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A REMOTE-CONTROLLED ROBOT-CAR IN THE TPS TUNNEL

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Abstract

A remote-controlled robot-car named “PhotonBot” was put into the TPS accelerator tunnel and is equipped with a 360° LiDAR for SLAM and navigation, two cameras for perception and first-person view, and a thermal imaging system. The robot can be remotely controlled and can send data to a remote PC through Wi-Fi. With SLAM, it can go more freely without being restricted to a designated path. In order to ensure it can work continuously, there is a wireless charging station in case of a low battery.

INTRODUCTION

In the last few years, robotic technology has found more and more application areas. For example, TIM, the Train Inspection Monorail, is a mini vehicle autonomously monitoring the 27-km long LHC tunnel and moving along tracks suspended from the tunnel's ceiling. It is packed with sensors for visual inspection, infrared imaging and environmental monitoring (oxygen, temperature) and was put into use in 2016 [1]. In 2018, they came up with a robotic platform called “CERNBot” for complex interventions in presence of hazards like ionisation radiation. The platform is modular and flexible [2][3]. A mobile autonomous robot platform, MARWIN, is designed for performing maintenance and inspection tasks alongside the European XFEL [4].

The Taiwan Photon Source (TPS) with a circumference of 518.4 m includes a low-emittance synchrotron storage ring and a booster with an energy of 3 GeV. To monitor the environment inside the tunnel during top-up injection mode, a remote-controlled mobile robot named “PhotonBot” was developed.

SPECIFICATIONS

The PhotonBot is developed from a model called ”Turtlebot3 waffle-Pi”, which is a product from the company ROBOTIS [5]. It consists of a single board computer (Raspberry Pi 3 Model B), a 360° Laser Distance Sensor (LDS-01), a Raspberry Pi camera, a main robot controlling board (OpenCR1.0), a Bluetooth module, 2 servo actuators (Dynamixel XM430), a Li-Po battery and a 3D printed scalable structure (Fig. 1). The 360° Laser Distance Sensor LDS-01 is a 2D laser scanner capable of sensing 360° collecting data from the robot’s environment to use for Simultaneous Localization and Mapping (SLAM) and Navigation. OpenCR is the main robot controller board and is an open-source control module for Robot Operating System (ROS), developed for ROS embedded systems to provide completely open-source hardware and software. The DYNAMIXEL XM series can be operated by one of six operating modes: velocity control mode for wheels, torque control mode or position control mode for joints, etc. The robot is thereby able to get precise spatial data by using two DYNAMIXELs in the wheel joints. The PhotonBot can bear a load of up to 30 kg and its maximum translational velocity reaches 0.26 m/s [5].

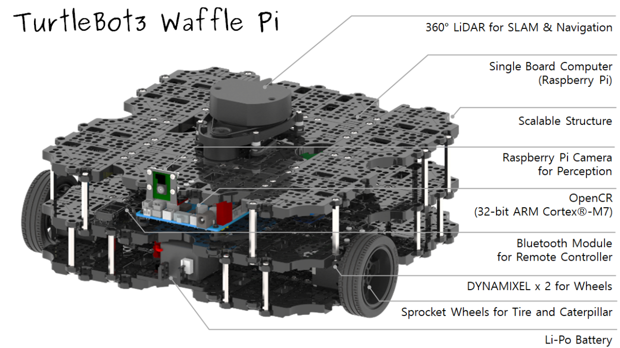

Figure 1: Turtlebot3 waffle-Pi.

BASIC OPERATION

The PhotonBot can be controlled through Wi-Fi as long as both the single board computer (SBC) and the remote PC are connected to the same router. The following describes some basic operations.

Teleoperation

The robot can be teleoperated by various devices such as a keyboard, PS3 and XBOX 360 joysticks. It can be moved linearly or to rotate by using interactive markers on ROS visualization (RViz) (Fig. 2). It can also be moved or stopped by LDS data and it stops automatically when it detects an obstacle ahead. The robot can be moved by 2D point (x, y) and z-angular. For example, if one inserts (1, 1, 90), it moves to point (x = 1 m, y = 1 m) and then rotates 90° (Fig. 3).

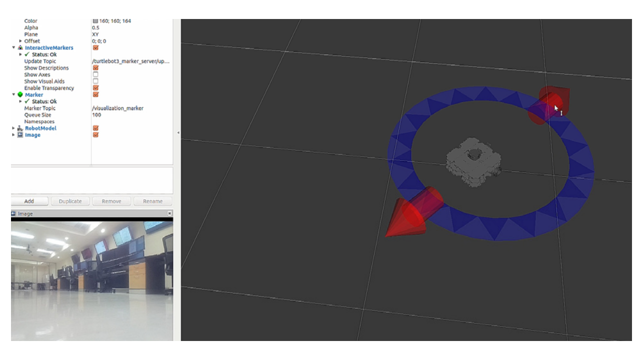

Figure 2: Interactive markers on Rviz: drag the red arrows to move the robot forward or backward and the blue circle to rotate.

