行政院國家科學委員會專題研究計畫 成果報告

適用於飛機上排爆機器人之設計與研發
研究成果報告(精簡版)

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適用於飛機上排爆機器人之設計與研發

(Design and Development of a Bomb Disposal Robot for Airplanes)

計 畫 編 號：NSC 95-3114-E-002-003
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主 持 人：鍾添東副教授 國立台灣大學機械系
計畫參與人員：陳勇志、張哲源 國立台灣大學機械系

Abstract **-** The purpose of this project is to design and develop a bomb disposal robot for airplanes. Firstly, procedures performed for bomb disposal missions on board airplanes is investigated, traditional commercial bomb disposal robots from the market is also reviewed, and robot specifications suitable for airplane on board bomb-removal is determined. Then several concept designs for the robot are proposed. The main components of the robot include chassis, wheels, arms, grippers, transmission unit, power unit, detective unit, and operator control unit. Bomb-removal operations are also simulated in a 3D virtual environment representing on board airplane situations. As for the operator control unit, an operation interface is developed, and signals from motors, sensors, and CCD cameras are integrated into the interface such that motions of the robot can be detected and controlled under limited space inside and outside airplanes. Finally a prototype of the robot is manufactured, and performances of the robot for moving in airplane inside and climbing over airplane outside are tested. The project for this year is the first year of the 3-year project. The mission for the first year is to do the robot concept design and to manufacture the mobile system of the robot, including chassis, wheels, transmissions, and the motion control units.

Keywords: bomb disposal robot, mobile robot, wall climbing robot, airplane security task

I. Introduction

In recent years, the effect of 911 terror event in America causes that countries around the world enhance the airplane security protection and manage strictly dangerous things. However, security loopholes still exist in the strict protection. So the airplane flight security is threatened by growing crises. Terrorists may attempt to place bombs in the airplane and make terror events to explode a passenger-carrying aircraft. By the way they disturb people and make turmoil. Therefore the problem of security is becoming more and more important.

In the aspect of the country security and military affairs, robot plays a very important role. The field of mobile robotics has matured quickly in the past decade, with more and more robots entering practical field service. The two most active application areas for mobile robots so far have been military and law enforcement. For law enforcement, most robotic activities to date have been in the area of explosive ordnance disposal, where robots are used to keep the human bomb disposal expert out of harm’s way.

The terroristic means are serious problems all the time. Unpredictable risks hide in any public place, including airplanes and trains. Especially high jacking an airplane is like a walking bomb that could go off anytime to every body. So the security issue becomes more and more important. Many developed countries attempt continuously not only to get information at the first time but also to handle problems appropriately. On the basis of security, bomb disposal robots have been used extensively in this field.

This project proposes the design and development of a bomb disposal robot for airplanes, so the robot must be able to walk on the narrow passage inside the airplane at first. However general and commercial bomb disposal robots are used for outdoor principally, the size is relative large and unsuitable for airplane on board bomb-removal. In addition, this project will combine reconnaissance function with the bomb disposal robot. So the robot is needed not only to walk on the ground but also to climb on the vertical plane for monitoring outside the airplane.

According to above characteristics, this project prepares to develop a novel bomb disposal robot. The initial task is to review existed techniques and improve them further. The stable motion mechanism of the robot is designed to fit in with the narrow passage inside the airplane and stick on the outside surface of the airplane.

II. Paper Review

A large amount of overseas factories and companies already invest a lot of resource in the field of robot to carry relative design and development out. Many important techniques have been proposed by means of patents and papers. So in the beginning of this project, paper review is a very significant step.

Vanguard company [1] produced 「Vanguard™ MK1」robot, Figure 2.1. This robot is very light and agile, and can be used both indoor and outdoor. Vanguard™ MK1 has the capability to respond to bomb threats, to perform hazardous materials handling and tactical and surveillance tasks. However the weight of Vanguard™ MK1 (440mm) is too large to fit the passage inside the airplane.

Figure 2.1 Vanguard™ MK1 robot [1]

Foster Miller company [2] produced a small robot 「SOLEM」, Figure 2.2. SOLEM is a lightweight, portable robotic rover designed to perform inspection tasks. It is a very dexterous platform able to operate in all weather conditions, day and night and endowed with amphibious capabilities. SOLEM dimensions are about 500×355×203 mm and its mass is 15 kg.

Figure 2.2 SOLEM (courtesy Foster Miller) robot [2]

Foster Miller company [3] produced a bomb disposal robot 「TALON」, Figure 2.3. TALON military robots are powerful, durable and lightweight tracked vehicles that are widely used for explosive ordnance disposal, reconnaissance, communications, hazmat, security, defense and rescue. They have all-weather, day/night and amphibious capabilities and can navigate virtually any terrain. TALON has the high payload capacity and its mass is 45 kg.

