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ITJ

ISSN 1812-5638

INFORMATION TECHNOLOGY JOURNAL

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Information Technology Journal 13 (13): 2187-2195, 2014
ISSN 1812-5638 / DOI: 10.3923/itj.2014.2187.2195

Hybrid Wireless Indoor Robotic Surveillance System

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Abstract: The proposed robotic system based on the self-propelled vehicle to patrol periodically in the designed area working as a surveillance robot and some fixed cameras. Under such design, the proposed scheme not only ensures the operation of surveillance being well performed but also extends the operating time because of the surveillance robot being equipped with auto-recharging ability. The proposed scheme also proposes an auto-recharging mechanism for the patrolling vehicle to move automatically in a wider range and record the monitored images within a predefined patrolling route to improve the performance of the traditional fixed cameras security system. Besides, the surveillance robot can be connected to the internet in order to be remote controlled by the smartphone or website at anytime and anywhere to move the patrolling robot to the position and get the indoor images we want if needed. On the other hand, the fixed cameras mounted on the wall of the security area help surveillance process proceed during patrolling robot being charged. An IPCAM is also mounted on the proposed patrolling robot to record the real-time images and transmit them back to the server via WiFi system for the face detection analysis. As an alarm report, the proposed hybrid robotic system would use the build-in network agent module to notice users of any intruder detected. Experimental results are given in the paper to demonstrate its performance.

Key words: Mobile device control, surveillance robot, wireless IPCAM, auto-recharging, face detection

INTRODUCTION

The applications of security systems are more popular nowadays to discover the intruders and prevent the secured area from their damaging behaviors caused by thefts whether at home or working places as the incidents of theft grew more frequent. As a result, intruders or thefts easily invade the places if there are without surveillance systems. The consequence of such invasion might injure people and cause the loss of property or something even worse. Thus, a suitable security system is necessary to protect our home and working place from the intruders. The traditional security system gives some protection via fixed cameras but still has some dead zone cannot be monitored. On the other hand, the mobile security monitoring system has been also developed to improve the security of the traditional system. The diagrams of the fixed cameras and mobile security system are shown in Fig. 1. Figure 1a shows the traditional security system composed of some fixed cameras. Unfortunately, the fixed cameras system only captures those images within the coverage of fixed cameras. Therefore, there are some dead zones in the surveillance area. Thefts might secretly invade our home or working place by hiding themselves in those dead zones. To improve such situation the mobile security system being developed as shown in Fig. 1b, in which, the self-propelled patrolling vehicle acts as a security patroller in the security area to monitor all area not only the fixed area monitored by the fixed cameras but also those dead zones of the traditional fixed surveillance system (Lee *et al*., 2011). The surveillance robots can be controlled via computer networks by the real time feedback images from the IPCAM mounted on the robot and/or positioned with the help of RFID (Radio Frequency Identification) techniques (Park and Sim, 2008; Xiao and Zhang, 2009; Kim *et al*., 2010).

Some applications adopted WLAN (Wireless Local Area Network) to enhance the remote monitoring capabilities by using the wireless network to control the surveillance robot (Luo *et al*., 2007; Ku and Cheng, 2007). Besides, the face detection technique was also adopted to record and recognize the intruders (Xie, 2005; Zuo *et al*., 2010; Wang, 2007). Moreover, the moving objects can be also detected with the similar technique (Viola and Jones, 2001). No matter where the user is, he can monitor the indoor situation by using tolls with communication networks in hand.

As known, OpenCV is an open source and it can be used in most of the operating platforms e.g., Linux and Windows. OpenCV is developed by the Intel Corporation not only for image processing but also providing interface

