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# Application of UAV in maritime search and rescue activities

Xiaojie Wang

**WORLD MARITIME UNIVERSITY**

Dalian, China

# APPLICATION OF UAV IN MARITIME SEARCH AND RESCUE ACTIVITIES

By

**WANG XIAOJIE**

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## DECLARATION

I certify that all the materials in this research paper that are not my own work have been identified, and that no material is included for which a degree has previously been conferred on me.

The contents of this research paper reflect my own personal views, and are not necessarily endorsed by the University.

(Signature):           Wang Xiaojie

(Date):               July 10, 2014

**Supervised by:**

Dr. Zhu Yuzhu

Professor

Dalian Maritime University

Assessor:

Co-assessor:

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**ABSTRACT**

Title of Research Paper:          **Application of UAV in Maritime Search and Rescue Activities**

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The continuous development of global economy offers new opportunities for industries of marine fishing, ocean shipping, offshore oil and gas, ocean engineering construction, coastal tourism and so on. Meanwhile, the growing number of ships increases the likelihood of marine accidents. As the last line of defense at sea, maritime search and rescue system plays an important role in protecting people and property. Marine safety is the eternal topic on increasing the possibility of finding targets and the success rate of rescue.

Search and rescue operation is complex since the systematic process contains two parts: the first step is search, the second one is rescue. In order to send targets to a safety zone successfully, both of these factors are indispensable. Compared with the rescue part, the searching process is the foundation of the whole operation. Once the target is found, the battle is half done. If the target can not be found, the rescue work could not start.

As important developing platforms, UAVs can be used widely in maritime search and rescue activities. With the rapid development of computer and communication technology, the performance of UAVs has been improved. Their application field expands fast. At the same time, with the development and application of remote sensing technology, the applied range of UAVs keeps broading. They have become the most important supplement of satellite and aircraft remote sensing.

In this research paper, the composition and working procedures of UAV and their

remote sensing system are described, and the benefits of UAVs are analyzed. Synchronously, this research paper analyzes the feasibility of the UAVs in search and rescue activities, and forecasts the UAVs' application prospect.

**Keywords: UAVs, Remote Sensing System, Maritime Search and Rescue Activities, Application**

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# LIST OF ABBREVIATIONS

AIS        Automatic Identification System

ASI        Air Speed Indicator

DARPA      Defense Advanced Research Projects Agency

DARO       Defense Airborne Reconnaissance Office

DoD        Department of Defense of the United States

ECIDS       Electronic Chart Display System

EOTS       Electro Optical Targeting System

FLIR       Forward Looking Infrared

GPS        Global Position System

IMU        Inertial Measurement Unit

MSA        Maritime Safety Administration

NASA       National Aeronautics and Space Administration

SWOT      Strength Weakness Opportunity Threats

TTL        Transistor-Transistor Logic

UAV        Unmanned Aerial Vehicle

USA        the United States of America

USCG       United States Coast Guard

VTOL       Vertical Take-off and Landing

VHF        Very High Frequency

**Chapter 1 Introduction**


## 1.1 Backgrounds and significance

The world's development is to an ever increasing extent depending on the transportation of persons and goods. Being as a great and powerful shipping country, China enjoys 18,000 km of coastline, 120,000 km of inland waterway as well as abundant marine resources. By the end of 2009, China has 20 ports with 100 million tons and 8 of them are among the top ten in the world. There are 1,769,000 merchant ships in China for transporting 93% of the foreign goods, 95% of imported crude oil and 95% of imported iron ore. These data shows that the waterborne economy takes quite a large proportion in Chinese national economy with the rapid development of waterway transportation.

Due to the wide application of modern science and technology, the ship construction level, the reliability of marine equipments as well as the scientificity of maritime communications have been improved. As the result, there is a corresponding improvement in navigation safety conditions. But apart from factors of ships themselves, marine traffic safety is influenced by many factors such as natural condition, navigation condition, management of ships and ports, shipmen and so on. It is difficult to avoid marine accidents completely. According to relevant data, the percentage of major accidents in all marine accidents raised from 48.3% in 1995 to 76.1% in 2000, the number of persons and ships in distress at sea has increased by

about 2.6 times and 1.3 times respectively from 2000 to 2005. These data show an upward trend in the number of marine accidents. It is very important to enhance our ability of maritime search and rescue and the respond to emergencies in order to protect the life and property of people.

