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Intelligent Surrounding Recognition for Robot Direction Control

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ABSTRACT In this study, we present a novel robot navigation system based on multi-sensors. The sensors include laser range finder, electronic compass, Zig-bee module and camera, to construct the navigation and monitoring system for robot. This system can remote control robot and monitor its status by real-time images for security patrol in the room at any time. Based on sensing information, micro-controller can control motors to drive its moving directions and speed. Laser scanning rangefinder is used to allow the robot to detect obstacles by the viewing range of 0 to 240 degrees. Zig-Bee locator can provide relative indoor position information in a wide space. The electronic compass is adopted to control the moving direction of robot. The computer calculates the sensing data and its results are sent to the micro-controller, to enable the robot walking on the middle of the passageway. The system is successfully implemented and demonstrated in real environment.

INDEX TERMS Robot, laser scanning rangefinder, Zig-Bee locator, navigation, compass.

I. INTRODUCTION

In recent years, attention to indoor environmental safety is an important issue in today's society. People life and property security are very cared in the twenty-first century, especially developed countries are more evident. The traditional security system has limitations and drawbacks. Most of them are with security company hired security guards. The current security system may install video- recorder in each interior space of the building to monitor the environmental status. However, they only can monitor the fixed space, some blind spots there. Recently, smart robot system is developed to execute the work of environmental safety. We can control the robot to play its mobility and flexibility sufficient to assist patrol rounding for a long-time. Once there is an emergency situation, the robot can instantly arrive here and sent important videos to users using remote control. For this purpose, auto navigation is one of the important issues for a mobile robot. The moving destination for robot is determined by the pre-schedule or sensing signals. The positioned system is used to control the robot following the best path from the current location moving to the target location. In outdoor, Global Positioning System (GPS) can be employed to identify the robot position [1]. However, it is hardly to receive GPS signal in indoor. Hence, another approach with extra sensors must be adopted.

In the past, many researches studied about the positioning and navigation for robot control in indoor [2]–[20]. The imaging vision methods are used to record the environmental images and then to recognize them for robot navigation [2]–[5]. Visual techniques had been applied by many feedback control laws and modeling methods. Generally, visual techniques required huge image data processing, which causes to slow-down for the control speed. Sensor-based approaches [6], [7], such as ultrasonic sensors and laser scanning rangefinder, are presented. The former only detect the distance of one direction between robot and obstacle, which is difficult to create the best path for robot. The latter can be used to create 2D path with wide angles to construct the environmental information. The wireless-based with RSSI signal is used to detect the location of robot [8]–[10]. This approach calculates the RSSI signal strengths of all transmitters to determine the robot's position by wireless network sensing. The sensor module is embedded to desired area, and then to sort the strong RF signals to calculate the distance between robot and wireless modules. The fuzzy method [13]–[15] is also used to improve the accuracy to detect the robot position.

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Robot navigation is a main technique to control the robot to the destination [16]–[21]. In this study, we present auto navigation and positioning system for robot control based on multi-sensors that includes laser scanning rangefinder (LSR) and camera, electronic compass, and Zig-bee networking. Laser scanning rangefinder is used to find the best path for local navigation. The electronic compass is used to decide the rotating direction at the crossing path. The camera is an auxiliary system of laser scanning rangefinder to correct some blind points. The Zig-bee networking is used to construct global path planning and positioning point for robot. The rest of this article is organized as follows. The local navigation using Laser scanning rangefinder and camera is proposed in Section II. The Zig-bee networking for global positioning is presented in Section III. The implementation and experiments are described in Section IV. The conclusions are marked in Section V.

II. PROPOSED LOCAL PLANNING USING LSR

In this study, first we used LSR to find the best path for robot moving in a local region. The LSR employed URG-04LX-UG01 by HOKUYO Inc [22], which can sense the distance from 0 to 240 degree. The sensing information likes Fig. 1. For robot control, the moving path is searched in environment. In order to analyze the relative distance, we transfer the scanning depth data of LSR to a histogram, as shown in Fig. 2. The best moving path for robot can be calculated according the LSR information. Figure 3 shows the processing flow of the LSR algorithm. The histogram is further truncated to binary in order to adjust the width of path.

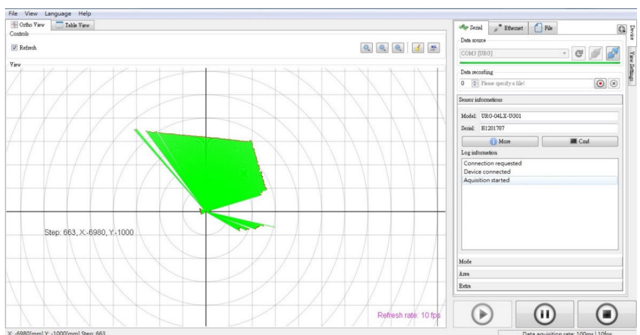

FIGURE 1. The sensing data from LSR.

