machine, it is equally important that an operator can see and operate the robot effectively. The operator can achieve this through both (1) Visual Control and (2) Robot Manipulation.

1) visual control: The team will leverage their previous expertise with virtual reality technologies [7] [8] [9] to expand upon an existing VR interface for the HTC Vive Pro headset. Figure 5 shows the VR setup used in past RoboCup Rescue challenges [10]. This will give them a clear view of what should be done with the robot along with predictions for future icons. For the Heads up Display (HUD), there are also several icons that can display useful information to the operator such as whether the motors are overheating or overloaded, or whether the TeleBot's connection was disrupted. There is also a camera view to the main operations room to display the actions of the human operator. For the support operator, we provide a standard 2D webcam view from TeleBot-3R's many cameras. The assistant operator can use the video stream to help the primary operator finish the operation.

2) robot manipulation: The team will be using the same four manipulation methods used in previous competitions, which are (1) Algorithmic control, (2) Telesuit control [11], (3) Mannequin control, and (4) PCGUI control. Our primary control method is algorithmic control, and we employ a predefined aim to predict the target location in our system. The camera view provides input on the goal location to the robot once it is in place. Once this is done, the algorithm will then take control, using the MoveIt protocol to manipulate the item along the line. The Telesuit controller is a backup control system employed when the algorithm can no longer safely continue the operation or when the algorithm fails. It's a custom-made sportswear outfit with various IMU sensors that monitor and transmit the operator's movement to the robot.

With the power of a VR headset, the operator can control the robot from a first person perspective, which greatly improves the operators ease of control. The operator can make use of two Oculus controllers in order to simulate the arm and body movements of the robot, making it very immersive. The other method of control is through a simple GUI on a computer. It will make use of a button and slider-based control system that runs on the support operator's computer. This trusts the assistant operator's PC as the ultimate safety control if the VR system fails.

III. Application

A. Setup and Breakdown

Due to the heavy weight of the robot and the use of a VR control system to operate it, we will have two people responsible for its setup. The first-person will take care of using a spare laptop to connect the robot and use the keyboard to drive it into the venue, while the second person will be the main operator that will set up the VR station using a VR-ready laptop. Once setup is complete, it will take 7 to 15 mins for the operator to connect with the robot using the current network. The robot has a battery that can last up to 2 hours at maximum performance. Once the operation is complete, the person with the spare laptop will use the keyboard control to return the robot to its original location. Then, the other operator will start dissembling the VR station, which will not take more than 10 minutes.

B. Mission Strategy

Our approach consists of combining preset goals in our system and real-time environmental data. This is to allow our robot to function autonomously as much as possible. When the algorithmic plan fails, we will implement a VR-based control system to take control. The operator will be able to observe and operate objects as if they were the robot to provide more efficient and accurate mobility. Our team's objective is to develop an innovative solution for the rescue robot field.

C. Experiments

As part of our efforts to improve the design and functionality of our disaster response robot, we initially put it to the test at the World Robotic Summit (WRS) in 2018, a highly

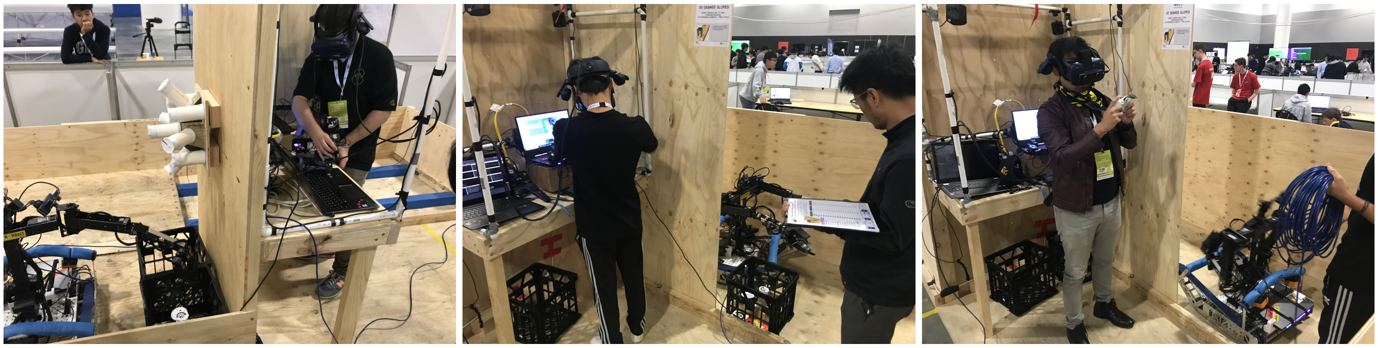

Fig. 5: Demonstrate of visual control set used in the past RoboCup-2019 challenge

competitive event that challenges teams to develop robots capable of navigating simulated disaster scenarios. Although our robot performed admirably, we discovered certain design flaws that needed to be addressed. Once we returned from Japan, we wasted no time in setting up a testbed in our laboratory to run experiments and fix these flaws.

Through rigorous testing and experimentation, we could identify the root causes of the design flaws and implement effective solutions. Our efforts paid off, and we were pleased to see significant improvements in the robot's performance.