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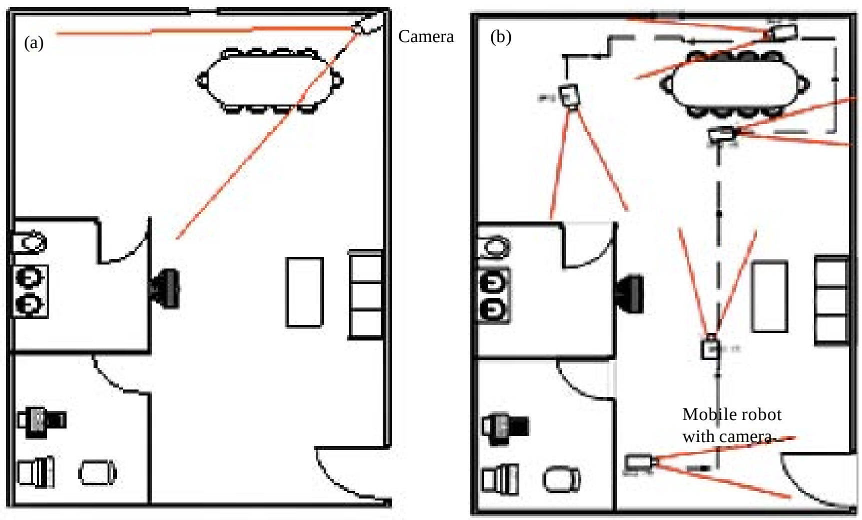


Fig. 1(a-b): Traditional fixed cameras and mobile security system (Lee *et al*., 2011) (a) Fixed cameras system (b) Mobile security system

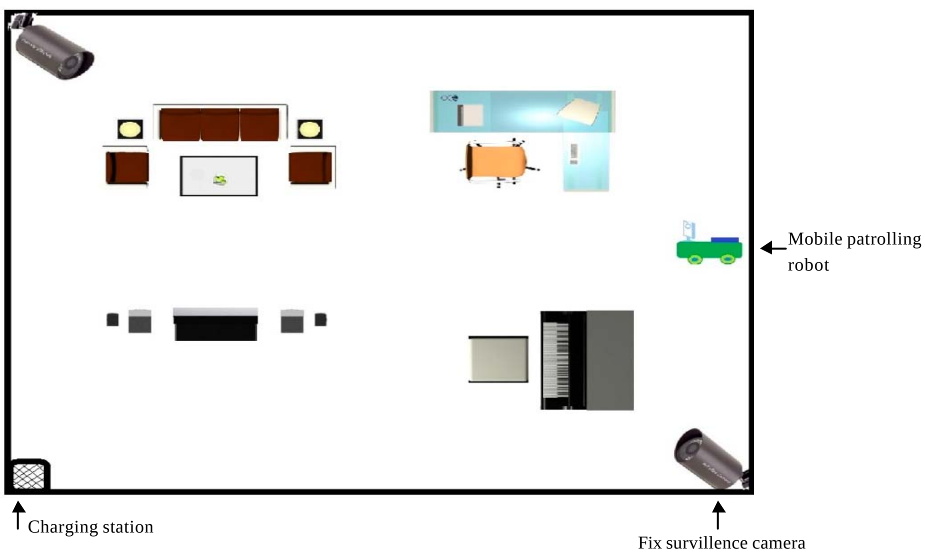


Fig. 2: Proposed hybrid security system

to create pictures by C programming language, etc.,. It can be used to face detection, handle object tracking, texture analysis, etc., (Bradski *et al*., 2005).

In this study, OpenCV technology is used for face detection to identify intruders. Adopting the proposed surveillance robot of the scheme, the security of indoor surveillance will be upgraded. The mobile security robot gives more information combining with the fixed cameras security system as shown in Fig. 2. The proposed hybrid surveillance system has the following improvements comparing with the traditional and mobile security systems: (1) The dead zones are monitored by the mobile robot, (2) The fixed cameras send back the real time images all the time even during the charging periods of the robot, (3) The random time of recharging periods makes patrolling schedule unpredictable, (4) Face detection helps surveillance more effective on identification of intruders.

Besides, an auto-recharging mechanism was also developed to ensure the mobile robot always being full of electricity. With a random period of recharging cycle, the patrolling periods are also random which makes the patrolling schedule unpredictable. Experimental results are provided to demonstrate the performance of the proposed system.

SYSTEM ARCHITECTURE

Figure 3 below shows the overall sketch of the proposed hybrid surveillance system. With the help of Wi-Fi communication system, the users can monitor the situation of the indoor security area which is under surveillance both by two fixed cameras and a surveillance robot. The overall system can be divided into following parts: the wireless PTZ-IPCAM (Pan Tile Zoom) video capture system, (Yu *et al*., 2010) the face detection system, the remote monitor system, alarm transmitting system, photo-based vehicle position detection systems, the recharging system and wireless monitoring and control system as shown in Fig. 3.

