Laboratory environment monitoring and specimen transport robots

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Article Info	ABSTRACT
	Robots have been used in various areas to replace manpower, reduce costs, and facilitate more effective resource allocation. This study sought to assist the business of the bureau by developing two robots using the Robot Operating System. The developed robots have autonomous intelligent navigation functions and are suited to monitor the environment of the laboratories in the bureau. One robot had a temperature and humidity sensor and an infrared thermal camera, and it could be used to patrol and monitor the laboratory environment. The other robot had drawers in which specimens could be placed; robotic arm in the elevator could coordinate and control elevators, enabling the robot to move and transport specimens autonomously. Plenty of tests were conducted to verify the feasibility and practicality.

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1. INTRODUCTION

Thanks to technological maturity, experience accumulation, and product renewal, much progress has been made in the development of robots since the first robot was constructed. Robots can partially replace manpower and increase efficiency, and they are reliable and easily manageable. Applying robots to certain tasks has become increasingly common. G. Indrawan *et al*. aimed to preserve Balinese script and thus presented a robotic system including a transliterator web application and a robotic arm, which can be used to give Balinese script writing knowledge [1]. N. S. Ali et al. tried to avert hazardous tasks such as demining by designing a controllable computer robot to detect metals [2]. To help people with household chores, J. Lee et al. developed an Arduino-based multifunction floor cleaning robot that can both vacuum and wipe [3]. H. Widyantara *et al*. proposed an olfactory mobile robot integrating omnidirectional thermal anemometers and unmanned devices to trace harmful gas in open air [4]. E. Abana *et al*. developed a robotic rake to mix and turn paddy during sun drying, which is significant to maintain the quality of grains [5].

Among these applications, some of current research, products, and patents have primarily emphasized the use of robots for laboratory monitoring and object transport. For laboratory monitoring, previous studies have investigated integrating robots with monitoring cameras, sensors, and network functions. Some monitoring systems can even provide remote monitoring and alert functions concurrently alongside other functions. Abdul Aziz *et al*. used wireless sensors to monitor laboratory temperature during oil palm tissue culturing [6]. Joshi *et al*. displayed temperature on liquid crystal displays to reduce temperature fluctuations induced by people entering and exiting the IVF laboratory [7]. People are used to installing several cameras to continuously monitor environment, which generate a large amount of data. Liu

et al. employed multiple sensors to determine the locations where accidents occur before switching on cameras, which contributed to energy conservation in comparison with conventional method [8]. A security monitoring system designed by Zhao *et al.* integrated cameras and sensors. Their monitoring server could display emergency alerts on a web page and signal any alerts using light and sound [9]. Jihua *et al.* transmitted images captured by a USB camera to a backup server, enabling users to view the images remotely and immediately, thereby achieving effective laboratory monitoring [10].

Research on robots used for transportation is relatively lacking, and thus we selected similar patents for analysis. Open patents for robots of this type mostly have basic functions such as autonomous mobility implemented by different methods. The main structure of "AUTONOMOUS MOBILE PICKING" [11] involves a vehicle base with an area for storing items and a mechanical arm. The base moves autonomously and can conduct item retrieval. The "Method and system for generating navigation data and transporting object" [12] is one object transport system. According to this system, the robot moves based on user-generated navigation data. The elevator was operated by a separate robotic arm using an image recognition device that could press the elevator buttons, thereby allowing the robot to move around multilevel buildings.

As mentioned above, robots have been widely applied, whereas they are still uncommon in public sectors. This study demonstrated the creation of two robots which were constructed for laboratory monitoring and specimen transportation, and the hardware foundation for each robot we adopted were TurtleBot3 with Lidar equipment. Through this study, besides the aim to utilize robots to gather and provide the environmental characteristics and assist the businesses of the bureau, simultaneously we sought to promote the use of smart technologies and ameliorate manpower shortage in the public sectors. It is worth mentioning that at present the laboratory monitoring robot patrol in the building after work everyday and the specimen transport robot also begin to serve in the building, driving the development of smart machinery in the bureau.