Marine accident is an accident which happens suddenly in bad weather. The key to success in search and rescue work is to find out the targets at the first time, to collect relevant information in a short time, to make a reasonable and effective rescue plan and set out the rescue resources as soon as possible. In recent years, China has increasingly stepped up the investments in constructing new model of rescue vessel and maritime rescue helicopter, and has greatly enhanced its rescue ability. China Rescue and Salvage of Ministry of Transport of the People's Republic of China website states that:

> By the end of 2010, this force had:
>
> (1) Rescued and salvaged 3,942 distressed vessels, 833 of which are foreign ships;
>
> (2) Removed 1,740 ship wrecks, among which 98 are foreign ones;
>
> (3) Saved 55,266 people in distress at sea, with 11,641 of them are foreigners;
>
> (4) Recoverd 61,990 million RMB (9,537 million dollars) property since the year of 2002.

Even so, there are still some shortcomings in this area. Sometimes rescue members only focus on the rescue work whereas overlook the earlier stage of searching. What's more, some rescue equipments have their inherent disadvantages. Rescue vessels have the disadvantages of slow response, short visual range. Rescue helicopters have the advantage of speed and vision, they can easily obtain the whole condition and understand disaster scene. They also have the advantages over rescue vessels in terms of searching special targets and pollution prevention monitoring. But

they can not carry out the rescue tasks at night as well as in the bad weather like typhoon because these environmental conditions are dangerous for pilots in the planes. Being one kind of aircrafts, unmanned aerial vehicles (UAVs) have all the advantage of a plane to overcome the above deficiencies. With the advantages of flexible, convenient and efficient, UAVs can fly to the incident area with a high speed and start the search working at anytime. Also, they have the ability to work all the time, taking images which are useful for the rescue work. With these advantages, UAVs have the chance to be the new professional equipments for maritime search and rescue activities.

## 1.2 Development and current situation of UAVs both domestic and abroad

As stated in the Unmanned Aerial Vehicles Roadmap 2002-2027[6] (2002, p. iii), there is a long and continuous history of involvement with UAVs. Stretching back to 1917, UAVs are mainly used as target for military purposes. With the improvement of technology, today's UAVs are more sophisticated and capable than ever. Not only used for military, UAVs have expanded into civil areas. Since the 1980s, with the rapid development of computer communication technology, many kinds of sensors with the features of digital, light weight, small size and high precision have appeared. As the result, there is a rapid expansion in terms of UAVs' scope and application. The endurance extends to dozens of hours from about one hour, the weight of payload increases from several kilograms to hundreds of kilograms. These changes have created favorable conditions for UAVs with multipurpose.

At present, UAVs are hot applications in the field of military. Many countries put lots of work on the research and application of UAVs. Figure 1.1 shows the growth trend of investment for UAVs in the United States of America (U.S.A.). As shows in the chart, the Department of Defense of the United States (DoD) annual funding for UAVs has increased dramatically from 106 million in 1988 to 3,460 million in 2010.

Even though the funding is for military purposes, it is also meaningful for UAVs changes from military purposes into civil purpose.
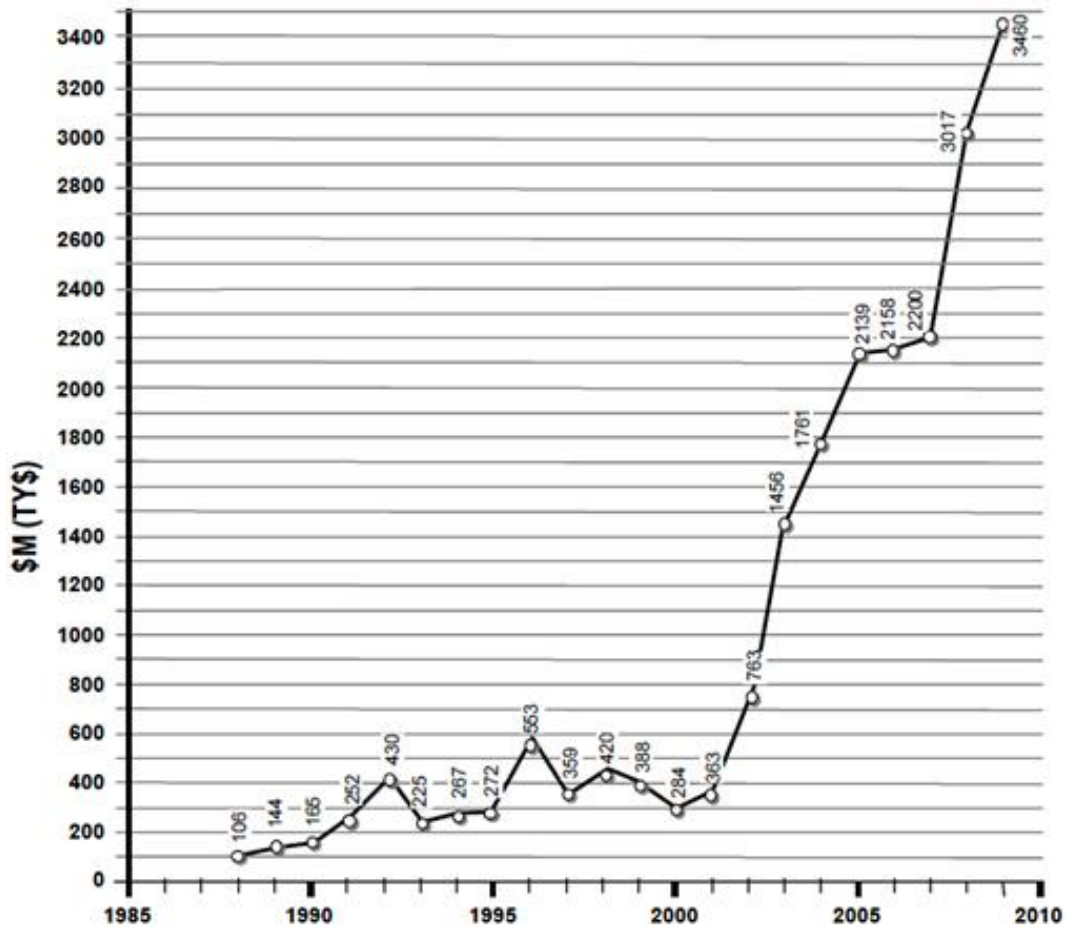


