DESIGN AND DEVELOPMENT OF AI AUGMENTED ROBOT FOR SURVEILLANCE OF HIGH RADIATION FACILITIES

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Abstract

Scientific instruments and utility equipment at high-radiation facilities such as the Advanced Photon Source at Argonne National Laboratory are often challenging to monitor during actual operation. To help augment monitoring capabilities, we are developing an instrumented robot that uses artificial intelligence (AI) to create a thermal and spatial 3D map of its surroundings. The robot can be self-driven or controlled remotely. The robotic vehicle—whose overall dimensions are 50 cm in length, 20 cm in width, and 20 cm in height—carries a depth perception camera to guide itself on a predetermined path; an IR camera for thermal imaging; dosimeters to measure stray radiation; and a cluster of other sensors to assist in communications and navigation, as well as measuring noise, vibration, temperature, and humidity of the surrounding space. This inexpensive robot is operated and controlled by NVIDIA's Jetson Nano^{TM} development board, one brushless DC motor, and one servomotor that controls the movement of the robot. All control and data acquisition programs are written in Python for ease of integration with institution-specific operating systems such as EPICS. The AI robot was trained using machine learning followed by the application of a trained algorithm for navigation. This paper discusses our preliminary development of the robot.

INTRODUCTION

Synchrotron radiation facilities such as the Advanced Photon Source, and nuclear radiation facilities—e.g., nuclear power plants, isotope fabrication plants, and nuclear material handling plants—often require continuous monitoring to ensure the safety of radiation workers, existing infrastructure, and the environment [1]. The existing practice for radiological monitoring uses static devices during operation or intervention using human operators. These methods are often costly, time-consuming, and challenging when intervention is necessary or unavoidable. In a radiation facility, the radiation decay and heat immediately after a shutdown due to routine maintenance or due to failure needs to be quantified quickly [2]. To assess the damage or contain/collect contamination is very difficult if human intervention is required [3]. In all such events, a robotic system can be beneficial to assess the condition of the instruments, collect any samples, and monitor the radiation [4]. Moreover, due to recent developments in robotics and artificial intelligence, it is easier to develop a robotic system that can be utilized for this purpose.

The challenge of monitoring scientific instruments in radiation facilities can be solved through this self-guided robot. Equipped with various sensors and artificial intelligence, the robot can successfully and autonomously navigate through facilities while acquiring thermal environmental data and images essential to monitoring scientific instruments, equipment, and the environment. The lead case around the robot protects its various electronic components from damage while navigating through a facility.

In this paper, we discuss our preliminary design of an AI-driven autonomous robot. The robot uses a ready-made radio-controlled car chassis that is equipped with an open-source software platform called Donkey Car [5] installed on a NVIDIA Jetson Nano board [6]. The robot was manually trained on a convoluted path using machine learning [7] and used its very own AI algorithm to select parameters to control the brushless DC motor and servomotor with help from processing the images that it acquired during its travels. The FLIR Lepton camera [8] was used to identify temperature anomolies in the acquired thermal images/video. The robot was trained to identify its travel boundaries via blue tape placed on the floor.

ROBOT DESIGN

The current design of the robot is a WiFi operated, front-wheel controlled, all-wheel-drive vehicle, as shown in Fig. 1. The textured wheels grip smooth surfaces and prove efficient traction over various other types of surfaces. The 3D-printed outer shell combined with lead plates protects the internal hardware from becoming damaged in high radiation conditions. The internal mounting structure allows for seamless cable management through routing slots between the NVIDIA Jetson Nano^{TM} and the motor controller. The slightly raised structure provides room for the batteries needed by the NVIDIA Jetson Nano^{TM}, the FLIR Lepton camera, the Intel RealSense camera, and the motors. The Intel RealSense mount maintains a consistent view of the robot's surroundings, while the FLIR Lepton mount is strategically raised to procure more useful thermography. The on-board NVIDIA Jetson Nano^{TM} acquires images and sensor data to control the robot. The robot can also be remotely controlled using SSH to acquire the navigation panel and access the robot's camera view. A brushless motor is used as a drive, while a servomotor attached to an Ackerman's steering trapezium is used for turning the vehicle. The controlling