2. RESEARCH METHOD

This study developed several robotic technologies independently using the Robot Operating System (ROS) [13]. The ROS provides most of the functions of traditional operating systems such as hardware layer abstraction, low-level equipment control, inter-process message transmission, and package management. Additionally, relevant tools and procedural libraries are provided that can be used to acquire, compile, and edit code and achieve distributed computing. The ROS standard package provides various stable and adjustable robot algorithms. The standardized ROS communication interface means that developers can devote more time on design and actualization of new ideas and computations, thereby avoiding repetition of existing research outcomes. Modern robots usually require multiple computers to calculate the numerous processes they conduct. Thus, a robot can be equipped with several computers, with each computer powering a part of the robot's transducer and driver. Alternatively, users can send control commands to a robot through their computers, such as a tablet or smartphone. This type of human-machine interactive interface can be considered as part of a distributed system. Therefore, the ROS can help resolve communication problems that arise between different processes when several computers are part of a distributed system.

Based on the ROS, we developed functions such as autonomous smart navigation, a human-machine remote control interface, fire and flood alerts/environmental temperature and humidity monitoring, flexible item storage and transport, and elevator operation; the design of each function was as follows:

2.1. Autonomous smart navigation
2.1.1. Mapping

High-Precision Lidar as shown in Figure 1 was used to construct a customized map as shown in Figure 2 of the building using the gmapping algorithm [14]. The Rao-Blackwellized particle filter was used with the gmapping algorithm to achieve simultaneous localization and mapping (SLAM). A study [15] indicated that gmapping has high stability and excellent performance in terms of the error rate and CPU load.

Figure 1. Lidar unit

Figure 2. Customized map of the building

2.1.2. Positioning

Taking the data from the Lidar and an inertial measurement unit as shown in Figure 3, the adaptive Monte Carlo localization (AMCL) algorithm [16] was adopted to achieve positioning as shown in Figure 4. The customized map was used with the algorithm to dynamically construct probability distributions of particles. Then, the Lidar-measured values were used to adjust the probability distributions until the positioning results converged.
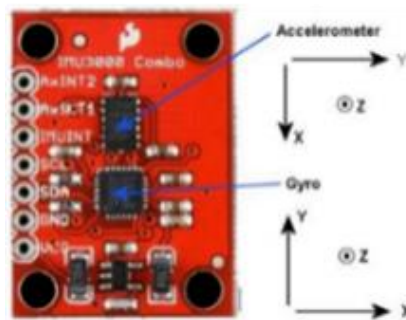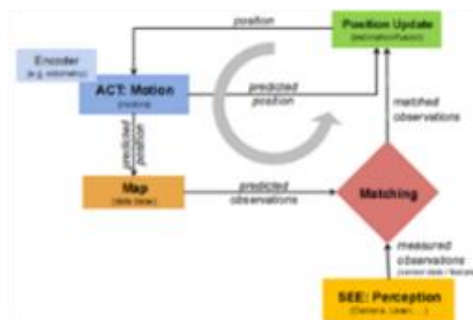

Figure 3. Inertial measurement unit

Figure 4. AMCL positioning

2.1.3. Route planning and following

The probabilistic roadmap (PRM) algorithm [17] was used for route planning by constructing connections between nodes that were subsequently used to locate obstacle-free routes between the starting and finishing point as shown in Figure 5. The Pure Pursuit algorithm [18] was used to execute the planned route, and look-ahead points were adjusted to ensure the route was smoothly and correctly taken as shown in Figure 6.
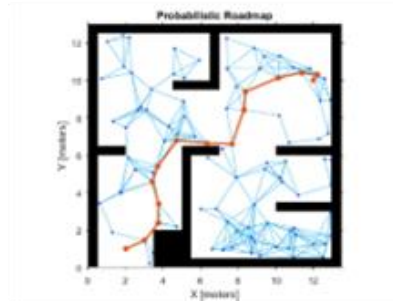
Figure 5. PRM route planning

Figure 6. Pure Pursuit route execution

2.1.4. Dynamic environment detection and obstacle avoidance

The vector field histogram (VFH+) algorithm [19, 20] was adopted for dynamic environment detection and obstacle avoidance as shown in Figure 6. This algorithm used the data received from the sonar as shown in Figure 7 and Lidar as shown in Figure 1 to construct the polar histogram of obstacles. Subsequently, the histogram thresholds and minimum turning radium were used to determine the required route for obstacle avoidance as shown in Figure 8.
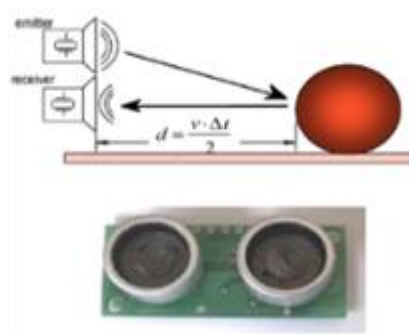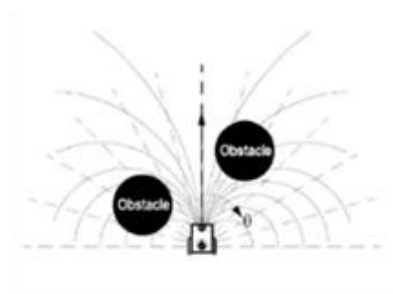