Figure 2.3 TALON (courtesy Foster Miller) robot [3]

J. Xiao、A. Sadegh、M. Elliott、A. Calle、A. Persad and H. M. Chiu [4] developed novel robots which can achieve quick motion on various wall surfaces and smooth wall-to-wall transitions, Figure 2.4. The adhesion mechanism is based on vortex attraction technique in that the interior air pressure is much lower than the ambient air pressure, and therefore a resultant attraction force is generated. DSP based control system is also used to enable the robot operating manually and semi-autonomously.

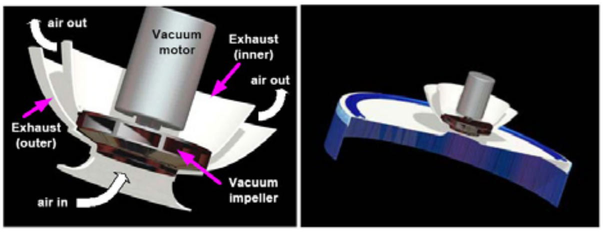


Figure 2.4 the vacuum chamber of robot with flexible bristle skirt seal [4]

H. Zhang、J. Zhan and G. Zong [5] proposed a new kind of cleaning robot named sky cleaner which is totally actuated by pneumatic cylinders and sucked to the glass wall with vacuum suckers, Figure 2.5. The robot can cross an obstacle safely and reliably when it moves from one column glass to another in the right-left direction.

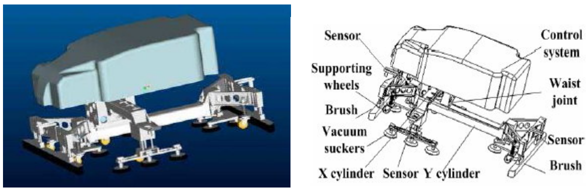


Figure 2.5 a sky cleaner robot [5]

F. Cepolina、R.C. Michelini、R.P. Razzoli and M. Zoppi [6] proposed a robot 「GECKO」 for cleaning vertical surfaces and ceilings, Figure 2.6. The sticking is guaranteed by suction cups which provide also a two directions mobility. An innovative suspension is used for both, assuring modulated pressure in the cups and their pressing/withdrawal relative to the wall.

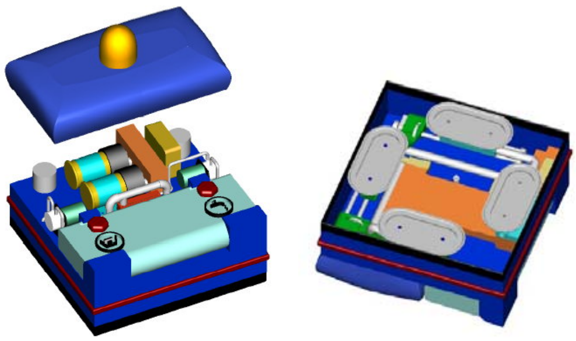


Figure 2.6 a view of Gecko with the cover disassembled [6]

M. A. Mino and R. Mukherjee [7] proposed two biped designs for miniature climbing robots, Figure 2.7. In the first design, one actuator provides steering and another two propel the robot in a cartwheel style gait. The cartwheel gait is quite effective but space required for the maneuver precludes certain applications. The second design uses under-actuation to provide two different forms of locomotion. It uses a crawling stride in confined environments and a faster pivoting gait in open environments.

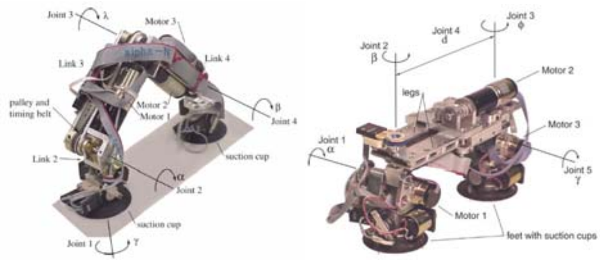


Figure 2.7 biped climbing robots [7]

Tokyo Institute of Technology and the Isikawajima-Harima Heavy Industries Company Limited [8] designed jointly a robot 「NINJA」 with legs, Figure 2.8. NINJA was settled to climb and move on different surfaces and with high payload. The robot has legs with a 3-dof parallel mechanism that allow high forces, a new mechanism for the ankles, a vacuum cup for high efficiency even when furrows or rough walls are encountered.