We were so encouraged by our results that we decided to take our experiments to the next level. In 2019, we participated in the World Robotic Summit once again, this time armed with a robot that had undergone substantial improvements based on our earlier testing. Our efforts were rewarded with even better performance results, and it thrilled us to see that our robot was now more capable and efficient than ever before.

Despite these successes, we remain committed to ongoing experimentation and improvement. To this end, we have recently applied to create a larger testbed within Kent State University. By expanding our testing capabilities, we hope to continue refining our robot's design and pushing the boundaries of what it can do in disaster response scenarios.

D. Application in the Field

Our team's objective as it relates to application in the field is to create an immersive control system that gives users the illusion that they are the robot themselves. Specifically, we are bringing VR and Telesuit technology together, implemented through ROS, for a simple, comprehensive user interface. This allows the user to focus on the task at hand rather than the technical operation of a robot.

IV. Conclusion

In this paper, we demonstrate the hardware and software components of our TeleBot-3R robotic system. Owing to its humanoid torso, immersive VR control system, and numerous graphical user interfaces, our robot is intuitive in operation, allowing an operator to smoothly adapt to its use. Furthermore, its semi-autonomous features and adaptable physical form make it dynamic in application, ensuring it is well-suited for deployment in a diverse set of unfamiliar and unpredictable environments.

TABLE II: Manipulation System

Attribute	Value
Name	TeleBot3R
Locomotion	hybrid: tracked & wheel
System Weight	56kg
Weight including transportation case	66kg
Transportation size	1.75 x 0.75 x 0.5 m
Typical operation size	1.55 x 0.55 x 0.3 m
Unpack and assembly time	400 min
Startup time (off to full operation)	20 min
Power consumption (idle/ typical/ max)	1100 / 2200 / 6600 W
Battery endurance (idle/ normal/ heavy load)	120 / 60 / 20 min
Maximum speed (flat/ outdoor/ rubble pile)	0.48 / 0.48 / 0.3 m/s
Payload (typical, maximum)	12/ 15 kg
Arm: maximum operation height	180 cm
Arm: payload at full extend	0.8kg
Support: set of bat. chargers total weight	12.5kg / 6kg
Support: set of bat. chargers power	1000W (100-240V AC)
Support: Charge time batteries (80%/ 100%)	55 / 70 min
Support: Additional set of batteries weight	12.5kg
Cost	95000 USD

Appendix A
Team members and Their Contributions

- Jong-Hoon Kim — Advisor
- Justin Dannemiller — System Design & Team Leader
- Bailey Wimer — Robot Design & Hardware
- Stefan Hendricks — Lead Software Developer
- Sean Peters — Object Manipulation
- Ikrame Rekabi — Human-Robot Interface
- Mohammad Shahin — SLAM Algorithm
- Shuvo — Object Recognition
- Saifuddin Mahmud — Motion Planning

Appendix B
Lists

A. Systems List

B. Hardware Components List

List all interesting components of your Robots and Operator stations. Include a hyperref link to the product page if possible - see the examples.

IV

C. Software List

Table V list all relevant software packages is used in our robot system.

TABLE III: Operator Station

Attribute	Value
Name	Tele-Op Station
System Weight	5kg
Weight including transportation case	5.5kg
Transportation size	0.4 x 0.4 x 0.2 m
Typical operation size	0.5 x 0.4 x 0.4 m
Unpack and assembly time	15 min
Startup time (off to full operation)	5 min
Power consumption (idle/ typical/ max)	60 / 80 / 90 W
Battery endurance (idle/ normal/ heavy load)	4 / 2 / 1 h
Cost	3000 USD

TABLE IV: Hardware Components List

Part	Brand & Model	Unit Price	Num.
Manupulator	Dynamixel Pro; XM540-W270	USD 2790	10
Drive motors	Dynamixel XM540-W270	USD 360	19
Drive motors	2.5 CIM Motor	USD 47	19
Drive gears	Top Box Mini	USD 95	04
DC/DC	Regulator	-	1
Battery Management	custom designed	-	1
Batteries	HRB LiPo 10000mAh 25C	USD 95	4
Batteries	HRB LiPo 5000mAh 22.2v 50C	USD 79	2
Micro controller	OpenCR	USD 180	1
Computing Unit	Dell Form Factor Desktop	USD 500	1
Computing Unit	ASUS ROG Laptop	USD 1500	1
WiFi Adapter	Linksys MR9600	USD 299	1
Cameras	Logitech 4k Camera	USD 199	1
Depth Cameras	Intel RealSense	USD 419	2
lidar scanner	Intel Lidar Camera L515	USD 589	1
Battery Chargers	LiPo Battery Balance Charger	USD 58	4
Upper Body	custom designed	-	1
Rugged Operator Laptop	ASUS ROG Laptop	USD 1500	1

TABLE V: Software List

Name	Version	License	Usage
Ubuntu	20.04	open	Utility
ROS	Noetic	BSD	Utility
PCL [12]	1.7	BSD	ICP
OpenCV	2.4.8	BSD	Object detection
Hector SLAM	0.3.4	BSD	2D SLAM
Octomap	1.9.0	BSD	3D Mapping

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