Figure 1.1 - DoD Annual funding profile for UAVs.

Source: Office of the Secretary of Defense (2002). *Unmanned aerial vehicles roadmap 2002-2007*. Washington: Author.

Represented by the U.S.A., many developed countries are using the latest UAVs in every field in daily life, such as in weather field, business field, geography field and other civilian areas. In Europe, UAVs are widely used in earth observation, coastguard and telcoms.
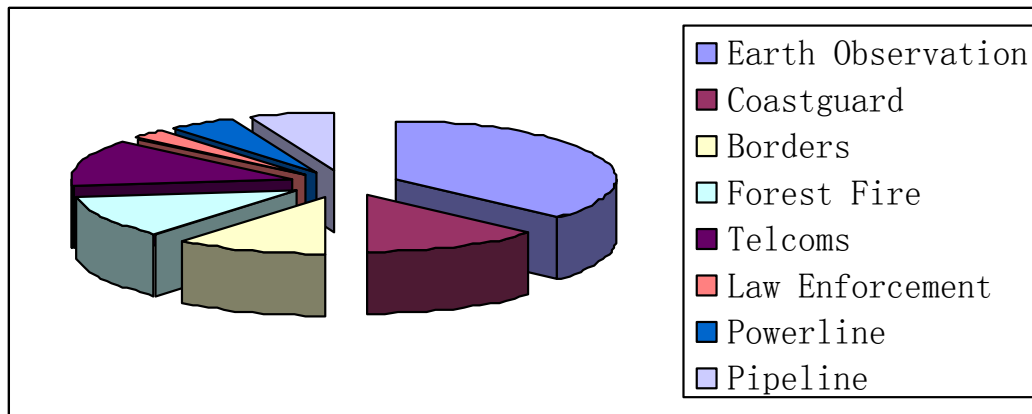
Figure 1.2 – Estimated European UAV market.

Source: Liu, Z. (2012). *The Research of applications and industrial design in police UAV.* Unpublished master's research paper, Donghua University, Shanghai, China.

China has worked in the research and development of UAV remote sensing monitoring technology for more than 10 years. Chinese Research Institute of Surveying and Mapping invented UAVRS2Ⅰ UAV remote sensing monitoring system which focused on remote control. In its research on 2003, it upgraded the old system, the methods of unmanned remote control, semi-autonomous control as well as autonomous control are implemented in its UAVRS2Ⅱ system. Its new UAV with the weight of 50 kg has the ability to take-off with the help of cars.

On August 8, 2005, the UAV, which is made by Peking University and Aviation Industry Corporation of Chian, finished its first flight successfully at Anshun Huangguoshu Airport. In this UAV, the advanced high resolution digital camera system made by The Institute of Remote Sensing and Digital Earth of China was used.

In 2006, Qingdao Marine Engineering Prospecting and Design Institute developed the TJ21 which was the first UAV with two engines. At the same time, the first UAV

remote sensing system for civil use was developed, too. It can be used in the maritime environment.