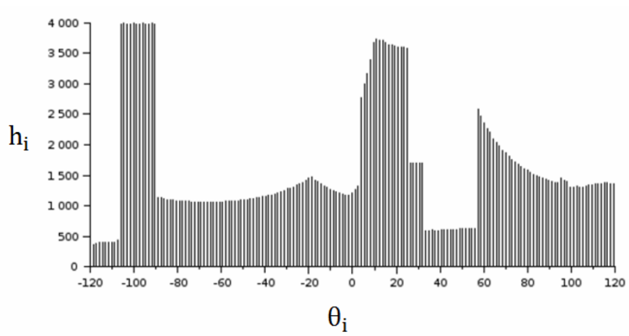

FIGURE 2. The histogram of scanning data.

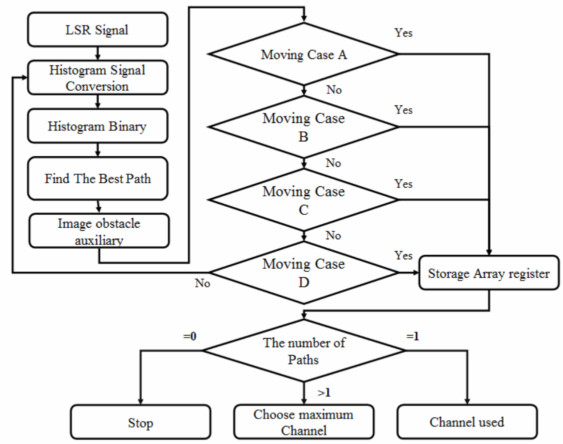

FIGURE 3. The processing flow of the LSR algorithm.

Besides, by camera sensing, the image processing method as an auxiliary can overcome the blind point of LSR. Then the kinds of path can be classified as four cases. The cases A∼D determine the possible path of robot and then the path is recorded. If the number of path is over one, the maximum width of path is selected. If there is no any path, the robot will be stayed there.

A. HISTOGRAM TRANSFER

Figure 4 shows the flowchart of transferring LSR signal to histogram. First, we change the unit with cm for the distance of LSR signal. If the distance is less than 2cm and larger than 400cm, we set to 400cm, since LSR sense the distance from 2cm to 400cm. Then the distance data is recorded to registers. The value is subtracted by the fixed threshold with 120cm, because the depth of 120cm is enough deep for robot moving.

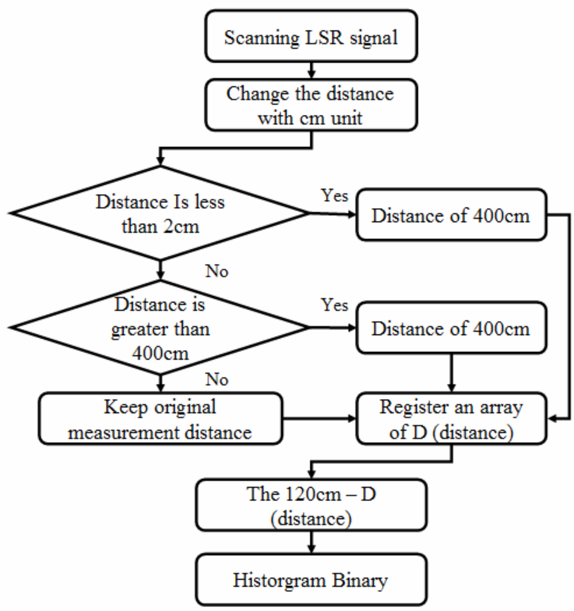

FIGURE 4. The flowchart of transferring LSR signal to histogram.

The distance with threshold is shown in Fig. 5(a). If the deep of path is over 120cm, the histogram is negative, otherwise, it is positive. With this feature, we can find which channel can be selected for robot passing. The histogram is truncated to binary as rules: if the value is less than zero, then set to zero. If the value is over 45cm, then set to high. Otherwise, the previous binary is used. The results are shown in Fig. 5(b). For example, the previous data is used when the histogram distance is between 0∼45, as shown in Fig. 6(a). The binary result is shown in Fig. 6(b). The former section 0∼45 data marked with black is processed with zero since the previous data is zero. The latter section data 0∼45 data marked with pink, where its histogram becomes high since the previous data is high. The high level implies the obstacle existed in the front of the robot. This channel is not available for the robot passing. If the histogram is zero, the robot can pass using this channel.