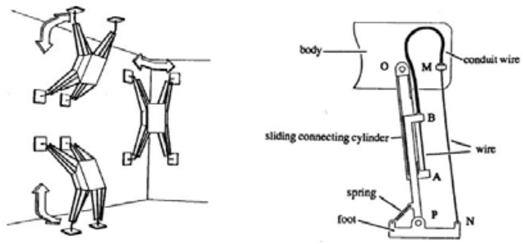


Figure 2.8 NINJA-1 robot [8]

III. Mechanical Design

The purpose of this project is to design and develop a bomb disposal robot for airplane. At first, design specifications are determined according to design requirements and the concept designs of the bomb disposal robots are proposed. Then primary parts of the robot are set detailed specifications and designed by the aid of the computer. In accordance with the completed CAD blueprints the prototype of the robot is manufactured. In the end many kinds of test for the robot prototype are performed to observe the locomotion.

A. *Design Specification*

The bomb disposal robot that this project develops will be used to search and collect information on the airplane surface and in the passenger compartment for a state of emergency. Therefore the robot must climb from the airplane side to the airplane top or any points to go on a risk task. So the robot must be mobile. Figure 3.1 shows the sizes chart of airplane Boeing 747. Figure 3.2 shows the section of a medium airplane with four seats in line.

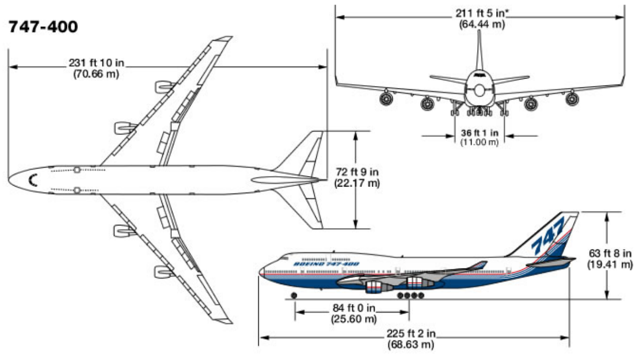


Figure 3.1 the sizes chart of airplane Boeing 747

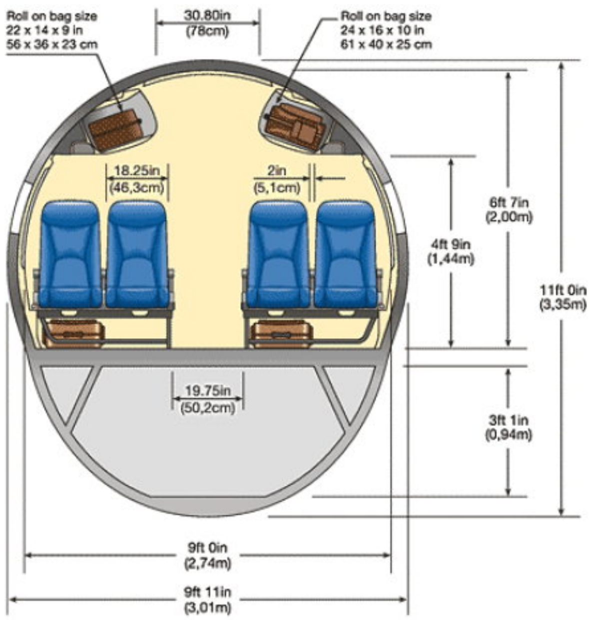


Figure 3.2 a typical cross-section of a plane [1]

In the first stage of this project, the purpose is the design and manufacturing of the mobile system in the bomb disposal robot. In order to make the robot walk in the passenger compartment, the weight of the chassis is designed to be smaller than the weight of the passage. In the aspect of reconnaissance, the robot is set to climb on the vertical and smooth surface, not on the curved surface of airplanes. And the robot must be small and light to promise the concealment and mobile as performing a task.

B. *Concept Design*

With the development of modern techniques, the movement modes of robots involve many types, including wheel, track, feet, combination, etc. So the environments and routes of the robot have to be determined before investigating the mechanism. And the concept designs of the movement mechanism will be brought out.

By the requirements, this project brings out two concept designs of bomb disposal robots.

The first design, bomb disposal robot, must carry out some different tasks as take away a suspicious box. A robotic system is composed of a mobile platform and a dexterous arm, Figure 3.3. Figure 3.4 shows two work conditions: under the seats and inside the hatboxes.

