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Remote Control Based Hybrid-Structure Robot Design for Home Security Applications

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Abstract – **Non-industrial Robot applications are getting more popular than ever. Moving capability is one of the most important features of non-industrial robots. In general, the movements of non-industrial robots are categorized as wheeled and legged mechanical platforms. The wheeled platform performs stable and fast movement characteristics; however, it can not move on humpy grounds or cross small doorsills. Contrarily, the legged platform performs better adaptations to different types of ground conditions; nevertheless, the walking velocity and stability and the larger energy consumptions restrict the practical applications. In this paper, we present a hybrid-structure robot with humanoid and vehicle types to perform home security tasks. To achieve home security issues, the smoke and temperature detection sensors are mounted on the robot. At the same time, the CCD camera is mounted on the head of robot to capture the guarded videos and to assist remote manipulations. The security robot is controlled remotely in terms of wireless manner. The proposed hybrid-structure robot behaves vehicle type in most of operation time to perform stable and fast movements and to reduce energy consumptions. When the robot enters humpy grounds or crosses small doorsills, the robot structure is changed as humanoid type to pass the non-flat grounds. Therefore, the proposed hybrid-structure security robot provides flexible adaptations to different types of ground conditions in home. Due to size limitations, the security robot can be used in regular apartments. Finally, a 50 cm in height security robot prototype is implemented in laboratory. The robot had been successfully tested for legged walking, wheeled driving, changing structures, cross small doorsills, remote manipulations, and remote monitoring of security functions.**

Index Terms - Humanoid robot; Hybrid-structure; Security robot; Remote manipulation.

I. INTRODUCTION

Security robot [2-8] is an important research topic in recent years. In general, the security robot consists of the movement platform, motion control module, vision module, sensor modules, and wireless communication modules. The movement platform is responsible for driving robots to move in environments. Due to different ground conditions, different types of mechanical designs are desired to fit practical issues. In general, dedicated moving types such as wheeled or legged are used.

The motion control module performs stable and efficient driving of robot actuators. Typically, digital motion controllers with high performance control lows are essentially required to achieve desired motion responses. The vision module is also important to security robots. The vision module does not only provide videos of the guarded environment in real time, but also instruct the users to manipulate the robot remotely. For example, Saitoh *et al.* [6] proposed the related work for security applications. The remote user can get videos around the robot by remotely operating the camera vision system mounted on the robot.

The sensor modules are add-on devices for specialized security purposes. In general, the smoke, temperature and CO sensors are typically required for security robots. Such sensors are desired to prevent big fires and CO toxication in advance. For example, Luo *et al.* [3-4] developed the multiagent and multisensor based real-time sensory control system for intelligent security robot. At the same time, the adaptive sensor fusion approach was also developed for the robot to detect the fire.

The wireless communication modules are responsible for remote manipulations of robots, transmitting real-time video frames and sensor data to host computers. In this manner, the remote users are capable of monitoring the guarded environment at remote sites. Related works are surveyed. In 2005, Luo *et al.* [5] proposed the intelligent home security robot. In addition, Schultz *et al.* [7] also presented the telepresence mobile robot for security applications.

Mobility is important to security robots. Most of past works devoted themselves to develop wheeled security robots [3-7] to perform simple constructions, fast moving, stable operation and energy saving purposes. However, the wheeled design can only be applied to flat grounds. The combined structure is useful for applications, such as the works from Adachi *et al.* [1]. They proposed the leg-wheel hybrid mobile robot. Meanwhile, the step-passing algorithm was also discussed.

Finally, the legged robots such as humanoid robots are desired to walk on humpy grounds or to cross small doorsills in terms of the flexible mechanical structures. Tanie [7] discussed possible applications of humanoid robots. The author mentioned that security is one of five important applications of humanoid robots. Nevertheless, the legged security robots are not feasible due to large amounts of motors, complex control algorithm, unstable mechanical structures, slow moving speed, and large energy consumptions.