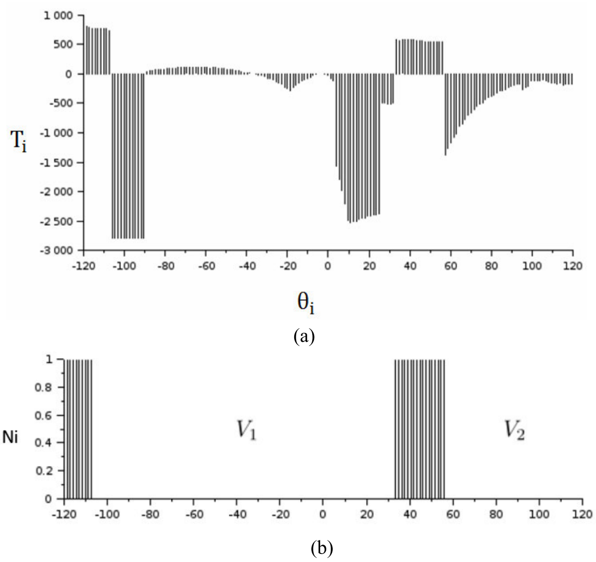

FIGURE 5. (a) The histogram with distance threshold. (b) the binary of 5(a).

B. DOUBLE SCANNING METHOD

The practical LSR signal existed boundary effect that degrades the accuracy to detect the width of channel. To overcome this drawback, double scanning methods are employed. Figure 7 shows the double scanning method to improve the accuracy. First, the scan direction is from 120 to -120 degree to find the histogram. Then, the -120 to 120 degree is scanned again. Finally, the fine result is obtained with OR operation of the two scanning histograms. The best passing path for robot can be found from the fine histogram. The histogram with zero can provide an available channel for robot passing. Figure 8 shows that there are two channels available. The best path is between A and B, which is the widest channel in all.

C. CHANNEL DECISION

According to the distance A and B to robot, we defined the distance A and B as the symbol D_{AB}; D_{AC} and D_{BC} are the

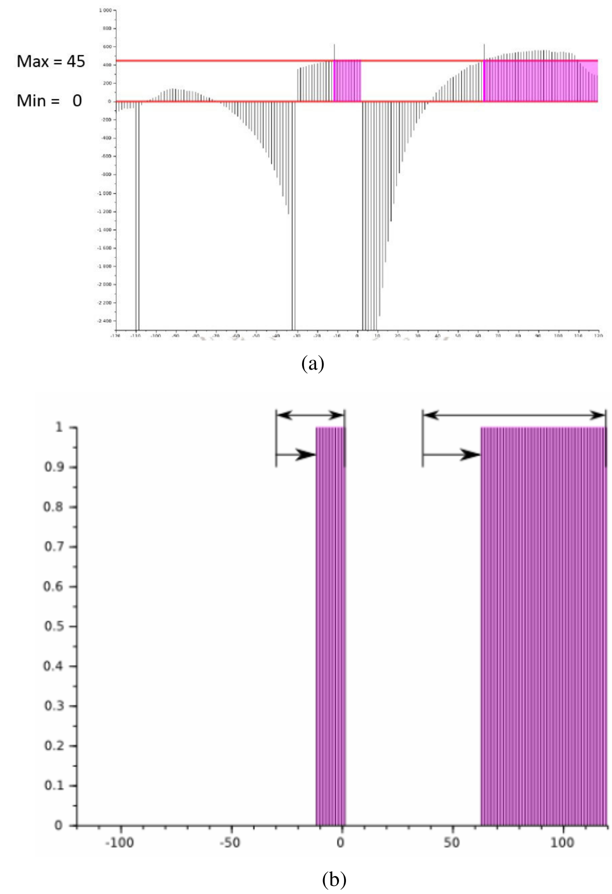

FIGURE 6. (a) The example of scanning data between 0∼45. (b) The binary data 0∼45 used the previous information.

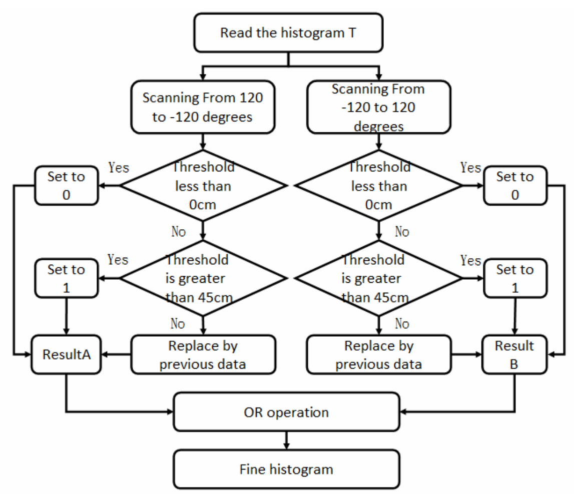

FIGURE 7. Double scanning method to overcome boundary effect.

distance A to robot (C) and B to C respectively. Then, we can classify to four cases:

Case A: If D_{AB}, D_{AC} and D_{BC} are all long distance, this is Case A, as shown in Figure 9(a).

Case B: If D_{AB} is wide for robot passing, but D_{AC} and D_{BC} are short, which means the obstacle is nearby the robot, this is Case B, as shown in Figure 9(b).