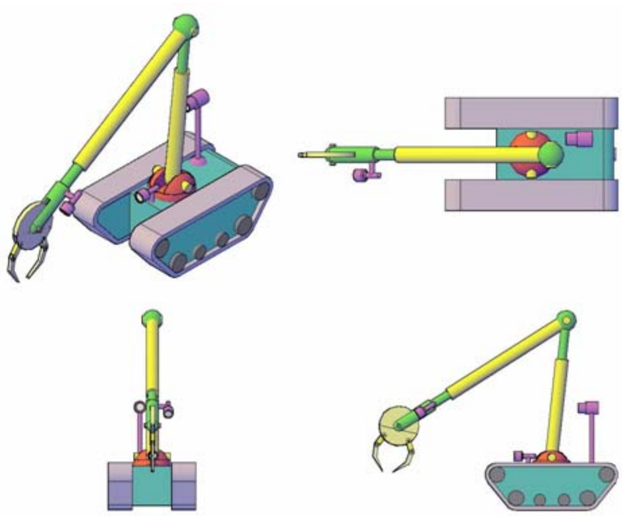


Figure 3.3 The first concept design: bomb disposal robot

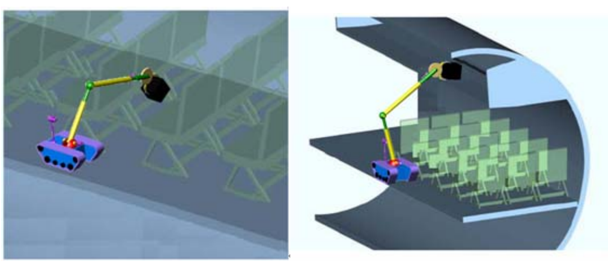


Figure 3.4 the robot work conditions

The second concept design, wall climbing robot, must perform remotely reconnaissance on the airplane plane for minimizing the danger and risks associated with the task. A robotic system is composed of a mobile platform managing transmission and an adhesion mechanism, Figure 3.5. The adhesion mechanism is to create a rotating column of air by a spinning rotor with some turbo vanes, and therefore a resultant attraction force is generated. Figure 3.6 shows the wall climbing robot moving on an incline.

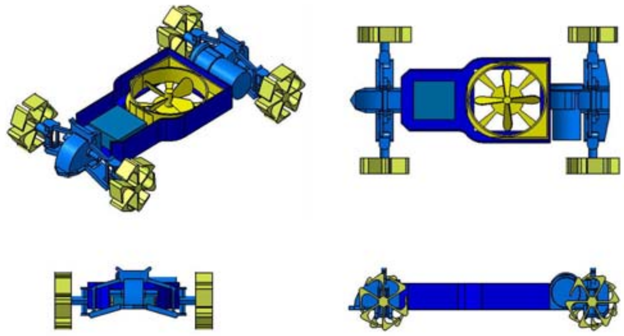


Figure 3.5 the second concept design: wall climbing robot

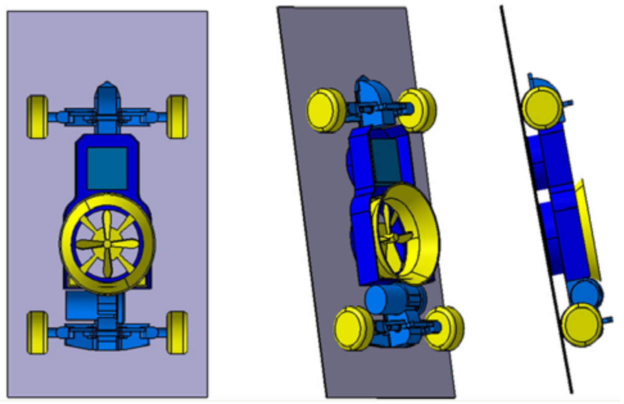


Figure 3.6 the wall climbing robot moving on an incline

C. Improved Design

For bomb disposal robot, the improved design of the mobile system, shown as Figure 3.7, is broken into three main components. The first component is the locomotion mechanism that is responsible for the planar motion on the surface the robot is adhering to. The other two major components are the adhesion mechanism and vacuum chamber seal. Combined together, they produce the most critical device that makes the robot “stick” to wall surfaces. Figure 3.8 shows the parts of the robot, including side frame, gear drive, exhaust, flow guide, gear box, wheel, etc. Figure 3.9 is the explosive view.