Therefore, based on the surveys of security robots, we develop a hybrid-structure based security robot. The robot body is constructed as 50 cm in height and 2 Kg in weight. The proposed security robot behaves the vehicle type and the humanoid type as well, and there are fifteen degree-of-freedom designed for walking of humanoid type and two additional degree-of-freedom designed for differential driving of vehicle type. In addition, the robot is capable of automatically changing structures between vehicle and humanoid types. Such an innovative design increases flexible adaptations to different types of ground conditions. The motion control module, vision module, sensor modules, and wireless communication modules are also implemented for general home security purposes.

Finally, this paper is organized as follows. Section II introduces the mechanical design of the hybrid-structure security robot; section III describes the DSP based controller designs for legged walking and wheeled driving; section IV illustrates remote security functions of the security robot; section V elaborates the practical experiments and their discussions; finally, the conclusions and future works are presented in section VI.

II. MECHANICAL DESIGN OF HYBRID-STRUCTURE ROBOT

The proposed security robot is designed as a seventeen degree-of-freedom (d.o.f.) mechanical structure, and it consists of fifteen independent link joints with limited angle ranges and two continuously rotary wheels. To design a robot with hybrid structures of humanoid and vehicle types, the following design considerations and procedures are required:

1. Formal designs: The formal designs of hybrid-structure robots are quite important. In other words, the robot must look like a humanoid robot or a vehicle robot when structure changes. However, the formal designs of two types of robots are hardly to be satisfied as well. In this work, the computer assisted engineering software of Pro/E [9] is used to design, modify and investigate formal designs of the proposed hybrid-structure robot in the first stage.
2. Changing structure stability: This function is used to evaluate the motion stability of robot structure that was designed in the formal design stage during changing structures. If the stability can not be maintained, the formal styles of the robot are redesigned until the formal styles and the changing structure stability are all satisfied.
3. Humanoid walking capability: This function is used to examine the walking capability of the humanoid type. If poor walking capability presents, the previous two stages must be concerned again to ensure that the formal design approval, changing structure stabilities, and humanoid walking capabilities are all satisfied simultaneously.
4. Vehicle driving functions: The vehicle driving functions are desired to drive the vehicle robot with any directions in terms of two continuously rotary wheels.

In summary, Fig. 1 represents the design scenario of security robot mechanical structures. Modification of mechanical structure by any consideration may affect the performance of the other two considerations. Therefore, the mechanical design of hybrid-structure based robot is more complex than humanoid robots or wheeled robots.

The final version of robot structure models for humanoid and vehicle types are designed as shown in Fig. 2 and Fig. 3, respectively. There are five degree of freedoms designed for each leg; two degree of freedoms designed for each hand; and one degree of freedom designed for the head. Especially, the video camera is mounted on the head to capture image frames in guarded environments. The head is responsible of rotating up and down so that the camera viewing angles can be changed in either humanoid or vehicle types. Note that the motors of the proposed security robot use the modular servo motors. The angular positions of joint type motors are controlled using the pulse width modulation (PWM) manner; the angular velocity of the wheel type motors are also controlled in terms of the duty cycles of PWM.

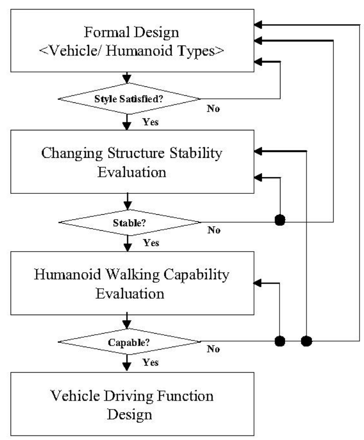

Fig. 1 Design scenario of security robot mechanical structures.

Fig. 2 Humanoid type robot structure Pro/E model.

The changing structure stability and humanoid walking capability are evaluated in terms of the Microsoft Visual C++ [10] based self-coded program, as shown in Fig. 4. This program is capable of flexibly constructing and revising 2D simplified robot structures in brief manners. In addition, the user can define motor operation sequences to investigate the

2D motions of robot. The gravity center of the robot is calculated when emulating the pre-defined motor operation sequences. Once, the gravity center of the whole body exceeds the pre-defined stable range, than the system stops the emulation and reports the conditions.