The self-propelled vehicle uses photo-based technology to control the moving direction. Photo resistors are previously installed on the route of the self-propelled vehicle. When the self-propelled vehicle moves across the photo resistors on the predefined patrolling path, the variance of resistors are detected by the microprocessor (Tibbo) and sends the signal back to the server to show the detected position on the map to indicate the status of the self-propelled vehicle. Smartphone (based on Android system) can also receive the position of the vehicle or send control commands via the Web server to control the direction of self-propelled vehicle. (http://www.hiapk.com/bbs/thread-6210-1-1.html; http://developer.android.com/index.html) Face detection subsystem detects human faces in the monitored area with the help of Intel's OpenCV library. The wireless IPCAM is mounted on the front of self-propelled vehicle. If a human face is detected from the IPCAM or the fixed cameras in the image file, the server would trigger the web agent module (e.g., MSN or Facebook) to send warning message to the user. User can use the PC, notebook, or Smartphone to monitor the situation on line and/or drive the self-propelled vehicle to the spots where the users want it to be.

The self-propelled vehicle is guided in automatic patrolling mode by the well-known method called Dead Reckoning estimation (Kleeman, 1992). By using the photo resistors as safety points, the error of tracking path can then be corrected. Moreover, a recharge station is installed to guarantee the surveillance vehicle to have enough of power during patrolling in duty. The cruising period can also be unregulated by a random variable been added in the recharging cycle.

THE HARDWARE ARCHITECTURE

Figure 4 shows the physical hardware implementations of the self-propelled vehicle and the smartphone.

