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Design and Development of a Wireless Robotic System for Radiation Detection and Measurement

Sabiha Sattar[1,3]*, Mohammad Jahangir Alam[2], Yasmeen Mawla[3], Md. Atiar Rahman[3] and Md. Abdullah Al Mamun[3]

[1]Military Institute of Science and Technology, Mirpur Cantonment, Mirpur-12, Dhaka-1216, Bangladesh; [2]Bangladesh University of Engineering and Technology, Palashi, Dhaka-1000, Bangladesh; and [3]Electronics Division, Atomic Energy Centre, Dhaka-1000, Bangladesh.

*Correspondence: sabihasattar@yahoo.com (Sabiha Sattar, Senior Engineer, Electronics Division, Atomic Energy Centre, Dhaka-1000, Bangladesh).

ABSTRACT

A wireless robotic system has been proposed for radiation measurement and monitoring around nuclear facilities. The purpose of the robot is to assist the radiation workers from getting unwanted radiation exposure. The system includes a ground vehicle, GM tube-based radiation counting unit, Raspberry Pi, Pi camera module, and web-based controlling and monitoring unit. With the developed robotic system, the robot is controlled from a server to be moved towards the desired location and measure the radiation level. Radiation level of natural back several radioactive point sources (Cs 137, Co 60, Mn 54) located at different places in the laboratory, has been measured and compared with a GM tube-based commercial survey meter Gamma Scout, w/ALERT model. Analyzing the measured data a deviation has been found varying from 0.29 to 2.18. The proposed system is suitable for radiation detection and measurement in absence of radiation workers in nuclear facilities.

Keywords: Robot, Radiation level measurement, Raspberry Pi, Python, HTML, CSS, and Web interface.

INTRODUCTION:

Nuclear technology is such an area where the underlying benefits are also accompanied with a series of risks. It could be the most hazardous environment for people if proper cautions are not taken. With accelerating demand, nuclear technology is being more broadly used in the power sector, medical treatment, industrial sector, educational sector and research field. As nuclear technology cannot be avoided, it is essential to take precautionary measures to protect radiation workers from getting exposure with unwanted radiation levels. According to the IAEA, effective dose to an individual worker should not exceed 20mSv in a year (IAEA, 1999). Once the worker reaches the maximum dose limit, he /she must stop working immediately in the nuclear environment. Hence, increased worker and longer time duration is required to do a hazardous task. To mitigate the problem, it is essential to use robots or robotic devices to assist in regular basis activities like area monitoring, source handling, inspection and maintenance as well as post accidental recovery. Use of robots in nuclear environments is very much demanding. Though there are very limited works covering this research area in our country, significant research and development work has been performed worldwide. A review work about the development and utilization of terrestrial robotic systems for the nuclear environment was performed to analyze their primary purpose and operating area (Tsitsimpelis *et al.,* 2019). SIMON, a Semi-Intelligent Mobile Observing Navigator was developed as a mobile surveillance and monitoring robot (Weber *et al.,* 1990). Firstly the robot was used at the US Dept. of Energy's (DoE's) Savannah River Laboratory to eliminate the need of human inspection for extended periods in a nuclear facility. SIMON was designed to measure and transmit radiation, temperature and to provide televised views of the nuclear facility. Another case study suggested that, instead of a static robot, mobile robots are more useful for regular based inspection and maintenance work (Fujii *et al.,* 2003).

Research presented an integrated gamma ray imaging sensor system, developed to enhance functionality of robots and telex robotic systems used in the nuclear industry (Redus *et al.,* 1994). The system is a combination of a video camera and gamma radiation detector for identification of radioactive sources. A telerobotic system was developed for maintenance operation in Spanish Nuclear Industry (Iborra *et al.,* 2003). It was showed, that commercial robots can also be used in nuclear environments with specific mechanical support, tools and software. Another series of work presented the capability of commercially available robotic hardware and measuring devices to identify nuclear activity in areas (Cortez *et al.,* 2007; Cortez *et al.,* 2008; Cortez *et al.,* 2009). In Japan, an autonomous robot was customized for remote sensing of radiation dose rate (Kobayashi *et al.,* 2012). A cleaning robot, Roomba was used as the autonomous robot with a scintillation detector. A wireless robot was developed to measure detector response for a moving source-detector configuration (Singh *et al.,* 2014). It was economic-ally designed to be operated in low radiation level environments like universities and medical centers, over plane surfaces. A prototype of a radiation monitoring robot was designed to work in a nuclear power plant area for detection of radioactive levels in waste containers and for detecting contamination (Maheswaran *et al.,* 2016). The robot was monitored and controlled by Lab VIEW serial communication through ZigBEE wireless communication protocol (Akter *et al.*, 2021).