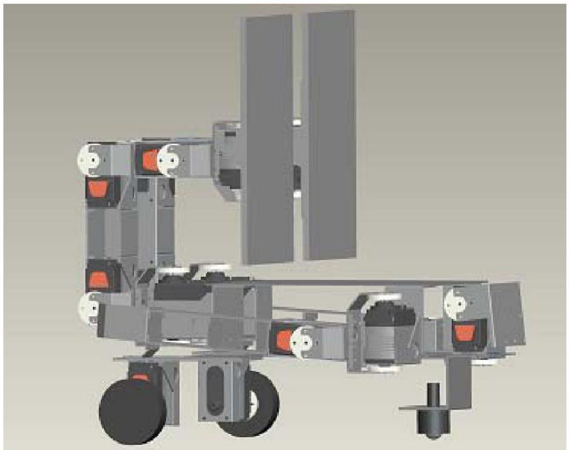

Fig. 3 Vehicle type robot structure Pro/E model.

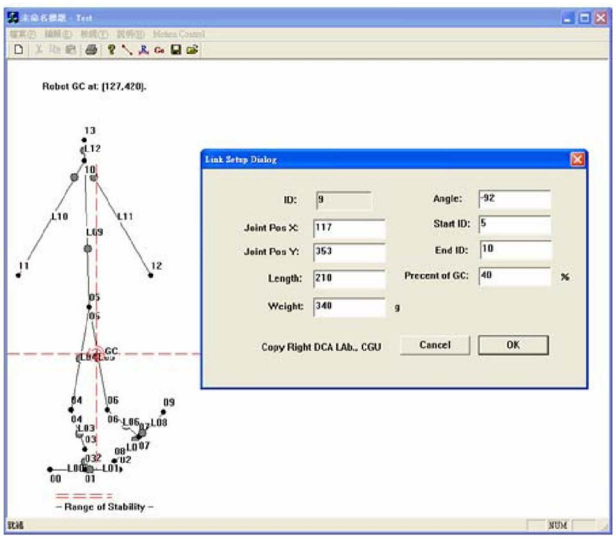

Fig. 4 Self-coded robot 2D motion evaluation program.

III. Realizations of Motion Controller

The motion and gait controls of the proposed hybrid-structure security robot are implemented as the PC based gait training program and the digital signal processor (DSP) based real-time gait controller. The overall signal and control block diagram is shown in Fig. 5. The PC based gait training program is a self-coded Microsoft Visual C++ based program, and it is responsible of accepting user's commands to tune the joint angles of the humanoid type security robot, as shown in Fig. 6. In summary, the gait training program consists of the following functions:

1. The program provides USB based communication interface with the DSP based gait controller.
2. The program controls the joint angles of the hybrid-structure robot in real-time (max: 20 joints).
3. The program records the gait training data in the Microsoft Access Database. The gait training data is further categorized as the gait programs, gait sequences and motor angles, and they are illustrate as follows:
   a. Gait program: It represents a single gait motion, such as flat walking, changing structure, crossing a small doorsill, etc. A program is composed of several sequences (max: 20 sequences).
   b. Gait sequence: It represents the end point of a gait program segment. Note that the time interval of the sequence is also defined. Especially, the motion of all joint motors can be synchronized at each gait sequence.
   c. Motor angles: Each gait sequence consists of angles of all motors on the robot.
4. The user can copy, modify, delete and recorded gait training data.
5. Finally, the program is capable of downloading the selected gait training data to the data memory of DSP based gait motion controller in terms of USB interface, so that the robot can be activated in standalone manner.