## 1.3 Text organization

This paper gives a brief introduction of UAVs as well as the UAV's remote sensing system and analyzes the feasibility of UAVs in maritime search and rescue activities. Also, it gives advices about the plan of using UAVs in maritime search and rescue activities.

(1) Brief introduction of UAVs and UAVs' remote sensing system including the concept, components and working principles.

(2) Strength Weakness Opportunity Threats (SWOT) Analysis for UAVs in maritime search and rescue activities.

(3) Cases of the application about UAV using for civil purpose in China and aboard.

(4) Application targets of UAV in maritime search and rescue activities.

(5) Design scheme of UAVs and their remote sensing system in terms of the working process, some essential performance, the arrangement of the whole system and the storage of UAVs.

**Chapter 2 Brief introductions of UAVs and their remote sensing system**

## 2.1 Overview of UAVs

### 2.1.1 Concept of UAV

Commonly known as drones, UAVs are aircrafts without pilots aboard. As stated in the Unmanned Aerial Vehicles Roadmap 2002-2027[6] (2002, p. 2), the definition of a UAV is "a powered, aerial vehicle that does not carry a human operator, uses aerodynamic forces to provide vehicle lift, can fly autonomously or be piloted remotely, can be expendable or recoverable, and can carry a lethal or non-lethal payload". Their flights are controlled by onboard computers or pilots on the ground. UAVs do not have cockpits inside but they usually equipped with some special devices such as high-definition cameras, differential Global Position System (GPS), Automatic Identification System (AIS), electronic autopilot, program control unit and so on for military and special operation applications. For UAVs, they do not need aviators, but controllers. Workers on the ground, on rescue vessels or in the remote control station can quickly and accurately detect, locate, identify, track, designate targets by UAV's baseline payload of radar, Electronic Chart Display System (ECDIS) and a laser range finder–designator. Under the wireless remote control, UAVs can take off in the same way as a conventional plane or use booster rocket to launch. Besides, they can start their flights by carried by other planes. When talking about the kinds of recovery, UAVs can land automatically like an airplane, or go back by using parachute or block. They can be used repeatedly. They are widely used in the

fields of maritime search, aerial reconnaissance, electronic interference and so on.

## 2.1.2 Types of UAVs

According to the endurance and the length of flight, UAVs can mainly be classified into four kinds: long enduration UAVs, medium range UAVs, short range UAVs and very short range UAVs (Wang, 2010, 115).

### (1) Long enduration UAVs

They are high-altitude drones with the feature of long flight. They can fly day and night with a fight time of 12 hours at least.

For instance, Xianglong is a high-altitude long-endurance UAV in China with a wingspan of 24.86 m, a takeoff weight of 6,800 kg, a payload capacity of 600 kg, a speed of 700 km/h and a endurance of 10 hours.

### (2) Medium range UAVs

With the action radius of 700-1,000 km, medium range UAVs can conduct surveillance by using infrared ray and cameras and transfer images and videos in real-time. They have two launching modes, one is air delivery, and the other is ground launch. For the task of recovery, medium range UAVs can go back into the ground by parachute, or be received by the large aircraft in the air.

Designed as an unmanned platform for battle reconnaissance, data relay and electronic warfare, CH-3 is a Chinese medium range UAV which can be configured with different payloads. It can fly up to 5,000 m and remain airborne for more than 12 hours.

**(3) Short-range UAVs**

Short-range UAVs are unmanned aircrafts which operate in the 150-350 km radius. The majority are mini UAV with the fuselage of 3-5 m and a weight of 200 kg or less. They can furnish with television cameras, Forward Looking Infrared (FLIR) system, infrared scanner as well as laser range-finder. Their launch and recovery methods are almost the same as the medium range UAVs.

**(4) Very short-range UAVs**

These UAVs are micro UAVs which can fly up to a point 10 km away with a weight less than 10 kg. They have the advantages of simple structure and convenient to carry. They can carry payloads like optical camera and infrared camera.

From the perspective of structure and airfoil, UVAs can be grouped into two categories: fixed-wing UAVs and rotary-wing UAVs (Wang, 2010, 115).

Fixed-wing UAVs are usually deployed for military in various countries. They have the traits of high security and high mobility. Their launch methods are classified into land-based and carrier-based.

Rotary-wing UAVs include subdivisions like traditional type helicopter, tilt rotor and coaxial rotor aircraft. These UAVs with simple structure and low cost have the abilities of vertical take-off and landing and free hovering in the air. They completely solve the problems relevant to recovery on carriers. They are featured by high flexibility for flying in all kinds of routes of flight at any speed. Besides, they are characterized by small flutter, low noise and high reliability.