The first nuclear power plant of Bangladesh is going to be operational very soon. Moreover, there are other nuclear facilities in the country like research reactors, nuclear medicine centers, etc. It is necessary to monitor the radiation level of these nuclear facilities on a regular basis. To do such specific routine work, use of robotics is a recommended practice. However, a very few research works on robotic systems for radiation measurement in nuclear fields of Bangladesh was found. In this work, a wireless remote controlled mobile robot has been designed to measure the radiation level around different nuclear facilities. The proposed system ensures safety of the human workers from unwanted radiation exposure, by assisting them with remote monitoring (both radiation levels and visual survey) of hazardous locations where human presence should be limited.

METHODOLOGY:

The main components of the robotic system are shown in **Fig 1**. The system consists of wheels with a gear motor, motor driver, Raspberry Pi, camera module, GM tube based radiation counting unit, power supply and controlling and monitoring unit. The robot developed for radiation detection and measurement is a two wheeler unmanned ground vehicle with a supporting wheel. An 11 inch x 6 inch rectangular shaped transparent acrylic board, called chassis, is the main platform of the robot. The light weighted board has made the chassis sturdy to assemble the electronic components and devices on it. The robot has two wheels with rubber tires. The Dimensions of the wheels are 2.5 inch and are attached at the two sides of the chassis. Additionally a steel ball caster and hard rubber wheel is attached at the bottom of the chassis to balance the structure and to ensure the robot had a smooth movement. Size of the ball caster wheel was 1inch x 0.5 inch. It could rotate 360º. Two DC gear motors are used with the wheels. The DC gear motor is an advanced variation of brush DC motors. With the help of the gear, the motor can produce high torque at low speed. The DC motor requires a high power and control signal to change the rotation direction and speed control which has been provided from the core unit (Raspberry Pi GPIO pins) via L293D motor driver board. Raspberry Pi is a small single-board computer used here as the core unit to control the robot and as well as create a web server on it. It provides access to the on-chip hardware i.e. GPIOs

(General Purpose Input/-Output) for delivering the control signal to the wheels connected through it.

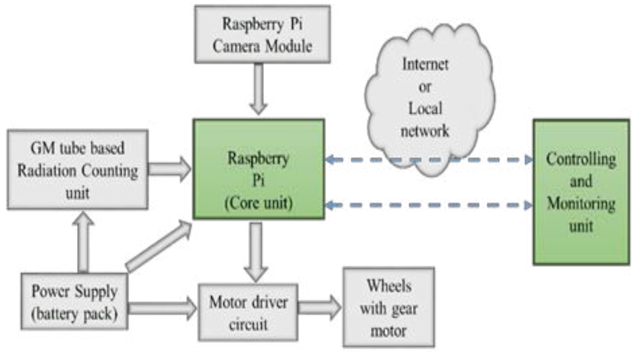


Fig 1: Block diagram of the Robotic System for radiation detection and measurement.