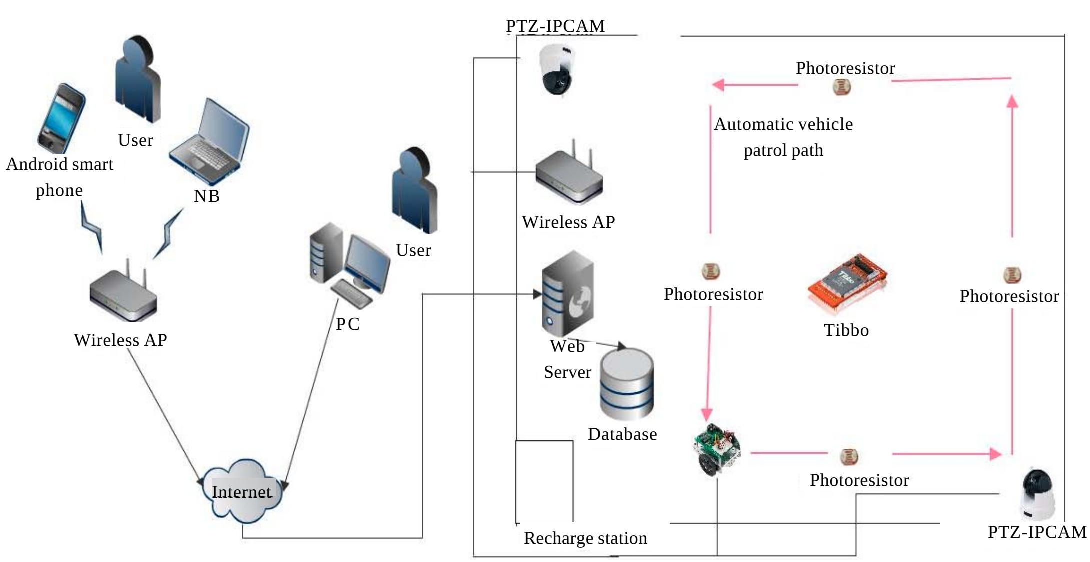


Fig. 3: Overall architecture of proposed surveillance system

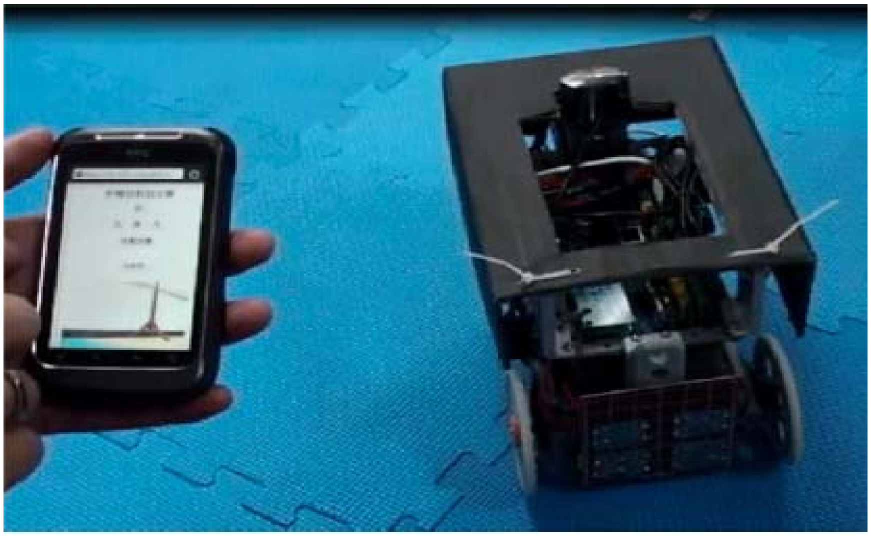
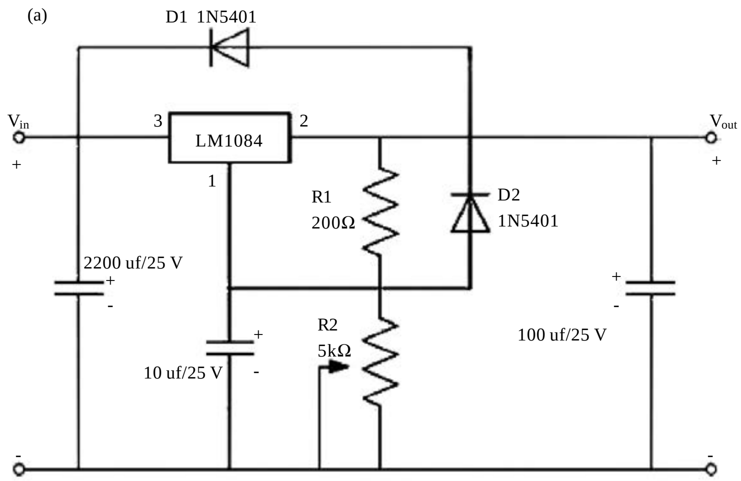


Fig. 4: Smartphone and proposed vehicle in experiment

Fig. 5: Microprocessor used in proposed system

The microcontroller of the self-propelled vehicle is DFRduino RoMeo 328. There are 14 sets of digital I/O interface (including 6 sets of PWM output), 8 sets of emulating analog I/O interfaces, 2 pairs of DC motor drives and 6 input buttons in the Atmega168 based microcontroller. This microcontroller is the main controller of the proposed security patrolling robot. The program to control the vehicle and receiving/sending message to the server were implemented by this microcontroller. An evaluation kit called Tibbo equipped with the microcontroller DFRduino RoMeo 328 manufactured by Tibbo technology is adopted in the proposed system. It is shown in the Fig. 5. Furthermore, the recharge station was also implemented under the following design as shown in Fig. 6. With the help of such mechanism, the surveillance robot can be recharged to extend the surveillance time. The circuit of the recharge station was designed as shown in Fig. 6a. And, the implementation of such design was implemented as shown in Fig. 6b. The recharge station was composed of the recharge circuit on the rear part and the mechanism part on both sides in white. The red indicator showed the