Figure 7. Sonar elements

Figure 8. Dynamic environment detection and obstacle avoidance

2.2. Remote human-machine control interface

The Representational state transfer (RESTful) API [21, 22] as shown in Figure 9 not only enabled us to operate intelligent machines on websites, applications, and mobile devices, but also sent images from its visual system to users as shown in Figure 10.

The RESTful API comprises three elements [23]:
- A URL for the web service, (e.g., http://example.com/resources/).
- A data-interchange format that is accepted and returned by the web service, (e.g., JSON).
- RESTful methods for making requests that are supported by the web service, (e.g., POST, GET, PUT, or DELETE).
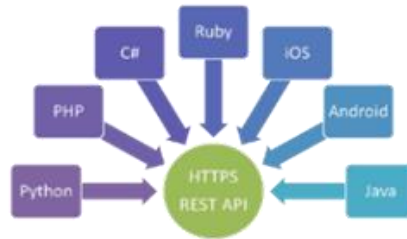

Figure 9. RESTful API framework

Figure 10. Human-machine remote control interface (exp: mobile devices such as tablets, smart phones…etc.)

The RESTful API uses HTTP as the underlying protocol [22, 24]. Compared with conventional web services, RESTful is lightweight with both client and server sides. On the client side, HTTP is used to request resources from the server side. The server side is responsible for processing requests and allocating resources. HTTP operation that can be used on websites, applications, and mobile devices enables quick and simple operation of smart machines using a visual interface.

2.3. Fire and flood alerts/environmental temperature and humidity monitoring

Environmental changes can occur anywhere within an area, and therefore in this study, the Optris PI 230 infrared thermal camera as shown in Figure 11 and DHT22 temperature and humidity sensor were selected to conduct environmental monitoring and provide early warning of potential fire and flood conditions. The purpose of these sensors was to compensate for the inadequacy of traditional fire and flood alerts by quickly detecting changes in the environment. The Optris PI 230 infrared thermal camera enabled environmental temperature monitoring. By examining temperature distributions, the camera could monitor for fire and flood conditions; moreover, it provided a convenient means for human-machine remote operation through client-side viewing of the environment's temperature. The DHT22 temperature and humidity sensor was used with an Arduino UNO board to record the environmental temperature and humidity, thereby also enabling early warning and prevention of hazardous environmental conditions.

Figure 11. Optris PI 230 infrared thermal camera

2.4. Flexible item storage and transport

The developed transport robot integrated item-carrying and autonomous navigation functions. The base of the robot provided the storage areas for users to placed and classified items. Using the central monitoring system designed in MATLAB, a target location for item delivery was selected. Subsequently, the robot traveled to the designated location and notified the recipient to complete specimen transport. The Arduino UNO board commanded an actuator to open and close the storage areas and sent instructions to the Sabertooth motor controller to drive the motor to rotate the left and right wheels.

2.5. Elevator operation

After the robot arrived at the designated position, it transmitted a signal over WiFi to the robotic arm in the elevator to press the required buttons to operate the elevator as shown in Figure 12. The highly stable vertical articulated robotic arm was connected to a control board using a USB port. It was placed in a fixed position above the elevator buttons, and the angle and force of the button pressing were set in advance. When users selected a specific floor using the central control system, the robotic arm pressed the buttons according to the command. This enabled the other robots to move freely around the building independently.

Figure 12. Button-pressing robotic arm in elevator

3.   RESULTS
3.1.   Laboratory monitoring robot
3.1.1. Composition

The laboratory of monitoring robot consist of a Lidar unit, a thermal camera, a temperature and humidity sensor, microprocessors, ROS, and peripheral equipment. The laboratory of monitoring robot is shown in Figure 13.