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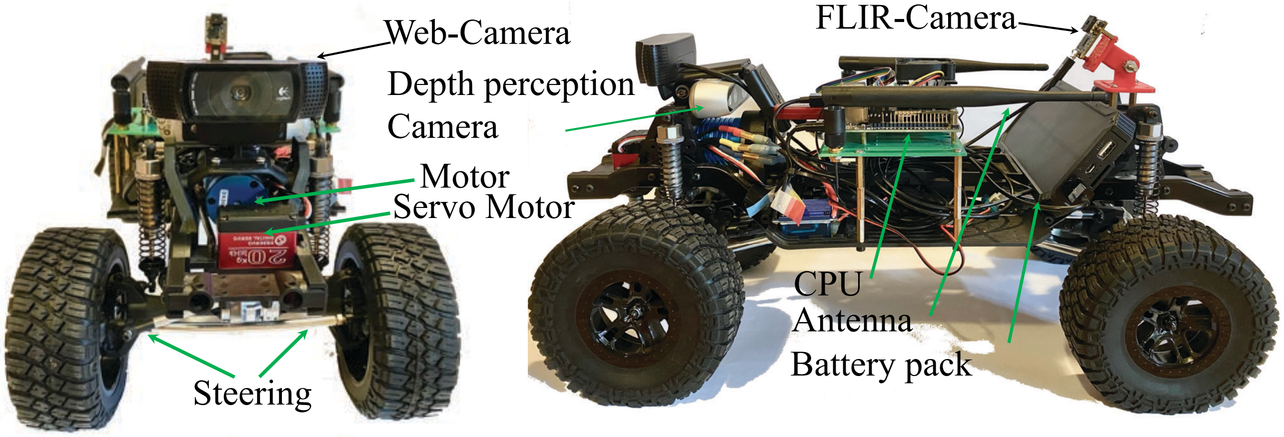

(a) (b)

Figure 1: Images showing various parts of the robot using (a) front view and (b) side view.

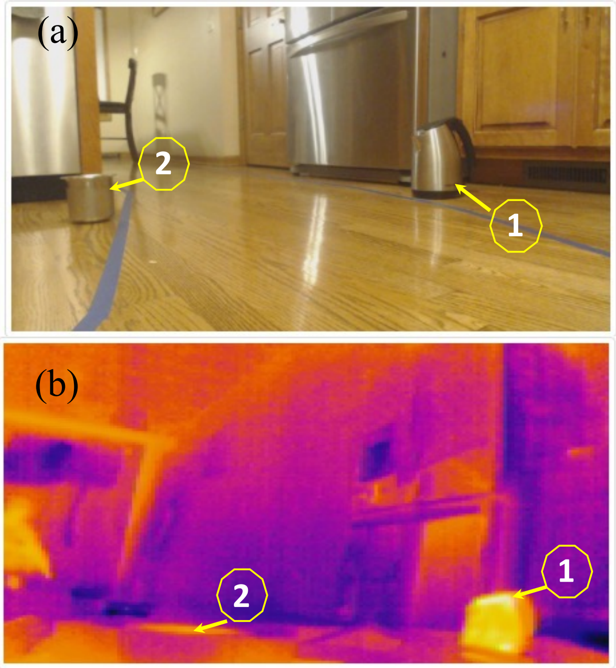

Figure 2: Computer interface images taken (a) by webcam and (b) by FLIR thermal imaging camera. Object 1 is a warm kettle and object 2 is a cold water container.

parameters for speed and steering angle were decided by image processing using machine-learned algorithms while acquiring the images during travel. It can autonomously navigate given areas while effectively avoiding virtual collisions by identifying the path boundaries with colored tape. The current design uses simple images acquired from the webcam, processes those images on board, identifies the boundaries, and avoids them by changing the motor speed and servomotor lever angle attached to the trapezium. The FLIR Lepton (thermographic camera) allows the robot to take thermal images periodically to monitor temperature and possibly identify unwanted hot spots within scientific instruments and utility equipment. The onboard sensors for temperature, humidity, and radiation, as well as noise and vibration sensors will acquire and relay this information to the control station. The final design will be able to avoid the obstacles by identifying them by depth perception camera and plotting the open area using artificial intelligence handled by the NVIDIA Jetson Nano$^{\text{TM}}$.

Mechanical and Electronics Hardware

The chassis is a ready-made radio-controlled toy car frame equipped with a singular brushless motor, a four-wheel drive transmission, and a servo for steering.

Various hardware works in conjunction to provide streamlined navigation using artificial intelligence. The Intel RealSense camera, which captures depth, and the FLIR Lepton, an IR thermal camera, connect to the NVIDIA Jetson Nano$^{\text{TM}}$, a powerful yet small computer capable of AI. The 16-channel PWM/servo driver, an I2C interface, provides the necessary infrastructure to steer and drive the robot (combining a 20-kg servomotor and a brushless motor). WiFi connectivity is necessary in order for the NVIDIA Jetson Nano$^{\text{TM}}$ to access the internet; it also provides a solution to remote control and image acquisition during the early stages of development. The DHT11 temperature and humidity sensor updates the robot with both these data periodically. A more minor yet essential hardware component is the battery temperature sensor, strapped around the battery, that is used to operate the 16-channel PWM/servo driver; this sensor triggers a stop to all motor functions when the maximum temperature threshold is reached.