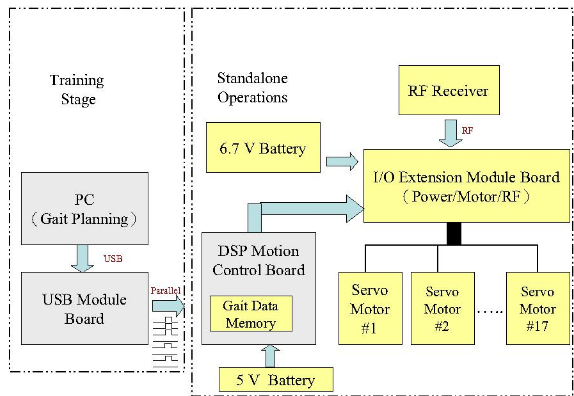

Fig. 5 Signal and control block diagram.

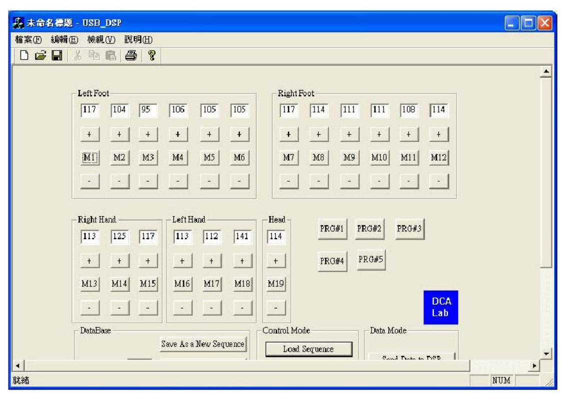

Fig. 6 Self-coded gait training program for humanoid type.

The DSP based motion controller is responsible of receiving individual control commands in training stage and receiving entire gait training data before standalone operations. For the training stage, the DSP receives the individual control commands and then controls the angles of corresponding motors. For the standalone operation stage, the

DSP receives the entire gait training data and then stores in the corresponding memory addresses for further remote controls.

During standalone operation stage, the DSP waits the commands from the RF data receiver module. The received RF data indicates the gait program ID. Once, the DSP controller receives a new gait program ID, it renews the motion command. To prevent suddenly changes of gait program when the previous gait program sequences are not complete, the DSP changes the program only when the previous program sequences are finished. In addition, the programs are further categorized as the infinitely repetitive program and the one loop program. Consequently, the infinitely repetitive program will not stop the execution until gait program changes.

In addition, the linear and parabolic interpolation approaches are implements for the DSP gait controller. There are several important features for the interpolation approaches:

1. The linear and parabolic interpolation approaches are capable of smoothing motor motions so that the stability of changing structure and humanoid walking can be improved.
2. The linear and parabolic interpolation approaches can reduce the amounts of training sequences.
3. The general angular modular servo motors do not support velocity control capability. Since the time interval of each sequence is defined for the linear and parabolic interpolation functions, the angular velocity control of motors can be easily desired. At the same time, all joint motors can be also synchronized at each sequence.

Finally, the photo of the DSP gait motion controller and I/O extension modular board is shown in Fig. 7. Because the DSP board is installed inside the body of the robot, an individual photo of the DSP board is shown at the right-hand-side of Fig. 7.

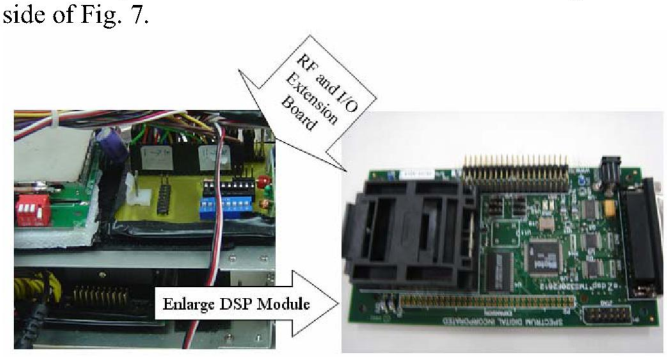

Fig. 7 Photo of DSP gait motion controller and I/O extension board.