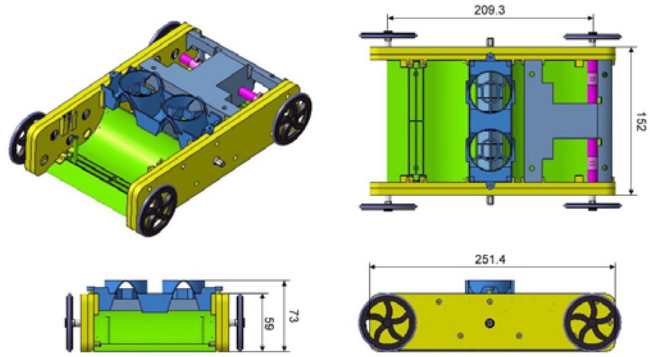


Figure 3.7 the improved design of the robot

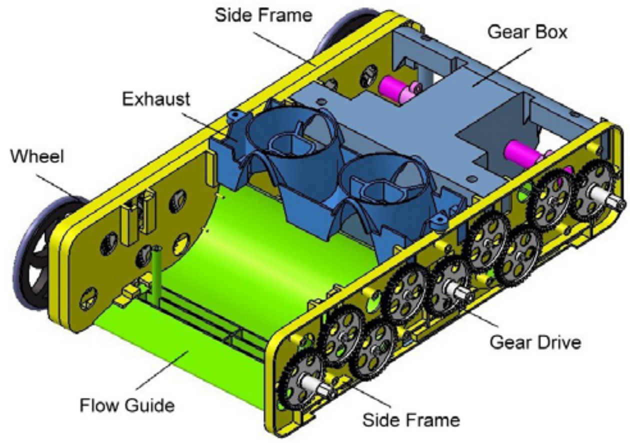


Figure 3.8 the parts of the robot

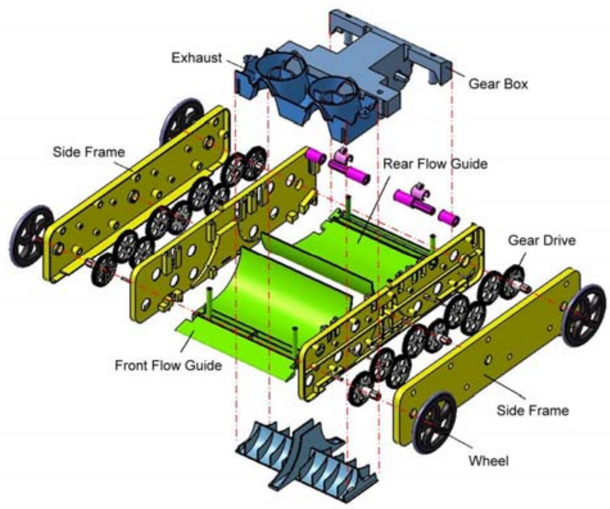


Figure 3.9 the explosive view of the robot

D. Locomotion Mechanism

For the locomotion mechanism, dual motors drive right and left gear mechanisms respectively to make the robot go forward, go back and turn. The robot moves straightly when dual motors running at the same time. And the robot turns around its center if one of the dual motors is drove.

The stability of the robot is required mainly in order to avoid strong vibration or overturn occurring when moving fast. Because of the high rotational speed of the power motors (15000 rpm) is unsuitable, the gear box is used to reduce the output rotational speed. The gear box is composed of 5 different pure gears. Figure 3.10 shows the arrangement of the gear train and individual tooth number. And the speed reduction ratio is

$$TV = VR_{AB} \times VR_{CD} \times VR_{EF} \times VR_{GH} = \left(-\frac{42}{8}\right)\times\left(-\frac{36}{14}\right)\times\left(-\frac{36}{14}\right)\times\left(-\frac{40}{12}\right) = 110.2$$

Therefore the output rotational speed is about 136 rpm.

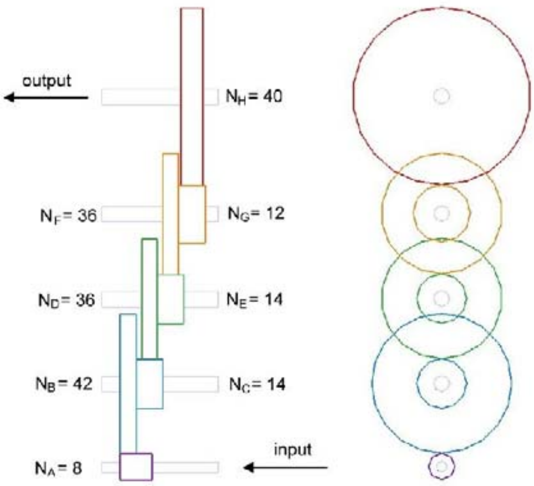


Figure 3.10 the arrangement of the gear train

Pure gears which have the same specifications, N=38 and m=0.868, are used as parts of the gear drive mechanism. Nine gears are assembled equally on right and left sides, shown as Figure 3.11. So wheels on both sides can run simultaneously.