Additionally, it has an on-board 802.11n wireless LAN adapter, which gives it the leverage to host a full website, locally on personal network or globally on the internet. As a result, separate communication devices like the WIFI dongle are no longer necessary. The Raspberry Pi Camera Module used here is a Pi camera version 2. It is a custom designed add-on board for the Raspberry Pi. Dimension of the board is 1 x 1 x 0.35 inch. It has a high quality 8 megapixel Sony IMX219 image sensor, featuring a fixed focus lens. It's capable of 3280 x 2464 pixel static images, and also supports 1080p30, 720p60 and 640x480p90 video. The module is attached to the dedicated CSI interface of the Raspberry Pi, which is designed for interfacing cameras. The Radiation Counting unit is a GM (Geiger Muller) tube based counter to measure radiation level. The unit consists of a GM tube radiation detector, high voltage circuit and GM amplifier circuit. The GM tube used in this work was Ne+ Halogen Gas Model 712 by LND.INC, USA. The GM tube requires high voltage (~550 volt DC) for its operation. The circuitry to generate high voltage from 5V, consists of a 120:1 turn ratio trans-former, a timer IC to generate pulse to switch ON/OFF the transistors and high voltage capacitor (1000pF, 2kV) to the output of the transformer to reduce output voltage ripple. In the GM amplifier circuit, the timer IC is used as a pre amplifier (mono stable multi vibrator mode of timer IC) for shaping and amplifying the electric pulses of the detector. The pick of the exponential pulses from the detector is too sharp to measure. So they have to be shaped and amplified before processing further. Then the pulse was given to the Raspberry Pi GPIO pin for calculating the CPM (count per minute). For displaying the result CPM is converted into µSv/hr by using conversion ratio 100. For robotic systems, power supply plays a very important role to power up all the modules. As it is a wireless robot, a battery pack is used as the power supply for it. The pack contains two 3.7V Li-Ion batteries, connected in series connection. As a result the output voltage is 7.4V. Maximum current capacity of the battery pack is 1020 mAh. The system requires 5V which has been regulated from 7.4V. A web server base interface method is introduced to design the controlling and monitoring unit of the system. This method is per-formed by network based communi-cation with Raspberry Pi on-board 802.11n wireless LAN adapter. The Raspberry Pi is programmed as a web server with a private IP address (192.168.0.11) which is connected to a local network. To get access to this server, the operator has to go http://192.168.0.11:5000 through a web browser. Python, html and CSS have been used to develop robotic interfacing and controlling programs.

Experimental Setup

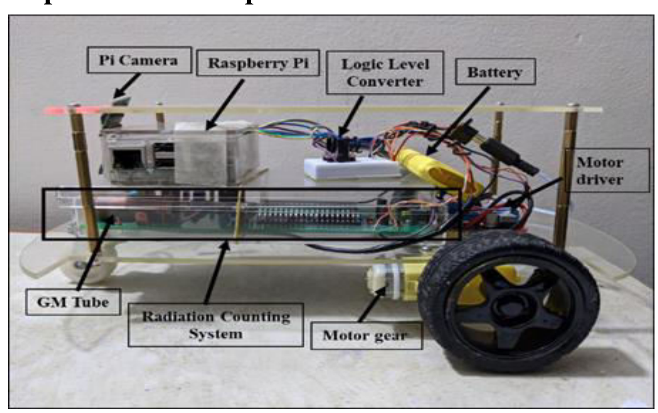


Fig 2: Hardware implementation of the robot.

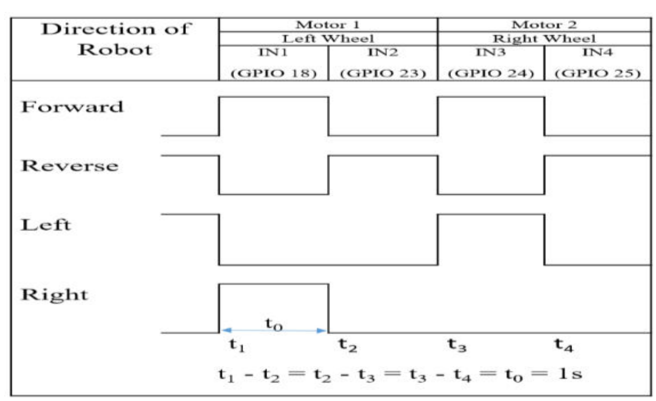


Fig 3: Control signals for robot.

The system is programmed to establish communication between the controlling device and the robot, control movement of the robot, measure area radiation, visual monitoring through an onboard camera and store the measured data for future analysis. After assembling the hardware parts and software interfacing, the completed system is shown in **Fig 2**. The gear-motored wheels of the robot get the control signals from the Raspberry Pi GPIO pin (18, 23, 24, and 25) through the motor driver board. The control algorithm of the robot is shown in **Fig 3**. The control signals are 1 instruction/ cycle for every direction movement. The relevant demonstration of the system for measuring the radiation level has been carried out in the open area and in the laboratory at Atomic Energy Centre, Dhaka. The robot was transmitting real time camera feed and followed the control signals to move in the desired direction. The readings of the radiation counting system were obtained in two conditions. Firstly, the natural background radiation was measured by the developed system and by the Gamma Scout in the open air experimental area, Atomic Energy Centre, Dhaka, when no radioactive source was present. Then, several radioactive point sources (Cs 137, Co 60, Mn 54) were placed at different places in the laboratory. The robot was operated to travel towards the source's position maneuvering with real time camera feed and stopped near the source by facing the GM tube at the source to measure the radiation level. At the same time, to measure the radiation level, Gamma Scout was also used, in the same condition. The step was repeated for varying the distance from 2 cm to 10 cm for each of the sources. **Fig 4** shows the set up for analyzing the performance of the radiation counting system.