Figure 13. External appearance of the laboratory monitoring robot

3.1.2. Laboratory monitoring robot user interface

Figure 14 shows the central monitoring system of the laboratory monitoring robot. The explanations of the interfaces are:
(1) Map displaying current location and current floor.
(2) Robot's current floor.
(3) Two speedometers on the left and right display current linear velocity and angular velocity, respectively.
(4) Selection of floor for the robotic arm in the elevator.
(5) Alarm: When fire, high temperature, flood, low temperature, and foreign objects are detected, an alarm sounds and an email is sent to the user.
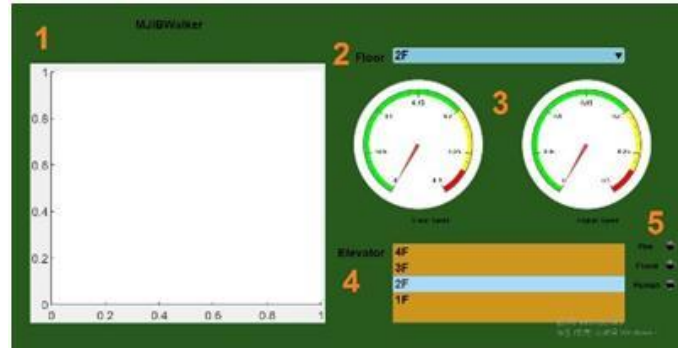

Figure 14. Central monitoring system of the laboratory monitoring robot

3.1.3. Testing

The laboratory monitoring robot was used to patrol a building as shown in Figure 15. When the robot detected abnormal conditions such as high or low temperature as shown in Figure 16 or a foreign object as shown in Figure 17, it produced an alert as shown in Figure 18 and sent an email to notify the users.

Figure 15. Laboratory monitoring robot on patrol
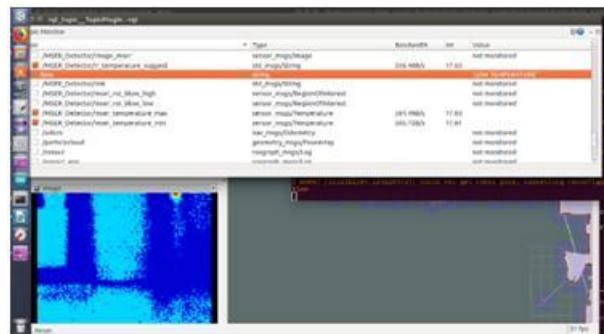

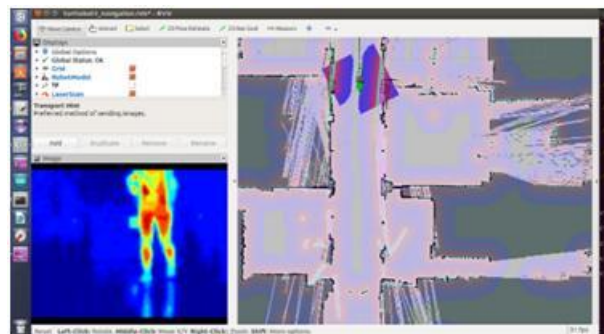Figure 16. Low temperature detection
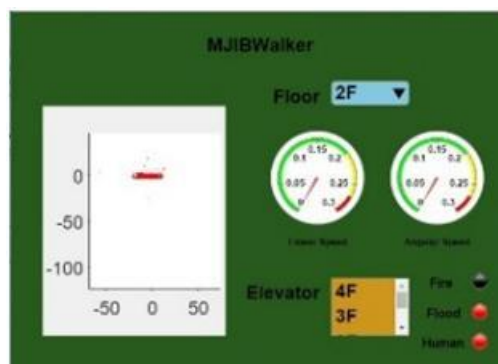

Figure 17. Foreign object (human body) detection

Figure 18. Alert display on user interface

3.1.4. Comparison

We compared the laboratory monitoring robot and reference researches; the details and analysis are shown in Table 1.