IV. IMPLEMENTATIONS OF REMOTE SECURITY FUNCTIONS

To achieve home security functions, several security sensing components and modules are attached on the proposed hybrid-structure robot. The implementations of remote security functions are realized as two different parts. The first one is implemented on the security robot; and the second part is implemented as the security web server and security robot host controller. The architecture of remote security functions are shown in Fig. 8.

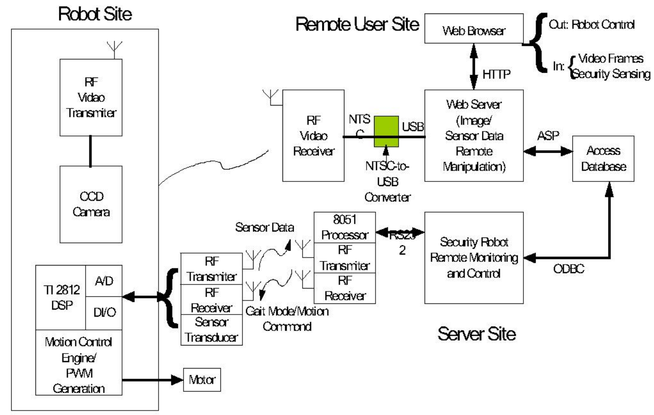

Fig. 8 Photo of DSP gait motion controller and I/O extension board.

For the security robot site, the RF based live video acquisitions module, smoke sensor module and temperature sensor module are attached on the robot. These modules are further elaborated as follows:

1. RF based live video acquisitions module: The RF based live video acquisitions module is composed of a small size CCD camera and a FR transmitter. The CCD camera is mounted on the head of robot so that the camera viewing angles can be adjusted. In addition, the analog RF video transmitter is used to transmit live video frames to the web server, as shown in Fig. 9 (a).
2. Smoke sensor module: The smoke detection module is usually used in the security applications. In this work, the smoke detection module is used to detect smokes, as shown in Fig. 9 (b). When the sensor activates, it enables the photo coupler to generate high voltage (+3.3V) to the DI (digital input) of the DSP.
3. Temperature sensing module: The temperature sensor uses the IC type sensor (with model: AD590) to detect the environment temperature. The transducer circuit converts current to voltage signal, and then the DSP AD (analog-to-digital) converts the temperature as digital data.

Consequently, the temperature and smoke data are packed and further transmitted to the host computer of the security robot in terms of the RF transmitter.

For the server site, two types of servers are implemented. The security robot remote monitoring and control server acts as the host computer of the security robot, as shown in Fig. 10. To collect data and to control robot, the 8051 single processor based RF communication controller is designed. The controller can receive the sensor data from the RF receiver and transmit the manipulation command using the FR transmitter. The RF communication controller also connects with the host computer using serial communication interfaces. In summary, the security robot host computer is capable of:

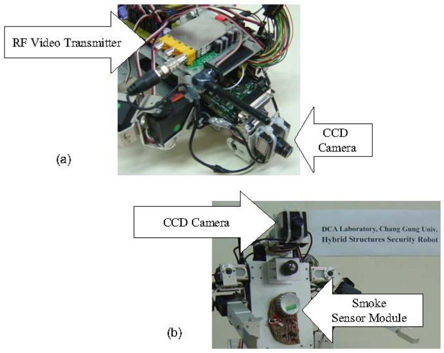

Fig. 9 Photo of CCD camera and smoke detection module.

1. Collecting temperature and smoke data from the RF communication controller, and then recording data in the Microsoft Access database in terms of open database connectivity (ODBC) protocol [10].
2. Retrieving newly updated manipulation commands from Microsoft Access database, and then transmitting them to the RF communication controller.

On the other hand, the web server is implemented for the remote users to investigate the guarded environment. The web server provides the live video frames and the status monitoring of sensor data. In addition, the user can also manipulate the security robot to move around the guarded area. The sensor data monitoring and robot manipulation commands are retrieved from and stored in the Microsoft Access database in terms of active server page (ASP) techniques. Therefore, the Microsoft Access database acts an import role for the data exchange between web server and security robot host computer.