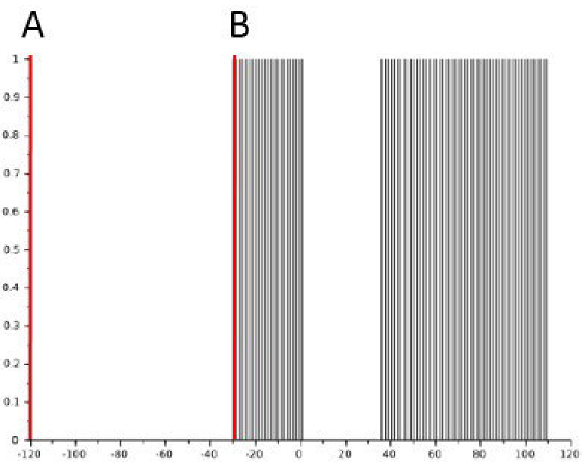

FIGURE 8. The best path found by the maximum zero width.

Case C: If D_{AB} is wide, but short D_{AC} and long D_{BC}, this is Case C, as shown in Figure 9(c).

Case D: If D_{AB}; is wide, but long D_{AC} and short D_{BC},, this is Case D, as shown in Figure 9(d).

To find the best passing way(BPW), first the maximum width of channel is searched as

$$BPW_{\max} = Max.(|A_i - B_i|), \quad \text{i} = 0.\text{to..n}. \qquad (1)$$

The maximum channel width is found from the n channels, when the n channels are available with enough width for robot passing. The maximum width with BPW_{max} is selected. Then we control the robot moving on the middle of BPW_{max} channel, as given by $(A_i + B_i)/2$, where the ith channel is the BPW_{max}, as shown in Fig. 10. When the channel width is close, the near channel for robot is selected. For example, the width of the channels A0∼B0 and A1∼B1 is close, the channel A1∼B1 is selected if the robot nears A1∼B1 there.

D. IMAGE AUXILIARY

The LSR signal is weak response to black thin material, such as chair leg. The robot can not detect this kind of obstacle using LSR device. In order to overcome this problem, we add a camera to sense the environmental image as an auxiliary system of LSR. Figure 11 shows the processing flowchart of image detection. The camera samples image in real time, and then color data is transformed to gray level. We set a horizontal threshold line, as shown in Fig. 12. Imaging data is scanned by checking vertical line-by-line from left to right. The image data is under to the horizontal threshold, the adjusted value (AV) is recorded to high. We accumulate the number of high AV. If the accumulated data is over than one threshold, its relative histogram becomes to high that implies obstacle existed here. The histogram of image detection and LSR scanning sensing are mixed by OR operation. One of them detect any obstacle, the histogram becomes high, which the robot can avoid attacking obstacles. The processing flowchart of mixed histogram is shown in Fig. 13.