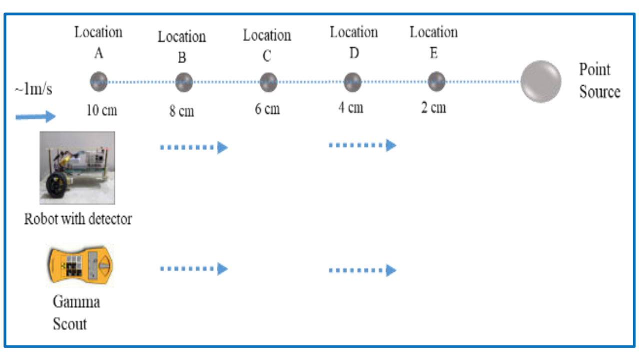


Fig 4: Experimental set up for performance analysis of the radiation counting system with developed system and with Gamma Scout.

RESULTS AND DISCUSSION:

The performance of the robot is reliable with the advantages of convenient maneuver, user friendly human-robot interaction interface, consistent execution, flexible drive, precise instructions and easy operation learning. The test result assessed that the unit components and programming functions of the robot are consistent according to the design. Features of the robot are given in **Table 1**.

Table 1: Features of the Robot.

Size	11" x 7" x 5"
Material	Plastic acrylic board
Weight	0.5 kg
Speed	~1m/s
Core unit	Raspberry Pi
Peripheral units	motor controller board, Pi camera module, radiation counting unit
Battery	Li-Ion, 7.4V, 1020 mAh
Operation time	30 mins
Wireless connectivity	Via WiFi network or Internet
Radiation Hardening	Shielding

A web page based user interface has been designed to execute the tasks of the system has shown in **Fig 5**. In the web page, there are three sections. A camera feed with date and time, four buttons- Forward, Reverse, Left and Right for the robot's movement control and a button for measuring radiation and data logging. When a button is pressed, a corresponding control signal is sent to the robot. Then the robot implements the task. **Fig 6** shows the logged data in a .csv file and via Microsoft excel. In general, the natural background radiation differs depending on the geographical position. In the experiment area, Atomic Energy Centre, Dhaka, measured value by the developed system was 0.2 µSv/hr. On the other hand, the measured value by the Gamma scout was 0.21 µSv/hr.

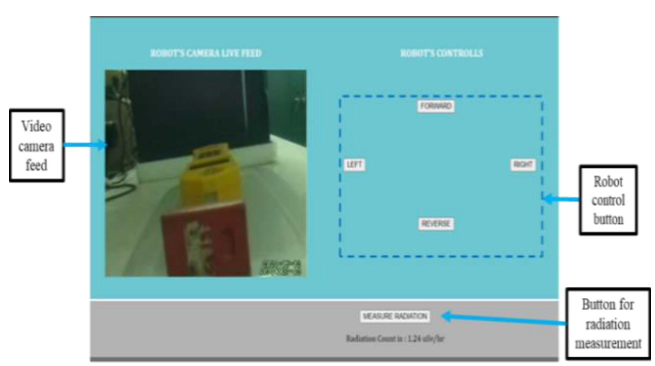
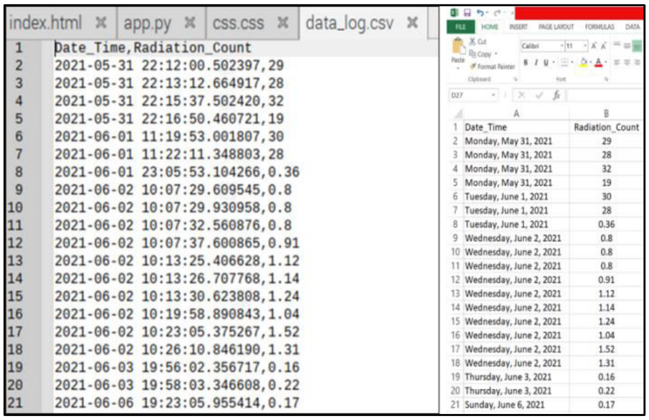


Fig 5: Web page based user interface.