Table 1. Comparison between laboratory monitoring robot and reference researches

Item	Laboratory monitoring robot	Reference researches	Analysis
Device	Wireless	Wired and wireless	Wireless monitoring device prevents the concern of wiring and enhance mobility.
Sensor	Humidity and temperature	Temperature	Other than temperature, humidity is also a key ambient factor in identification laboratories. For example, water leakage can be detected through humidity sensors.
Mobility	Mobile and flexible	Fixed	Fixed-type monitoring devices are convenient for location confirmation but lack flexibility; mobile monitoring robot enables specific areas to be strengthened.
Camera	Infrared thermal camera	Camcorder	Infrared thermal makes it easy to identify heat source and human body.
Monitoring Area	Extensive	Constant	Thanks to its mobility the monitoring robot is able to get anywhere if the Internet is connected.
Expense	Relatively cheaper	Might be costly	In a spacious laboratory, if the monitoring devices are fixed such as CCTV, it is necessary to employ many to monitor the whole laboratory, which will cost more than robots do.
Power	Auto-ducking	Wired charging	While wired charging is steady, the laboratory monitoring robot will send a voice alert before power exhaustion, and it contains an auto-ducking function.

3.2.   Specimen transport robot

3.2.1. Composition

The specimen transport robot consists of body with storage drawers, a computer, Lidar unit, a motor, and peripheral equipment. External appearance of the specimen transport robot as shown in Figure 19.

Figure 19. External appearance of the specimen transport robot

3.2.2. Specimen transport robot monitoring system user interface

Central monitoring system of the specimen transport robot is shown in Figure 20. The Explanation of the interface:
(1)   Map displaying current location and current floor.
(2)   Room the robot will travel to.
(3)   Two speedometers on the left and right display current linear velocity and angular velocity, respectively.
(4)   Switches for storage areas: the storage areas comprised three drawers that were controlled using an actuator.
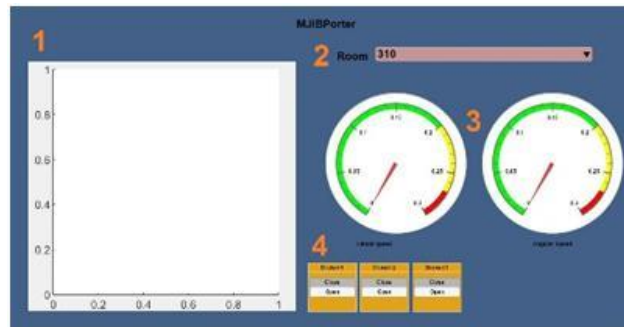
Figure 20. Central monitoring system of the specimen transport robot

3.2.3. Testing

The process of the specimen transportation conducted by the robot was shown in Figure 21 to Figure 26.

Figure 21. Opening a drawer through the central monitoring system (Figure 20), placing a sample, and selecting the target office

Figure 22. Robot moving to the elevator and sending a signal to the robotic arm in the elevator to open the elevator door

Figure 23. Robot entering the elevator

Figure 24. Robotic arm pressing the button for the floor on which the target office is

Figure 25. Robot exiting the elevator when the elevator reaches the target floor

Figure 26. Robot arriving at the target office and opening the storage drawer

3.2.4. Comparison
The difference before and after using the specimen transport robot is shown in Table 2.

Table 2. Comparison between before and after using the specimen transport robot

Before	After
The receipt and forwarding clerks need to ambulate in the building to deliver specimens and official documents, urgent or standard, to identification laboratories. The case officers also have to return identified specimens and submit official documents to upper supervisors according to the hierarchy afterwards. But it takes much time for the clerks and case officers to walk around offices and they can only carry a few specimens and documents during each delivery.	With the assistance of the specimen transport robot, the clerks can deal with urgent ones first; standard documents which are in the majority can be collected and transported later by the robot. All the case officers need to do is to place the specimens or documents in the drawer and click on the monitoring system, and then they can go back to work. Moreover, the robot is able to carry a large number of objects at one time, thus sharing responsibilities for objects delivery and saving time.

4.   CONCLUSION
We have presented two robots, the laboratory monitoring robot and the specimen transport robot, which are the very first developed and applied in the bureau. Both have been tested for feasibility and practicality; the effectiveness of using smart robots to maintain environmental safety, assist business execution, ease the manpower shortage and improve resource allocation were also verified. So far the laboratory monitoring robot has performed its tasks for several months; also the specimen help transport dozens of objects every day. More importantly, employing self-developed and assembled robots can considerably reduce costs. In the future, the research attempt is to develop technologies such as facial and license plate recognition for use with robots; deep learning is to be employed to expand the robots' monitoring ranges and intensify park security.

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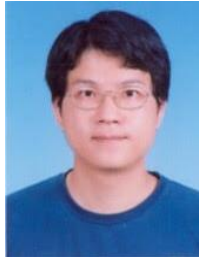
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