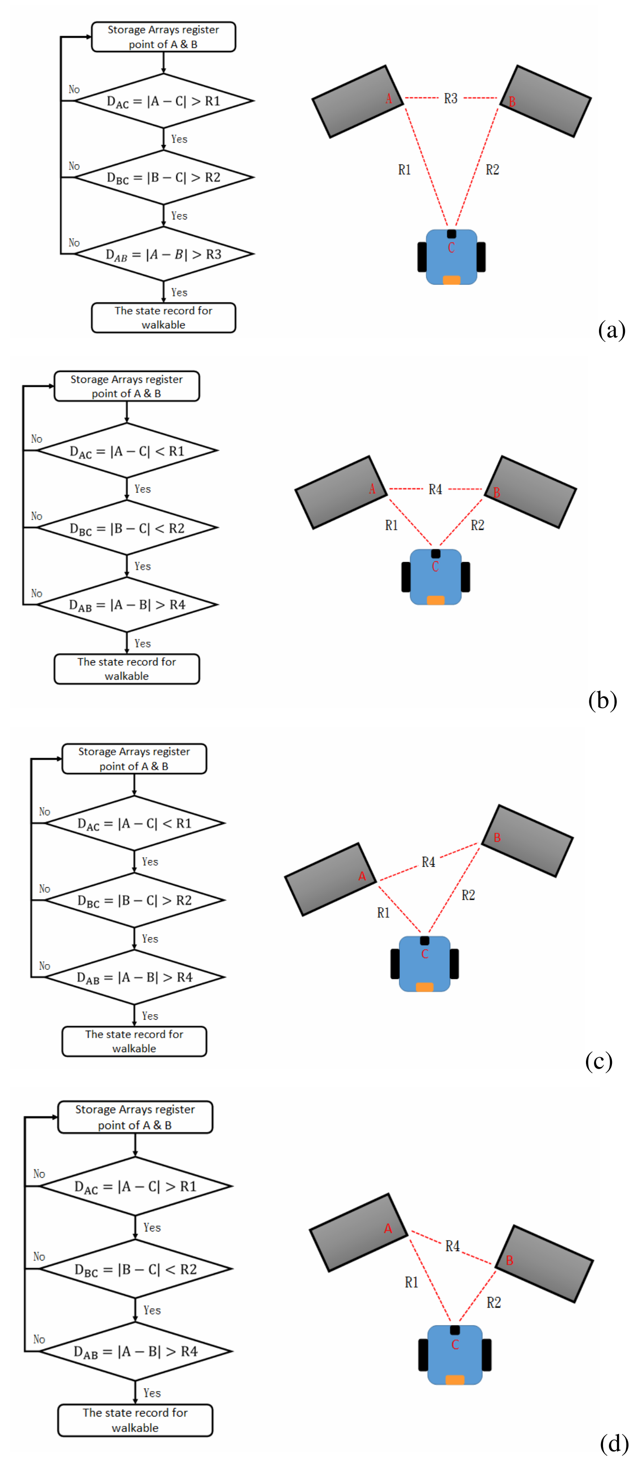

FIGURE 9. (a)∼(d) shows the distance between robot and obstacle under the case A∼D respectively.

III. PROPOSED GLOBAL PLAN BASED ON ZIGBEE

For global plan, the zigbee RF signal is employed as the locator [24]. The zigbee locator is positioned to some corners. The robot will receive RSSI (Received Signal Strength Indication) signals of all zigbee RF modulars and to compute its location in a free space. The global planning can guide the robot go to the destination with a map, as

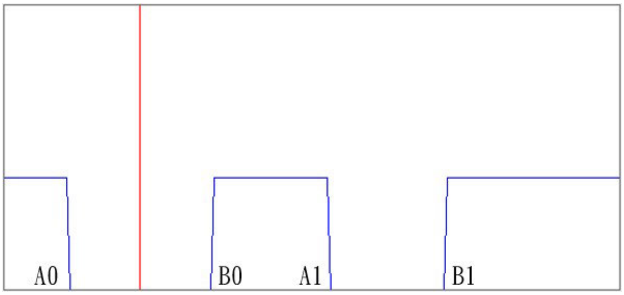

FIGURE 10. The best passing way for robot.

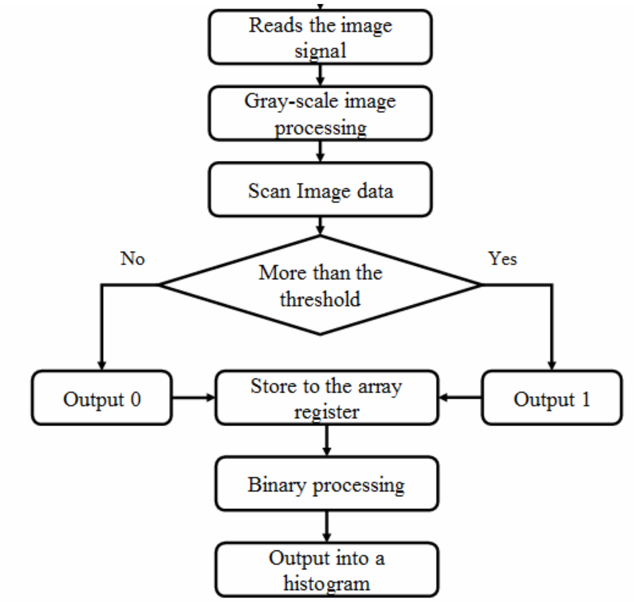

FIGURE 11. The processing flowchart of image detection.

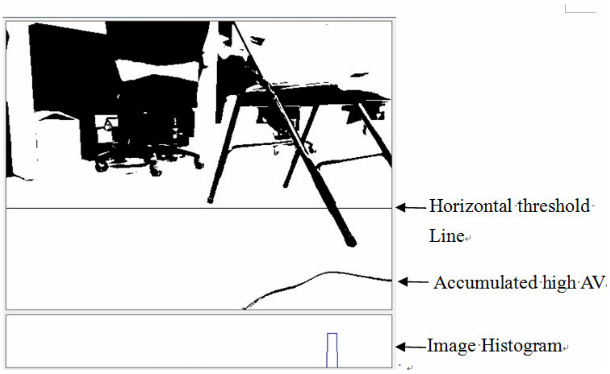

FIGURE 12. The histogram result using image detection for thin chair leg.

shown in Fig. 14. This is the top view for robot navigation, which can guide the robot to any place in the map. To design navigation system, the five points of destinations are marked as A~E, where C is laboratory inside; D is at the elevator; E is at the door outside of laboratory; A is at the middle of channel; B is a crossing point between channel and elevator. Each destination installs one Zigbee transmitter as a location reference node. For example, Fig. 15 shows the reference C point with zigbee modular, which the power is supplied