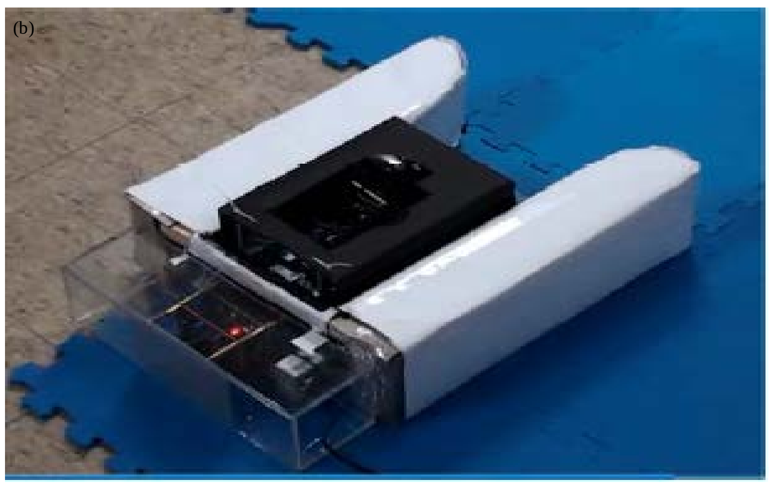


Fig. 6(a-b): Implementation of recharge station (a) Electrical circuit of recharge and (b) Recharge station

vehicle being in charge. Besides, the recharging time to full energy is approximate 17 min and the maximal surveillance time without recharge is about 150 min.

Thus, the recharge period is designed as below:

$$\text{Recharge cycle for robot} = \text{Int}\left(\frac{150\left(1-\text{random}(x)\right)}{\text{time percycle}}\right)$$

In the above equation, a random number random(x) is added to make the recharge cycle of the robot become unpredictable. Which leads the intruders difficult to expect the time schedule of the surveillance robot and thus the surveillance system becomes more secure.

SOFTWARE SYSTEMS

In the proposed system, the involved software systems included Jcreator LE, Eclipse, Visual Studio C# 2008, NorthSTAR, OpenCV and Visual Studio C# 2010. There were two major software programs among them as the followings. One was NorthSTAR software which was used to establish the MSN agent robot by writing the C language. The other was OpenCV which was a very important software used for face detection. In the proposed system, JAVA language was also adopted to cope with the OpenCV library to implement face detection. Under such design, face detection techniques was applied to the PTZ-IPCAM with the result as shown in Table 1. The mistakes were almost dependent on resolution of the pictures, larger the resolutions less the mistakes were made.

The angle between the detected face and camera lens was another factor which influenced the results of face detection of PTZ-IPCAM as shown in Table 2.

The comparison results with CCD camera are also listed in the following Table 3. In which, PTZ-CAM shows the much better performance than the CCD camera mounted on the surveillance robot does.

EXPERIMENTAL RESULTS

The proposed surveillance system was demonstrated with a series of simple experiments. The experimental setup was shown in Fig.7. The notebook computer played the role as a web server. There were four photo resistors mounted on the floor in white. Two fixed cameras were also deployed on the left and the right side on the floor.

The reaction of face detection was shown in Fig.8 as a intruder being detected. The situation was a person entering the security area and avoiding the surveillance robot but still be captured by the fixed camera. In Fig. 8a, a person appeared in the left image on the screen and the face is detected and shown on the server's screen. The web agent (MSN in this case) then sent a message to the user and the message was shown on the smartphone as in Fig. 8b.

On the other hand, if a human face is detected, the user can directly drive the surveillance vehicle by smartphone to the desired place for further action as shown in Fig. 9. The robot will send both the real time

Table 1: Results of PTZ-IPCAM with different resolutions

Resolution	Time (msec)	Pictures with faces	Pictures without face	Faces detected with actual faces	Faces detected but with no faces	Mistake (%)
640*480	64.8	150	50	134	1	2
704*380	53.3	150	50	136	2	4
320*240	49.25	150	50	137	17	34

Table 2: Results of face detection of PTZ-IPCAM

Resolution	Distance (m)	Up angle of face (max)	Down angle of face (max)	Left angle of face (max)	Right angle of face (max)
640*480	<4.4	30°	15°	30°	30°
704*380	<4.25	30°	15°	30°	30°
320*240	<2.30	30°	15°	30°	30°

Table 3: Comparison

Resolution	Time (msec)	Pictures with faces	Pictures without face	Faces detected with actual faces	Faces detected but with no faces	Mistake (%)
PTZ-IPCAM						
704*380	2.564	320	415	238	24	5.783
CCD Camera						
348*291 (96 dpi)	1.856	320	415	200	33	7.951