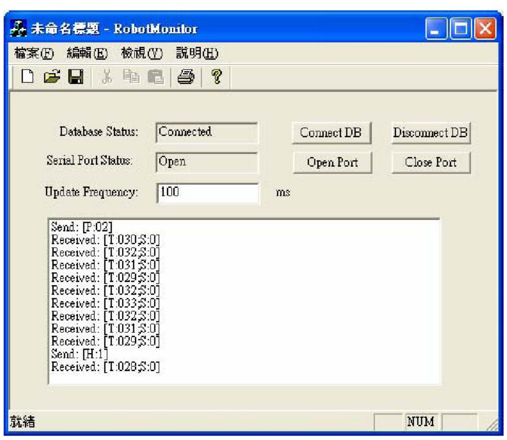

Fig. 10 Security robot remote monitoring and control server program.

V. Practical Experiments and Discussions

The hybrid-structure security robot prototype is realized as shown in Fig. 13. Left-hand-side photo shows the vehicle type; and right-hand-side photo shows the humanoid type. Meanwhile, the walking capability, changing structures, crossing small doorsills, passing stage with small height, and vehicle moving are experimentally tested. Due to limited paper pages, the most difficult motion of changing structures is discussed in this section. This experiment is to change the vehicle type as humanoid type. Since the security robot behaves the vehicle type in most of operation time, such a gait program motion is used only when the security robot would like to move on humpy grounds or to cross small doorsills. After passing special grounds, the robot changes itself as the vehicle type again.

The motor angles corresponding with the changing structure program sequences are further smoothized using the linear and parabolic interpolations. Fig. 14 shows the motor control angle results of fourteen motors (excepting head rotating motor and two wheeled motors) for changing structure program in terms of linear interpolation. Fig. 15 shows the intermediate video segments of changing structures. Finally, the user can define gait programs according to the ground conditions and applications using the gait training program to extend more wide applications.

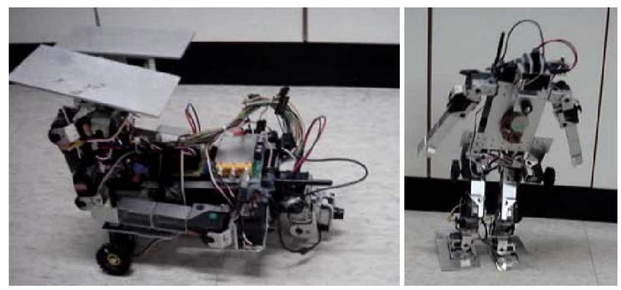

Fig. 13 Assembled vehicle and humanoid types.

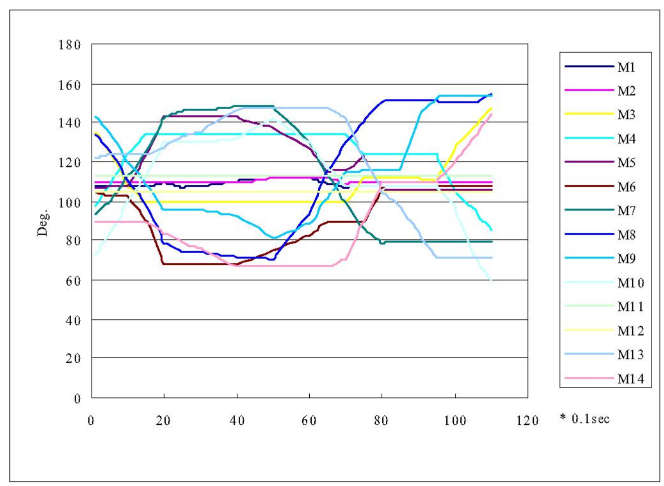

Fig. 14 Motor control commands.