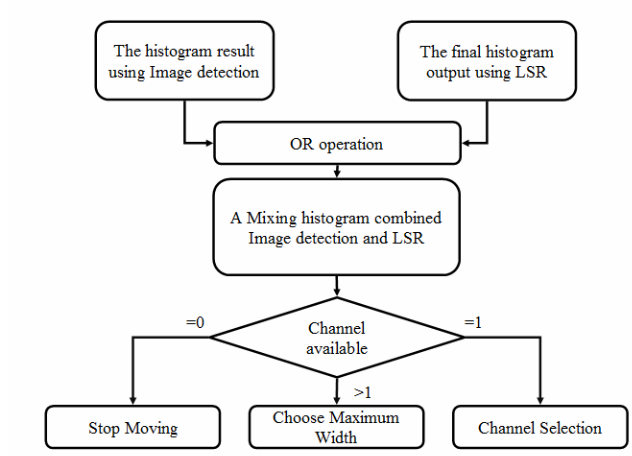

FIGURE 13. Combined LSR detection and image detection for thin obstacle.

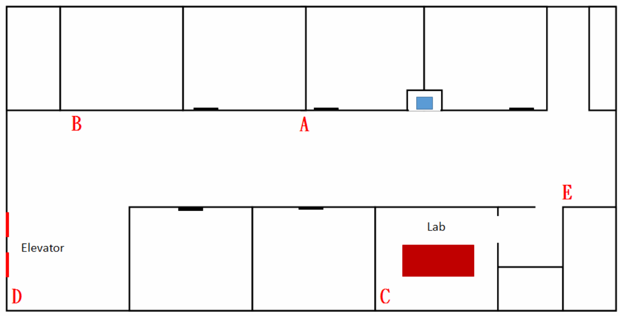

FIGURE 14. The top view for robot navigation with five destinations A~E.

with the battery. ZigBee locator can provide relative position information with RSSI signals. The robot has one Zigbee receiver that receives the RSSI of all Zigbee signals. The signals are sent to the flat compute and to compute the relative position of robot in the map [24]. The robot on the map can be moved immediately, according to the current RSSI signals.

For path planning, first we set the destination of robot, and read the signal of zigbee and electronic compass to identify the location and head direction of the current robot. We check

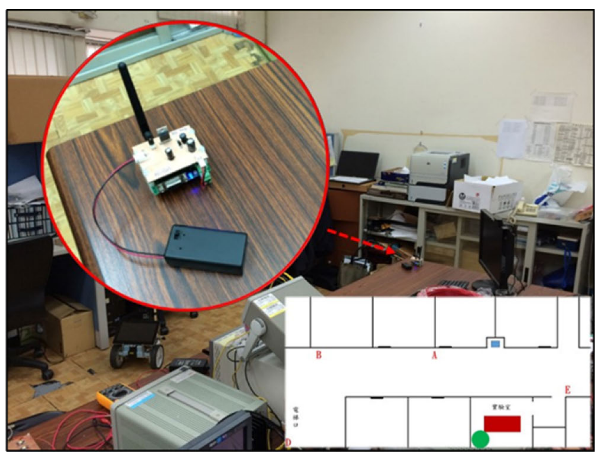

FIGURE 15. The reference C point with zigbee modular.

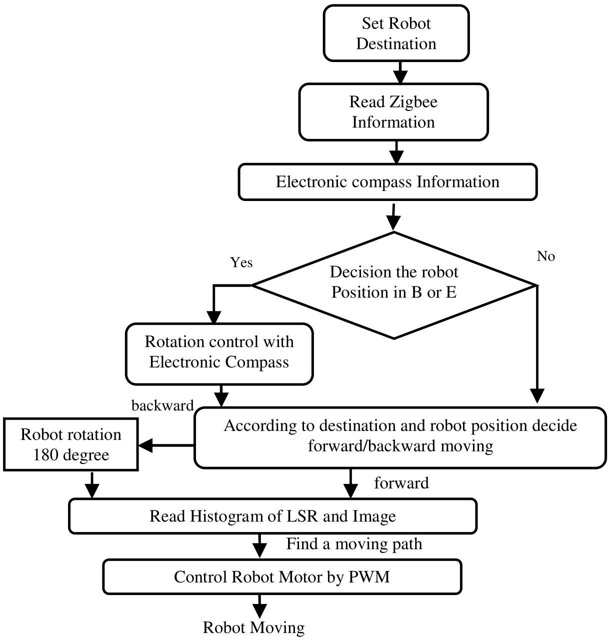

FIGURE 16. Robot navigation with global and local planning.

the robot whether located at the crossing points B and E. If it is at E or B, the robot moving direction should be rotated to laboratory or elevator. Figure 16 shows the robot navigation with global and local planning. According to the destination and the current location, we can decide the robot moving forward or backward. If backward moving, the robot rotates 180 degree that let the head of robot at the front of moving direction. Next, we read the histogram of LSR and image to search the best way for robot moving. The controller can send PWM signals to control the motors of robot to go to the destination.