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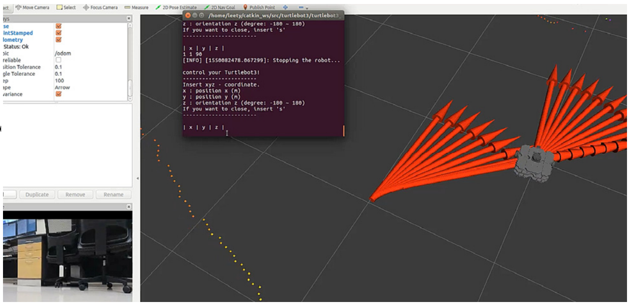

Figure 3: Point operation: the robot can be moved by 2D point (x, y) and z-angular. The red arrows show which direction it's facing while it's moving.

SLAM

Simultaneous Localization And Mapping (SLAM) was developed to let a robot create a map with or without the help of human beings. This is a method of creating a map while the robot explores the unknown space and detects its surroundings and estimates its current location (Fig. 4). The robot's movement is measured by the rotation of the wheels. Laser Imaging Detection and Ranging (LiDAR) detects obstacles and measure the distance. Combining the data from the encoders of the wheels and LiDAR, it can create a map.

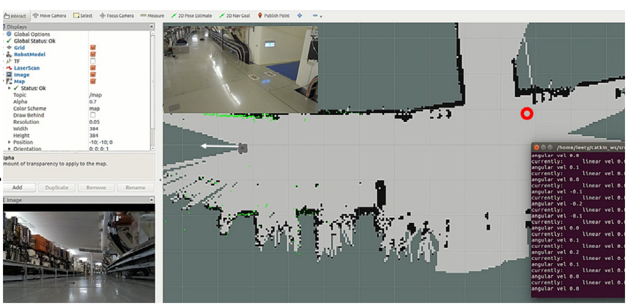

Figure 4: Building a map using SLAM and g-mapping. The white arrow shows which direction the robot and its front camera are facing. On the bottom left is the image captured by the front camera. On the upper center is the image captured by another camera on the red circle position.

Navigation

Navigation allows the robot to move from one location to the specified destination on the map created by SLAM. The robot moves from the current pose to the goal pose on the map by using the map, its own robot's encoder, an IMU sensor, and a distance sensor (Fig. 5).

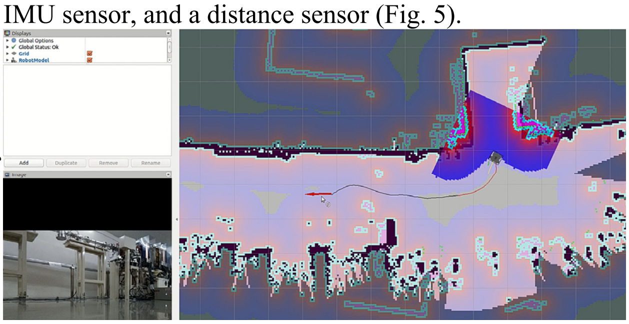

Figure 5: The navigation enables a robot to move from the current pose to the designated goal pose on the map. The small square surrounding the robot showing a red-to-blue gradient. The red appears near obstacles and blue indicates no obstacles nearby.

APPLICATION

To insert the robot into the TPS tunnel environment, a few modifications had to be made.

Height

The base plane for the electron orbit is 1350 mm from floor level. Three more layers, separated by a 300 mm space, were added to gain the final robot height of 1100 mm, which brings the sensors closer to the main accelerator components (Fig. 6). The strongest radiation is at around 1350 mm from floor level. The sensors on a lower stage can reduce the radiation damage. In order to get the measurement data at 1350 mm, a robot arm is under development. It'll cover the height from 1100 mm to 1500 mm or above, and provide more freedom to the sensors. The sensors will be able to detect the target from different positions and angles.

Figure 6: PhotonBot after adding three vertical extensions to increase its height to 1100 mm.

Power

To ensure the PhotonBot can operate for a long time, the commercially supplied 1800 mAh Li-Po battery was replaced with three batteries in parallel for a total of 16000 mAh. Thus, the working hours have extended from 20 minutes to 2 hours depending on the workload.

To make the PhotonBot work continuously, a charging station is necessary. In order to simplify the charging mechanism, a wireless charging module has been integrated with the batteries. The wireless charging module has an output of 12 volts and a higher power of 40 watts compared to commercial wireless chargers for cell phones, which run mostly at 5 volts and around 10 watts. It also provides a longer charging distance of 5 cm between the transmitter and receiver coil than the commercial ones with less than 1 cm (Fig. 7). The transmitter coil has been laid in the floor at the charging station, and the receiver coil is installed on the lower layer of the PhotonBot. As it parks on the transmitter coil, it will start charging.