E. Vacuum sucker

The vacuum sucker is composed of an exhaust and a vacuum chamber seal. The exhaust composing two axial fans is located at the center of the whole. The air would be drawn out along the direction of the fan axis, Figure 3.12. The shape of the chassis is designed curvy to guide the air flow smoothly. In order for most aerodynamic attraction devices to maintain that attraction force due to a pressure difference, the low pressure zone where the aerodynamic forces act need to be enclosed by a vacuum chamber. The interior air pressure is much lower than the ambient air pressure, and therefore a resultant attraction force is generated. This vacuum sucker allow the robot to travel on various smooth surfaces.

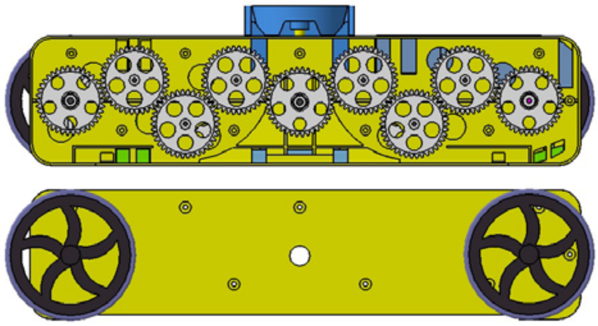


Figure 3.11 the arrangement of the gear drive mechanism

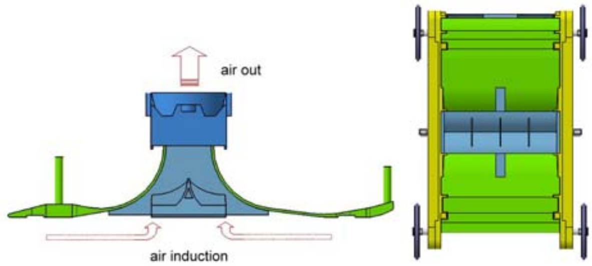


Figure 3.12 Vacuum suckers

F. Control system

Control system is one portion in whole project. In the system, climbing robot is controllable with rechargeable batteries, signal transmitters, control card and etc. All assemblages are integrated together. In this way, robot can be controlled through CCD camera, wireless transmitter and wireless receiver. The environment around robot will be detected and transmitted to the monitor through wireless mode. By the pictures on monitor, robot will get new orders from user. The advantages are without terrain restriction and far distance.

Whole system is integrated as Figure 3.13. The order from remote controller to command interpreter is translated to machine code, making DC servo motor work. Therefore, the fans start to attract the chamber and wheels are drove. Meanwhile, environment around robot is changing. The pictures caught by CCD camera are transmitted by wireless transmitter through wireless receiver to mobile surveillance which translating analog signals to digital signals. Then pictures are observed on the monitor.

In this project, making robot with vision is one of goals for sensing environment around it. Therefore, constructing whole system is convenient for improvement of future work.

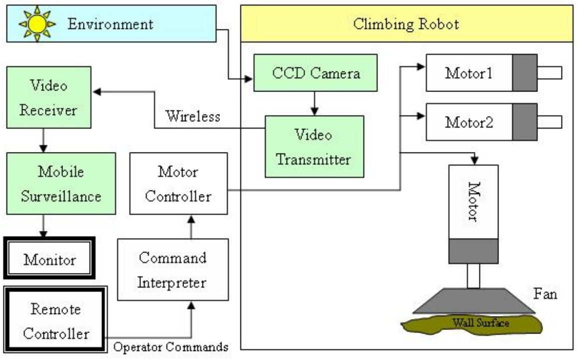


Figure 3.13 Control system constructions

G. *Remote Controller*

In order to control robot, the control system of the model car has been modified for moving forward and backward in the meantime. In sides, wheels of model car are driven by each motor. Each motor is controlled by each button. Because avoiding the time difference when controlling, add one button to improve.

When the buttons switch on, the signal is converted through the control chip and furthermore the frequency of 27 MHz is transmitted through the antenna. The effective range is 100m.

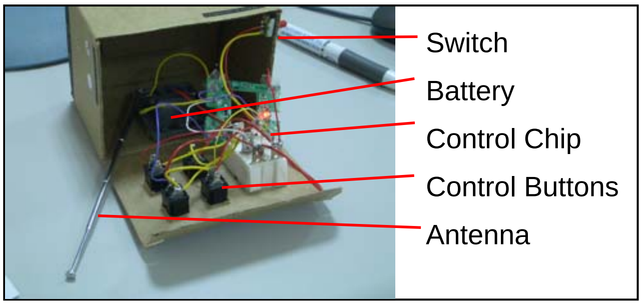


Figure 3.14 Internal construction of control box

H. *Detective system*

For constructing image processing system and selecting camera, the small and high-resolution camera is needed for image acquisition device. The following units are considered: Pinhole NTSC camera, CMOS camera, USB camera, wireless IP Network camera, and wireless CMOS camera. In spite of dimension and high resolution, the weight and effective range is considered as well. Therefore, the wire Pinhole camera with wireless transmission device is constructed in detective system. The image can be transmitted to monitor. Whole system shows as Figure 3.15.