IV. SYSTEM INTEGRATION AND EXPERIMENTS

We integrate multi sensors and controller for robot navigation to the specified destination. Figure 17 shows the system control diagram of robot control. In the local control of robot, we used one PIC processor [23] to read compass information and to control PWM of motors. The linear correction is used to overcome the wheel friction to let the robot moving straight. The values of PWM and compass sensing are shown on LCD display for debugging. A flat PC is employed to read the information of zigbee, LSR and camera. The control algorithms are implemented by C programming with multi-threads to promote the processing speed. The results of computing are sent to PIC through blue tooth for robot motion control.

For real-time robot control, the computer program used multithreading approach that can execute sub-routines in parallel to save the executing time. The four threads are employed in this system, where the first for laser signal; the second for compass and motion control, the third for zigbee, and the fourth for camera. Figure 18 shows the flowchart of multithreading execution for real-time robot control. The robot motion is determined by the sensing signals of LSR, compass, zigbee and camera. The sensing values are read to four threads and executed in parallel processing. The information of one sensor is processed with one processing core for real-time control. Users can select the direct motion control mode or the patrol mode. Direct motion control mode is to control robot speed, direction, forward or backward by users' command from remote computer. The patrol mode is auto navigation for robot moving according to the sensing information and the map. First users set the patrol destination, and then robot can move according to the planning route. The computer calculates the current location with zigbee RSSI signal, and to find the best way with LSR. The camera is used to detect the thin black obstacle. The turn of moving direction is determined by with compass sensing.

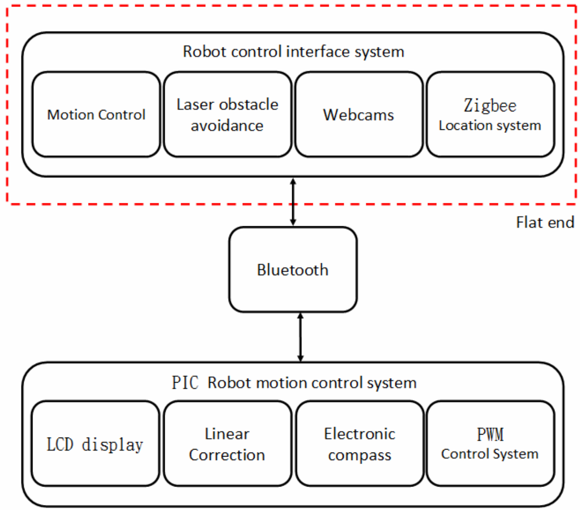

FIGURE 17. The system control diagram of robot control.

To verify this system, we design a robot with the integration of the mechanism, hardware circuits and software code. The mechanism is designed with Al metal in the bottom, which mounted with high-torque two motors. The motor with Gearbox reduction ratio is 15, and feed with 12V. The Figure 19 shows the prototype of our proposed robot that consists of flat PC, one control broad with a microprocessor and motor driving chip, four sensors(LSR, camera, Zigbee, compass), two power motors and battery system. One omni wheel (at the back) is used to balance the two power wheel (at the front). The flat computer was carried on the robot to implement the navigation algorithms by software control. The control board is realized with a microprocessor that receives the signals from the flat PC to control the robot moving direction. The compass is set at the highest to avoid obstacles to interfere with the signal. The microprocessor read the data of compass through I^2C interface, and then shows on LCD display. The camera is set the second high position, for wide view angle sampling.

Now we demonstrate the robot navigation system in experiments. The starting point of the robot locates on the way between A and B on the middle of the corridor, as shown

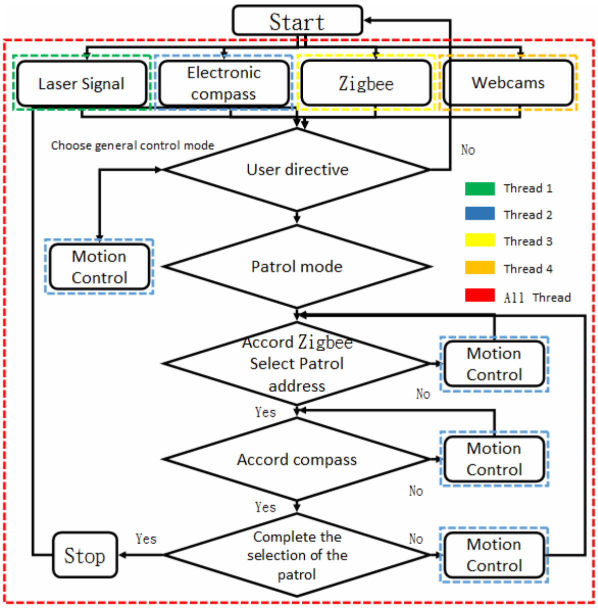

FIGURE 18. Multithreading execution for real-time robot control.