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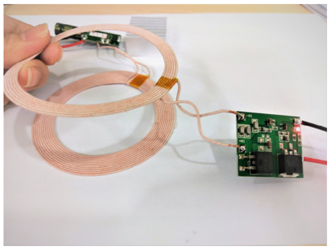

Figure 7: A 40 watts wireless charging module can induce current up to a distance of 5cm.

Sensors

To monitor the temperature distribution of machine components during high beam storage, a thermal imaging mod-ule (FLiR Dev Kit [6]) and a camera were installed (Fig. 8). A Lepton longwave infrared (LWIR) imaging module, included in each FLiR Dev Kit, acts as a camera with a resolution of 80 × 60 pixels and is smaller than a dime while capturing infrared radiation input in its nominal re-sponse wavelength band (from 8 to 14 microns) and out-puts a uniform thermal image.

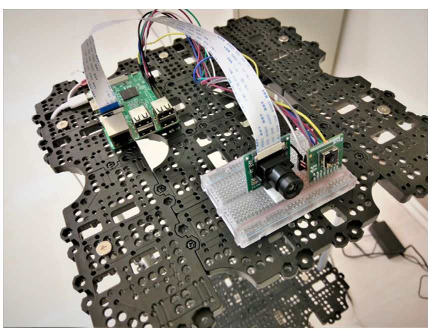

Figure 8: A Pi camera and a thermal imaging module (FLiR Dev Kit) were hooked up with another Raspberry Pi.

Results

The first application is to take panoramic pictures and virtual reality (VR) videos in the tunnel (Fig. 9). Second, real-time inspection images and thermal images of different components were captured during 405 mA stored beam current operation (Figs. 10-13). The images show the temperature distribution, which allows the detection of any abnormal hot spots as a precaution.

Most of the main components such as the SBC, LiDAR, controlling board and actuators are placed closed to floor level, so it helps to lower the radiation damage. The PhotonBot operates now in the TPS tunnel for two months and all the functionalities still work fine. The lifetime of the PhotonBot against the radiation is still under observation.

Figure 9: A panoramic picture taken by the PhotonBot in the TPS tunnel.

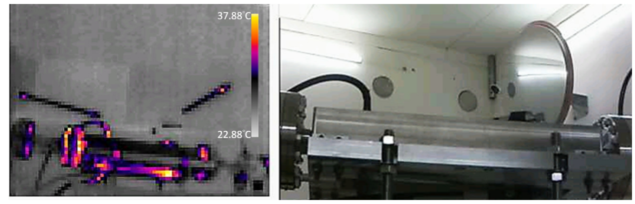

Figure 10: Thermal image of a strip line kicker.

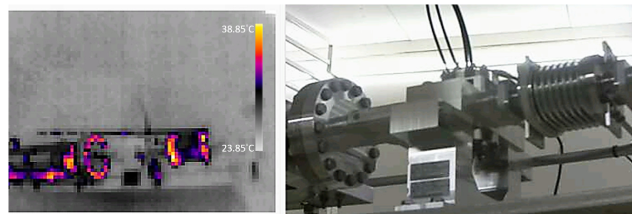

Figure 11: Thermal image of a flange and bellow.

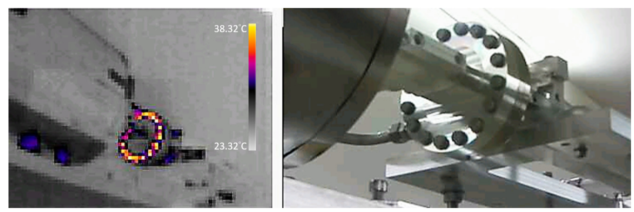

Figure 12: Thermal image of a flange.

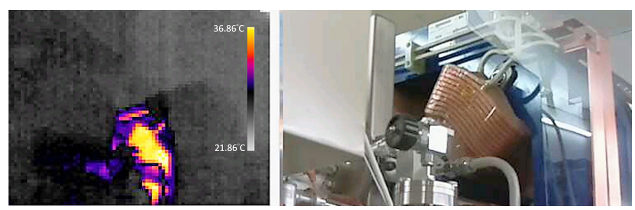

Figure 13: Thermal image of a magnet.

PROSPECT

To give the sensors more freedom in detection, a robot arm is under development. It'll allow the sensors to measure objects at different angles and positions. More instruments, such as radiation detectors, will be mounted on the PhotonBot to measure radiation intensity and distribution in the machine tunnel.

Furthermore, imaging recognition will be implemented in the PhotonBot to find the charging station and automatically park itself.

CONCLUSION

The PhotonBot combines a variety of technologies such as a robot system, internet of things (IoT), wireless charging, VR and self-driving (SLAM, navigation and imaging recognition) to particle accelerator components. On the other hand, particle accelerator facilities which have large, isolated, restricted and radiation protected areas provide good testing sites for robots. The PhotonBot is based on open-source hardware and software, which offers a relatively cheap platform for development and integration. More applications will be developed in the future.

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