High-resolution SHARP CCD is used for the wire Pinhole camera. It includes 300K pixel, 420 TV Lines horizontal resolution, and 1/3-inch CCD image sensor. Dimension is 30(L) ×30(W)×20(H) mm , and weight is 257g.

In order to transmit image to monitor and expand the transmission range, the camera is equipped with wireless transmission device. Therefore, the monitor can receive the image in a safety distant.

Wireless transmission device includes transmitter and receiver, transmit frequency: 2.4G Hz. 4 Channels.

Transmission range can be up to 2 km in the without any obstacles (such as buildings, walls and glasses etc.). Wire Pinhole camera connects with transmitter and image can be transmitted to the receiver. The receiver transmits the image signal to the computer. Due to the signal from receiver is analog signal, it need to be farther processed by PC. PC with Mobile Surveillance can receive and read image signal. Mobile Surveillance in accord with NTSC standard can retrieve 60 images per sec with software.

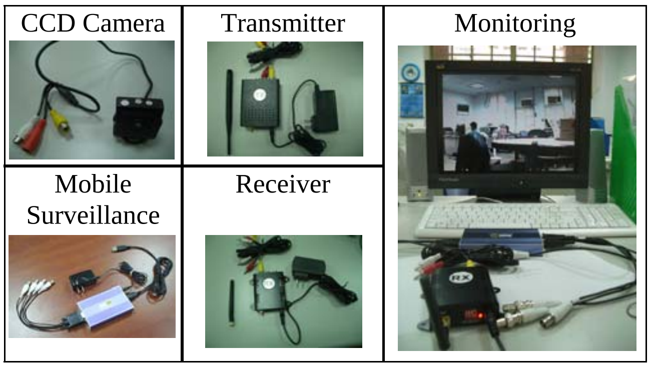
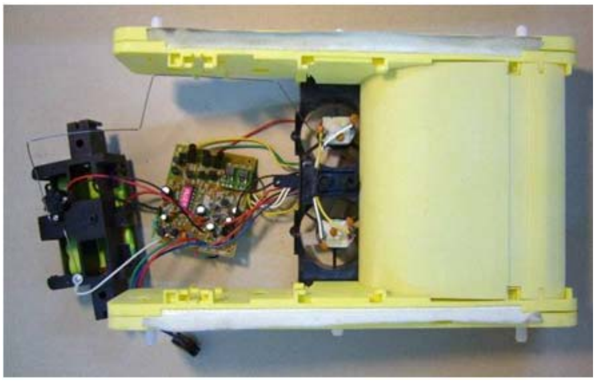


Figure 3.15 Assemblages of detective system

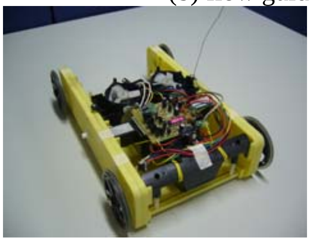
IV. Prototype Manufacturing

The manufacturing of the prototype is composed of four steps: gear assemblage, flow guides assemblage, components assemblage and packaging, shown as Figure 4.1.


(a) gear assemblage



(b) flow guides assemblage



(c) components assemblage

(d) packaging

Figure 4.1 the prototype of the robot

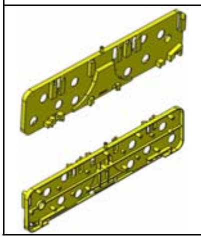
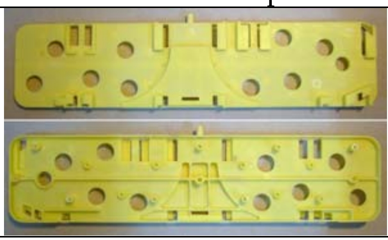
CAD model	Manufactured components
	

Figure 4.2 internal side frames

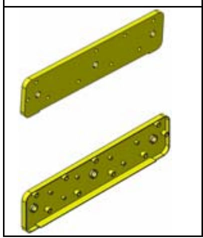
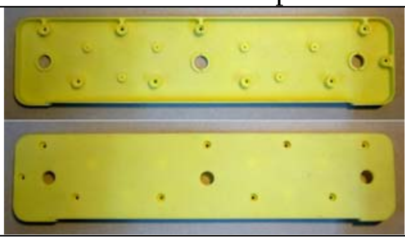
CAD model	Manufactured components
	

Figure 4.3 external side frames

The main parts are manufactured in accordance with completed CAD models, including internal side frames, external side frames and flow guides. Because of considerations of minimal weight and low purchase price, above parts are produced by CAD design models and CNC computer aided manufacturing, as Figure 4.2, Figure 4.3 and Figure 4.4.