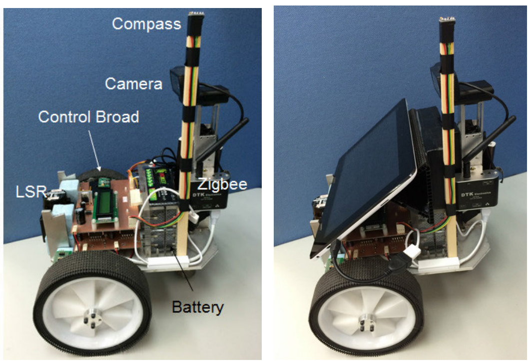

FIGURE 19. The prototype of our proposed robot.

in Fig. 20(a). If the destination is set to laboratory in the point of C, the navigation system guides the robot move forward to the points A and E. The robot will stop at the point of E that is gate of laboratory. Then the robot turns its direction to the gate according to the compass information, as shown in Fig. 20(b). Then the robot enters to the great gate of laboratory and going the small gate of laboratory C, as shown in Fig. 20(c). The demonstration shows that the proposed multi-sensor method can successfully navigate the robot to the destination according to the pre-schedule. The schedule can be planned in computer to denote to reach that destination at the specified time. Then the robot can follow the schedule to arrive the destination.

Now we discuss about the methods of robot control. There were many techniques to navigate the robot in the past literatures. The Kinect system provides the image depth to create the 2D map that is used for the passing path of robot [4]. However, this depth information is easily effected by the environmental brightness to reduce its accuracy. The laser scanning rangefinder (LSR) is a reliable device to scan the surrounding accurately for the localization of a mobile

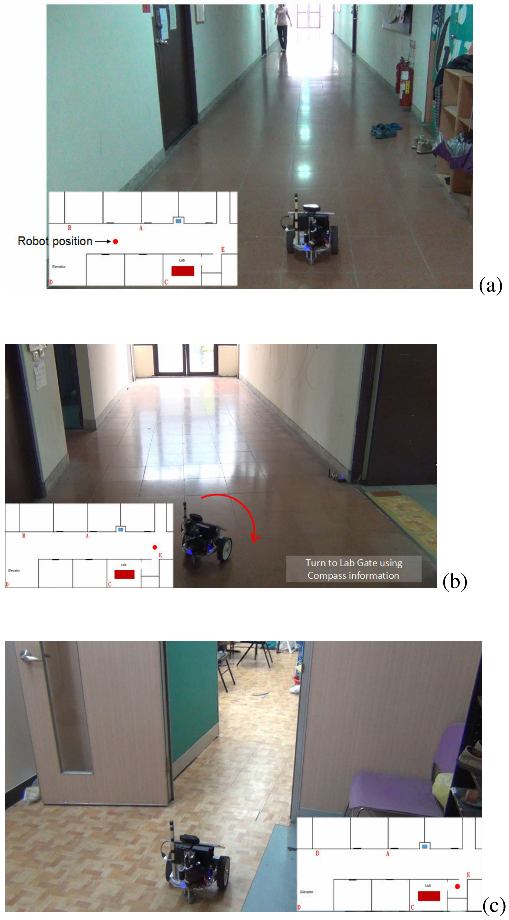

FIGURE 20. Shows (a) The robot navigation on the way between the location A and B. (b) Control robot turn to Lab. gate by compass sensing. (c) Robot enter to Lab.

robot [6]. However, it fails to detect the black obstacle. The RSSI signal is used to control the robot moving [9]. Since the RSSI signal is not very stable, the estimated distance error is about 1m. In this article, we presented double scanning method for LSR to improve the accuracy. By image auxiliary consisting of LSR, the black obstacle can be detected efficiently. Moreover, the system integrated Zigbee RSSI signal to detect the location of robot in a free space, which can monitor the robot on the remote computer. The compass sensor is used to control the robot direction with head straight going, and turns the direction at the crossing space. With multi-sensor control, the moving control can be more accurate than the signal sensor.

V. CONCLUSION

In this study, we presented a navigation system of robot using multi-sensors. The RSSI signals of zigbee are used to calculate the location of robot in a free space. Laser information with double scanning method is proposed to find the best channel for robot passing. Besides, the camera is used as an auxiliary of LSR when the robot faces a thin obstacle. Besides, the compass sensor is used to make sure the moving direction. The prototype of robot is successfully realized, which consists of a flat computer, control board, two motors and multi-sensors. The navigation algorithms had been developed and integrated into robot system. Both of the user mode and patrol mode for robot control are effectively implemented. Results demonstrate that the navigation system can be guided the robot to the desired destination by a remote computer when the patrol mode is set.

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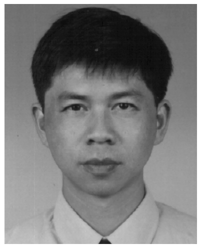

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