Fig. 7: Experimental setup

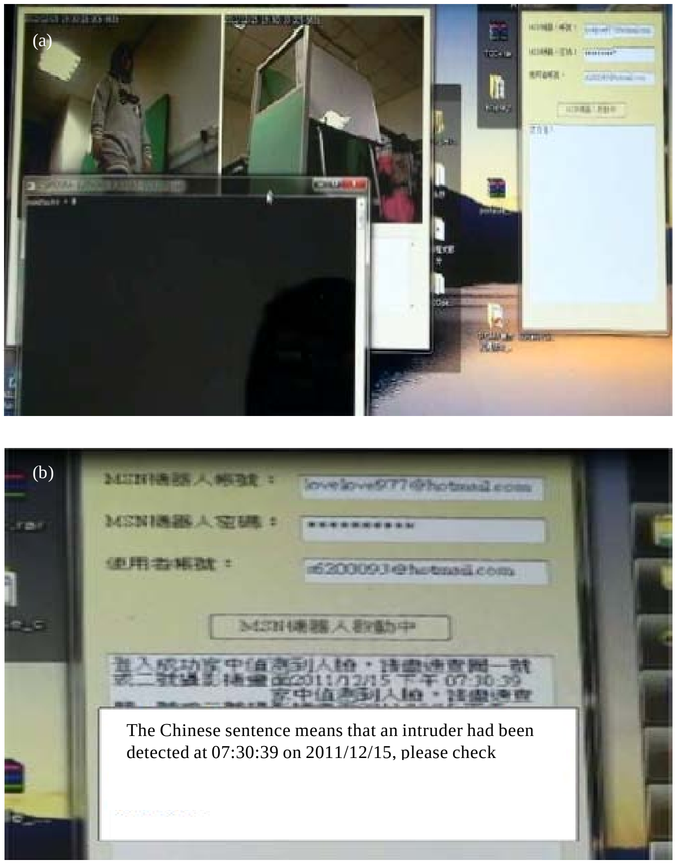


Fig. 8(a-b): Implementation of face detection (a) A person appears on the left screen (b) The notice of intruder shown on the smartphone in Chinese by MSN agent

Fig. 9: Control of vehicle by smartphone

image and sound back to the control center for identification and decide the further response.

As mentioned before, a recharge station had been developed to ensure the surveillance vehicle away from power empty. On the other hand, the vehicle patrolled on a predesigned route designed by Dead Reckoning method to keep the surveillance on the track. With the help of photo resistors mounted on the floor, the path of the vehicle can be corrected and remained in the correct route. Moreover, the proper mechanism design of recharge station helped the vehicle get into the precise position for recharging. And which ensure the surveillance robot leave the station in a certain spot as shown in Fig. 6b in previous section.

CONCLUSION

The proposed hybrid surveillance robotic system was implemented by a combination of a web server, a self-propelled vehicle, two fixed cameras, four photo resistors, a recharge station and a smartphone connecting each other via wireless networks to provide the functions of surveillance, face detection and remote control. To summarize, there are some conclusion remarks of the proposed system can be addressed as bellows: (a) The proposed hybrid surveillance system equips with not only a mobile surveillance robot but also two fixed cameras to provide wider range of monitoring. (b) The warning messages can be sent back to the security web server and/or paged to the smartphone of user by web agent if any intruder being detected. (c) Face detection technique is adopted in the proposed system to identify the intruders. (d) The surveillance vehicle can be navigated by predesigned program or online smartphone if necessary. (e) The Dead Reckoning method is adopted to control the vehicle in a predesigned route and four photo resistors are also mounted on the floor to correct the direction of vehicle if necessary. (f) A recharge station had been developed in the proposed system in order to ensure the mobile vehicle full of power during surveillance. The proposed hybrid surveillance system had been developed and implemented with some proper designs described in the previous sections. The feasibility of the proposed scheme was also validated with the satisfactory experimental results.

ACKNOWLEDGMENT

This study is partially sponsored by the projects of NSC 101-2221-E-147-002- in Taiwan.

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