Intel RealSense D435i Depth Camera Equipped with a bmi055 inertial measurement unit, the Intel RealSense D435i Depth Camera provides depth and time-stamped data. When required, the inertial measurement data can be asso-

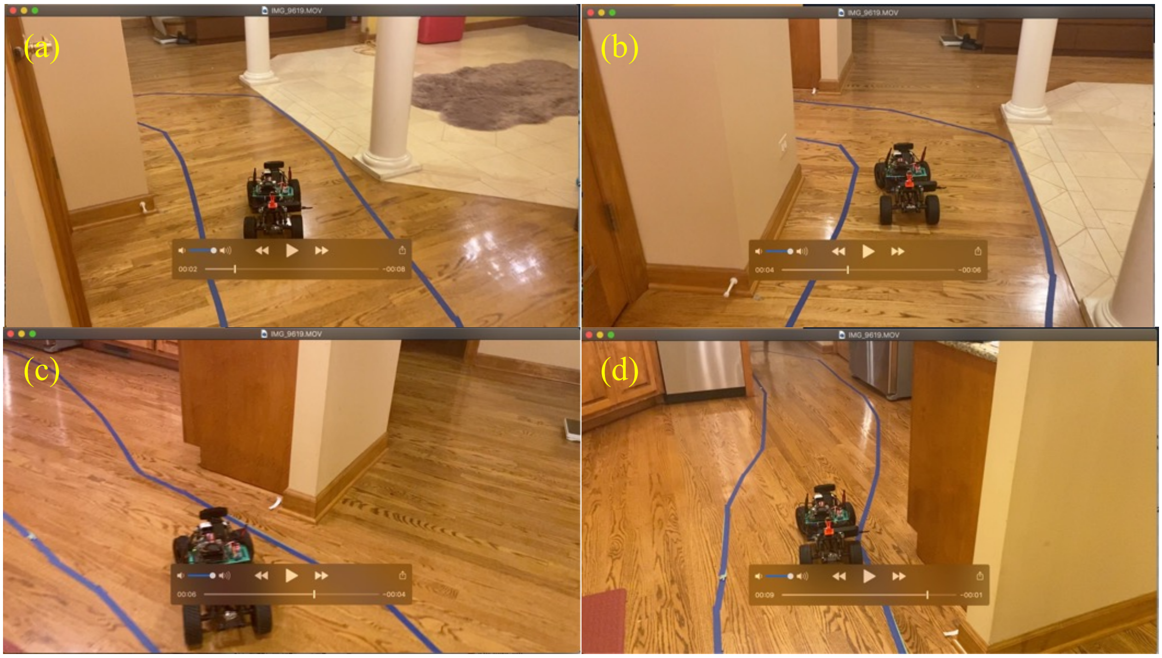

Figure 3: Still video images showing the robot self-navigating the path at intervals of (a) 2 s, (b) 4 s, (c) 6 s, and (d) 9 s.

ciated to detect changes in terrain via measurements of the rate of change of acceleration.

FLIR Lepton The FLIR Lepton is a micro thermal camera module that allows for contactless temperature acquisition and provides a thermal color grade picture of the acquired surroundings.

Programming and Operation

Figure 2(a) shows an image taken by the webcam attached to the front of the robot, and Fig. 2(b) is a thermal image taken by the FLIR camera located at a height at the back of the robot. The robot was trained on a 10-turn closed-loop path using the computer-controlled remote. Nine training sessions were conducted to create the required epoch for machine learning. Donkeycar [5] was utilized to acquire a large number of images by controlling the robot to travel on a simple track. After acquisition of approximately 5000 images, a model was trained on a separate computer. After 25 hours of computing time on a computer, the final metrics were copied back to the robot's CPU. The configuration of the computer that trained the model runs an AMD Radeon 5700XT, an AMD Ryzen 5 5600x, with 16 GB of 3600 mHz RAM at CL16, and a NVME solid state drive. Figure 3 shows timelapse images of the robot moving on the track. The FLIR Lepton takes pictures using Python software. We integrated this into our Python code to simplify image acquisition.

NEXT STEPS

The team is implementing plans to navigate the robot solely using its depth-perception camera to avoid moving and non-moving hindrances. Incorporating an inertial unit will help us detect slippage and changes in terrain such as bumps. The sensor network will be programmed to acquire surrounding information. The authors plan to incorporate a microphone and speaker for communication purposes. After construction and testing of this first prototype, it was decided that a second camera may be necessary to provide for more efficient and accurate navigation and data acquisition, further straining the already-limited memory. The NVIDIA Jetson Nano$^{\mathrm{TM}}$ has 2 GB RAM on-board, a limiting factor for the AI process; additional memory would be required to process the increased amount of data.

CONCLUSION

The robot was successfully trained and navigated its way through a prescribed path bounded by blue tape. The thermal images acquired during the run show the capabilities of inexpensive hardware. This economical approach to monitoring can help operators quickly assess the state of the scientific instruments and utility equipment during operation or during decay time after a shutdown. The capabilities of this robot can be enhanced and used to find trends and indications of equipment problems well before failure leading to improved availability of the facility.

ACKNOWLEDGMENTS

Special thanks to Evan Johns and Steve Spreitzer for help in troubleshooting the camera communication with the robot. This research used resources of the Advanced Photon Source, a U.S. Department of Energy (DOE) Office of Science User Facility at Argonne National Laboratory and is based on research supported by the U.S. DOE Office of Science-Basic Energy Sciences, under Contract No. DE-AC02-06CH11357.

ISBN: 978-3-95450-229-5 ISSN: 2673-5520 doi:10.18429/JACoW-MEDSI2020-TUPC08

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