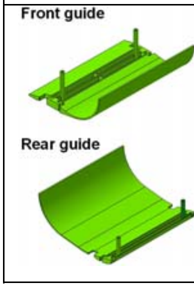
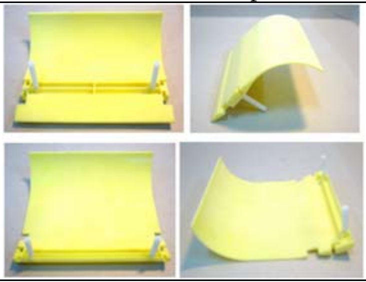
CAD model	Manufactured components
	

Figure 4.4 flow guides

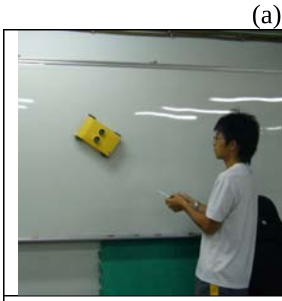
To make prototype manufacturing more efficient, some parts would be obtained from commercial products, including gears, fans, motors, etc. The rubber wheels are used to increase friction between the robot and the contact plane. Then all parts are packaged and the robot is drove by a 6V battery. For the prototype robot, dimensions are about 252×152 ×73 mm and its mass is 590g.

V. Prototype Test

The prototype of the robot has been successfully designed, manufactured and tested. Experiments were conducted to evaluate the design concepts, shown as Figure 5.1. The robot is able to move on ground with stable speed 27m/min and climb on various wall surfaces, such as white board, glass wall, concrete wall, marble wall, tile wall and airplane plane. The test results show that the robot performs well on ground and smooth walls and is able to stick on a ceiling.

	
Smooth floor	Airplane wing

(a) move test

	
white board	airplane plane

tile wall	ceiling

(b) climb test

Figure 5.1 the tests of the prototype

In this project, making robot with vision is one of goals for sensing environment around it. Therefore testing climbing ability of robot with whole control system (including detective system) is tried in the first year, as Figure 5.2. On ground, robot can sense clearly with many targets. But on walls, it's not obvious for moving distance with few targets. Besides, robot with whole system increases weight so that attractive force decreases. Although it's not huge different on ground, robot can't move smoothly on walls.

Inspection on ground	Inspection on wall

Figure 5.2 Tests of robot with detective system

VI. Conclusions

In the first year, this project proposes the mobile system of a bomb disposal robot for airplanes, including design, manufacturing and test. In the beginning, two different types of concept designs are proposed: bomb disposal robot and robot for both ground moving and wall climbing. Then an improved robot design is proposed further.

In the process of prototype manufacturing, the main parts are manufactured by CAM in accordance with completed CAD model. And some parts would be obtained from commercial products. The commercial small-scale camera module installed on the robot is used for collecting information.

The test results show that the robot performs well on ground and smooth walls and is able to be controlled remotely for reconnaissance.

This project not only completes the work item of the first year plane, but also performs the design of wall climbing and the assemblage of reconnaissance devices. And the results of the robot are good.

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適用於飛機上排爆機器人之設計與研發

(Design and Development of a Bomb Disposal Robot for Airplanes)

中文摘要

本計畫的目的為設計與研發適用於飛機上之排爆機器人。首先規劃排爆機器人於飛機內執行任務的程序，並評估一般市面上現有的排爆機器人，以訂定適用於飛機上排除爆裂物的機器人之規格。接下來提出與本計畫相關之數個機器人的概念設計；排爆機器人主要的零組件包括底盤、輪子、機械操控手臂、夾持裝置、傳動單元、電力單元、偵測單元及操作員控制單元等。並且在模擬飛機機內狀況之虛擬 3D 環境下,模擬爆裂物排除之操作過程。在操控單元方面，發展操作介面，並且將來自馬達、感測器和攝影機的訊號整合至操作介面中，使在飛機內及飛機外之有限空間下，機器人能夠被偵測與操控。最後製作一個機器人的初型，並測試機器人在機腔內之行走能力及在飛機外之爬行能力。本年之計畫是三年計畫的第一年，第一年之任務是進行機器人的概念設計，並且做出機器人的移動系統，包括底盤、輪子、傳動機構和移動控制單元等。

關鍵字：排爆機器人、移動機器人、爬牆機器人、飛航安全任務

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