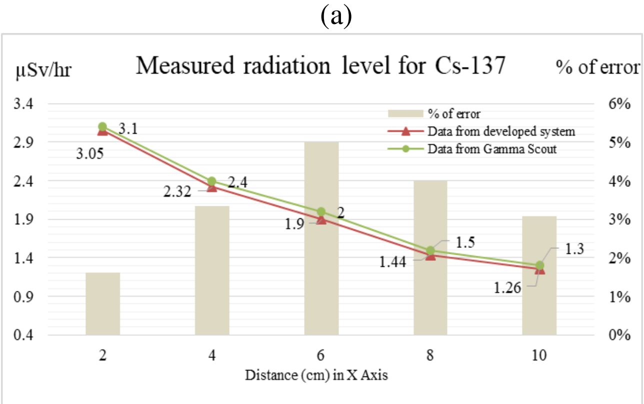

```
Date_Time,Radiation_Count
2021-05-31 22:12:00.502397,29
2021-05-31 22:13:12.664917,28
2021-05-31 22:15:37.502420,32
2021-05-31 22:16:50.460721,19
2021-06-01 11:19:53.001807,30
2021-06-01 11:22:11.348803,28
2021-06-01 23:05:53.104266,0.36
2021-06-02 10:07:29.609545,0.8
2021-06-02 10:07:29.930958,0.8
2021-06-02 10:07:32.560876,0.8
2021-06-02 10:07:37.600865,0.91
2021-06-02 10:13:25.406628,1.12
2021-06-02 10:13:26.707768,1.14
2021-06-02 10:13:30.623808,1.24
2021-06-02 10:19:58.890843,1.04
2021-06-02 10:23:05.375267,1.52
2021-06-02 10:26:10.846190,1.31
2021-06-03 19:56:02.356717,0.16
2021-06-03 19:58:03.346608,0.22
2021-06-06 19:23:05.955414,0.17
```

Date_Time	Radiation_Count
Monday, May 31, 2021	29
Monday, May 31, 2021	28
Monday, May 31, 2021	32
Monday, May 31, 2021	19
Tuesday, June 1, 2021	30
Tuesday, June 1, 2021	28
Tuesday, June 1, 2021	0.36
Wednesday, June 2, 2021	0.8
Wednesday, June 2, 2021	0.8
Wednesday, June 2, 2021	0.8
Wednesday, June 2, 2021	0.91
Wednesday, June 2, 2021	1.12
Wednesday, June 2, 2021	1.14
Wednesday, June 2, 2021	1.24
Wednesday, June 2, 2021	1.04
Wednesday, June 2, 2021	1.52
Wednesday, June 2, 2021	1.31
Thursday, June 3, 2021	0.16
Thursday, June 3, 2021	0.22
Sunday, June 6, 2021	0.17

Fig 6: Screenshot of data logging in (a) in CSV file; (b) data shown in excel sheet.

The measured radiation levels for the three point sources, presented in graph form have shown in **Fig 7**, **8** and **9**. By analyzing the graph readings, it was found that the readings of the developed system and commercial survey meter are almost the same with % of error from 0 to 15.79. Standard deviation was also calculated for the % of error which is very low 0.64, 2.18 and 0.29.

(a)



(b)