In addition to the motion experiments, the security functions are also tested. Fig. 16 shows the experimental setup of the security server. The configuration follows the descriptions in section IV. The video RF video receiver and the NTSC-to-USB converter are all presented in photo. Consequently, the remote users can connect the web server to control the security robot to move or walk to interested locations. The video frames and sensor data around the security can also be monitored. Fig. 17 shows the screen of security web page in remote sites. In this web page, the robot behaves as the humanoid type, and watching its leg position. In addition, the sensor data and manipulation functions are all provided. Consequently, the results preliminarily verify the hybrid-structure based security robot approach.

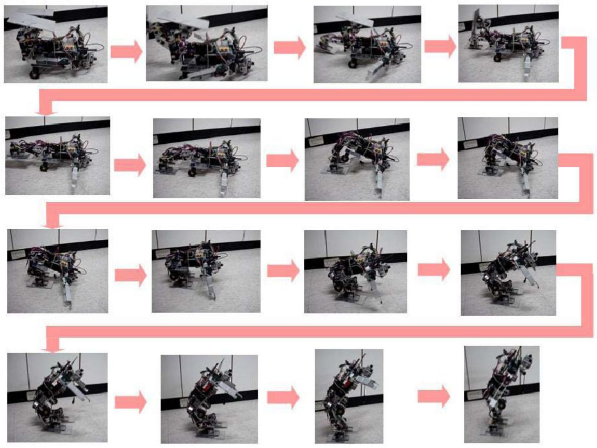

Fig. 15 Photo sequences of changing structures.

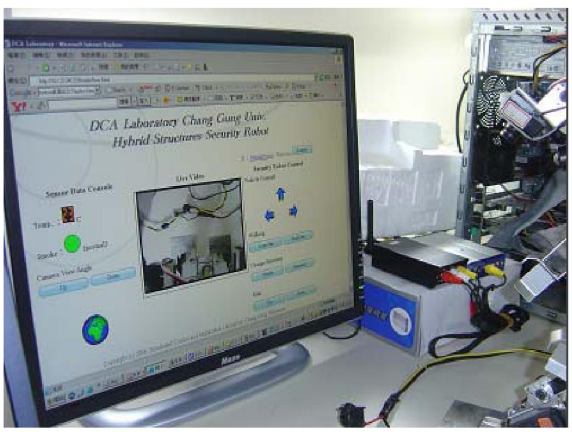

Fig. 16 System setup of server site.

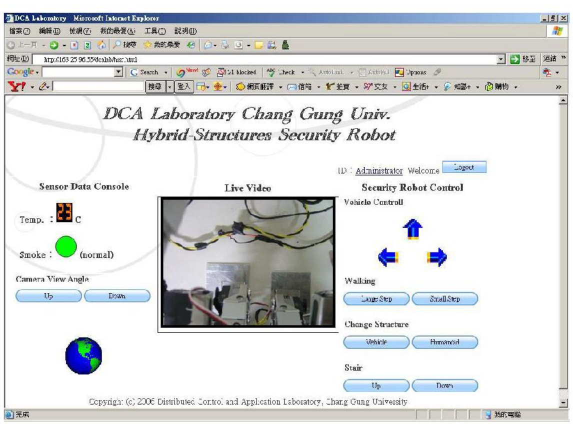

Fig. 17 Remote security web page.

VI. Conclusions and Future Works

In this paper, an innovative hybrid-structure based robot is proposed to promote home security applications. The security robot behaves the vehicle type for most of operation time. If the security needs to cross humpy grounds or small doorsills, then the robot changes its structure as humanoid type to deal with different types of ground conditions. Such a design significantly improves moving capabilities of the security robot. Especially, the changing structure stability and walking capability are evaluated before producing real robot. At the same time, the security functions of acquiring live video frames and collecting smoke and temperature data of the guarded areas are implemented and integrated using the web technology. Based on practical experiments, the motion capability and security functions satisfy the objectives of this paper. In the future, the larger size of robot will be implemented to cross larger doorsills or obstacles. In addition, the intelligent functions such as image recognition, sensor fusions, autonomous walking, path planning, automatic security monitoring, GSM/ 3G integrations are all potentially important issues to be developed for enhancing the functionality of the hybrid-structure security robot.

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