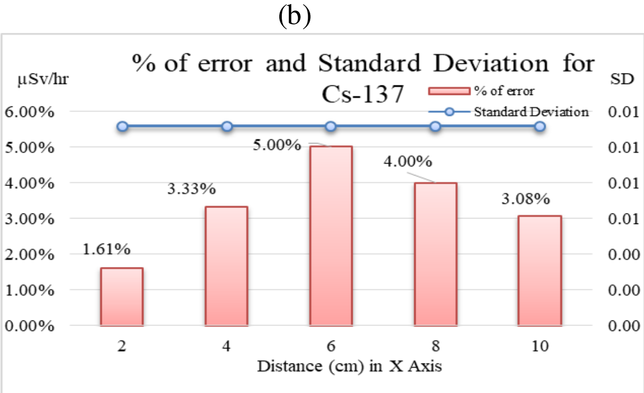
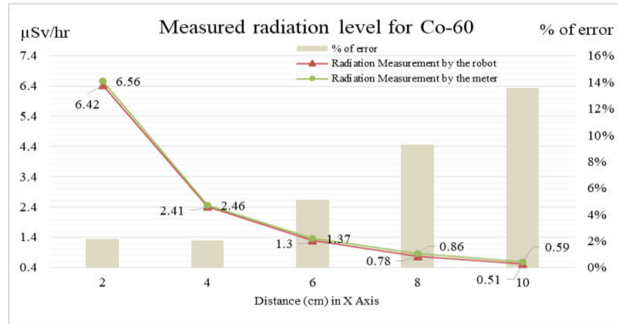


Fig 7: (a) Comparison of the radiation level measured by the developed system & Gamma scout for Cs-137 for different distances; (b) Standard deviation of % of error.

(a)



(b)

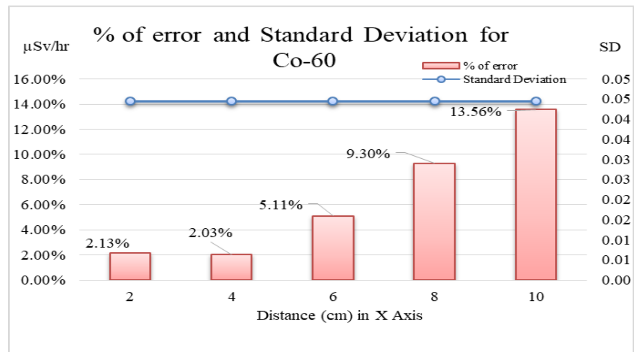
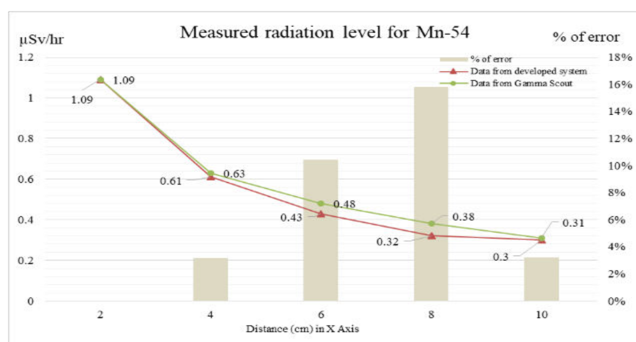


Fig 8: (a) Comparison of the radiation level measured by the developed system & Gamma scout for Co-60 for different distances, (b) Standard deviation of % of error.

(a)



(b)

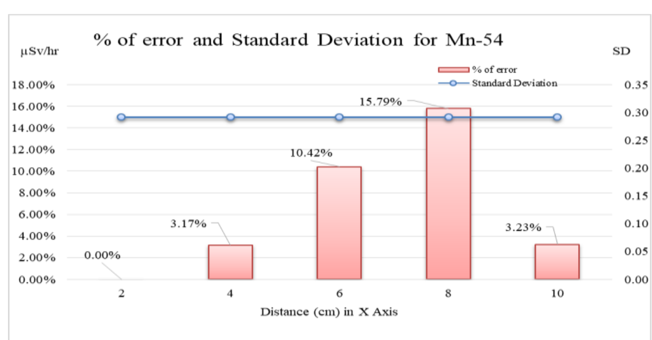


Fig 9: (a) Comparison of the radiation level measured by the developed system & Gamma scout for Mn-54 for different distances; (b) Standard deviation of % of error.

CONCLUSION:

A prototype of wireless robotic system for radiation detection and measurement has been developed in this work. It can be used for regular basis radiation level measurement in nuclear facilities remotely through a web server and store the data for future analysis. The system is beneficial for the radiation workers to avoid unnecessary radiation exposure. The experiments were carried out in an open area and a laboratory environment. Radiation level of natural background and different point sources have been measured and the measured value has been compared to a commercial survey meter. By comparing the readings it is found that there is a low range deviation of 0.29 to 2.28 which is acceptable. In future more adequate design would be developed to increase the operational time and robustness of the robot.

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CONFLICTS OF INTEREST:

The authors have declared no conflicts of interest to publish this research article.

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