**2.2 Overview of UAV remote sensing system**

**2.2.1 Concept of UAV remote sensing system**

UAV remote sensing system is a system designed for low-altitude surveillance and photo taking by using UAVs as platforms. Dedicated to obtain low-level remote sensing data of high resolution in low-altitude, it combines with high-technology about UAVs, remote sensing and GPS guidance. For its technology advantages of low cost, miniaturization, customization, UVA remote sensing system becomes an effective complement for airborne remote sensing technical system to get remote sensing data.

**2.2.2 Components of UAV remote sensing system**

Equipments of UAV remote sensing system include UAV platforms, a navigation and flight management system, a remote sensing sensor and its control system, a communication system and a ground recording and monitoring system.

Figure 2.1 – Structure of UAV remote sensing system.

Source: Lang, C. (2010). *Application of Unmanned Aerail Vehicle (UAV) in the dynamic monitoring of regional land use.* Unpublished master's research paper, Xi'an University of Technology, Xi'an, China

**(1) Navigation and flight management system**

Major components of navigation and flight management system include attitude gyroscope, atmospheric pressure altimeter, magnetic heading sensor, GPS navigation and positioning device, flight control computer, actuator, power management system and so on. With the purpose of navigation and position, this system is mainly used to guide the aircraft flying at predetermined route, to control UAVs' flight attitude and flight path, to control the tasks system to complete the plan of aerial photography and to help the aircrafts to land safely.

**(2) Remote sensing sensor and its control system**

For capturing remote sensing images, the airborne remote sensing device and its control system are the main devices of UAV remote sensing system. This suit of armor includes airborne remote sensing facilities, the stabilized platform, the mission equipment control system etc.
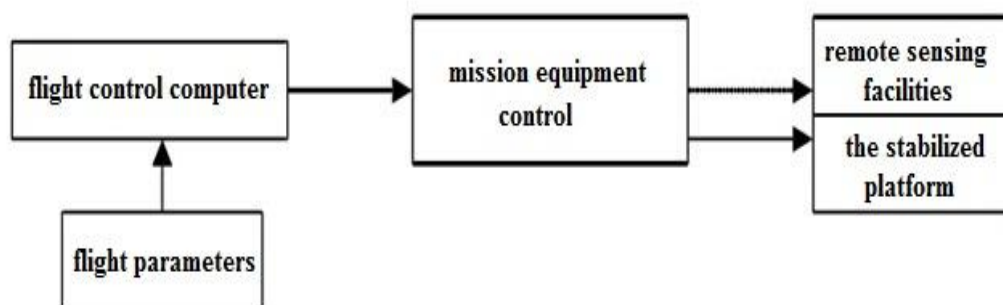


Figure 2.2 – Remote sensing facilities and the control system.

Source: Bing, Y. Y. (2008). *UAV remote sensing in a mine iron resources monitoring.* Unpublished master's research paper, Liaoning Technical University, Fuxin, China

**(3) Communication system**

In this system, a data transceiver and a Transistor-Transistor Logic (TTL) communication port of navigation processor are connected with RS-232 port of data radio by signal connectors, while RS-232 port of the data transceiver in the ground station is linked with the same port of laptops in the same way. By this means, UAVs send their real time flight data which are in the form of the curve to the ground station by using digital radio and receive instructions from the ground station. Similarly, the ground station sends telecontrol messages to UAVs to set up or change the flight route, flight altitude and course in this way.

**(4) Ground recording and monitoring system**

Based on the information sent back from remote sensing system and its control system, the ground recording and monitoring system which consists of laptops, ground control softwares, telecommunication cables and data radio shows the UAVs' location, flight line and flight path on an electronic map which has the ability of moving and zooming. During a flight, this system can monitor the plane's flight, modify the task and flight parameters in real time. Through ground control station software, controllers can input destinations directly by using a keyboard or a mouse, search and modify the old task files, as well as point out the destinations on the electronic map in order to enhanced performance of real-time control.

**2.3 Operating principles of UAVs and their remote sensing system**

**(1) Data acquisition**

In order to ensure UAVs and their system working around the clock, it is very important to reliably handle and send down the high resolution satellite data and information from the other sensors. Under the different circumstances, satellite transmission, stadia microwave transmission and out-of-sight transmission can be

used to send the data. In order to meet the requirement of processing synchronously and submiting the result in a short time, data should be coded and compressed before the transmission. The process of data acquisition is shown in Figure 2.3.
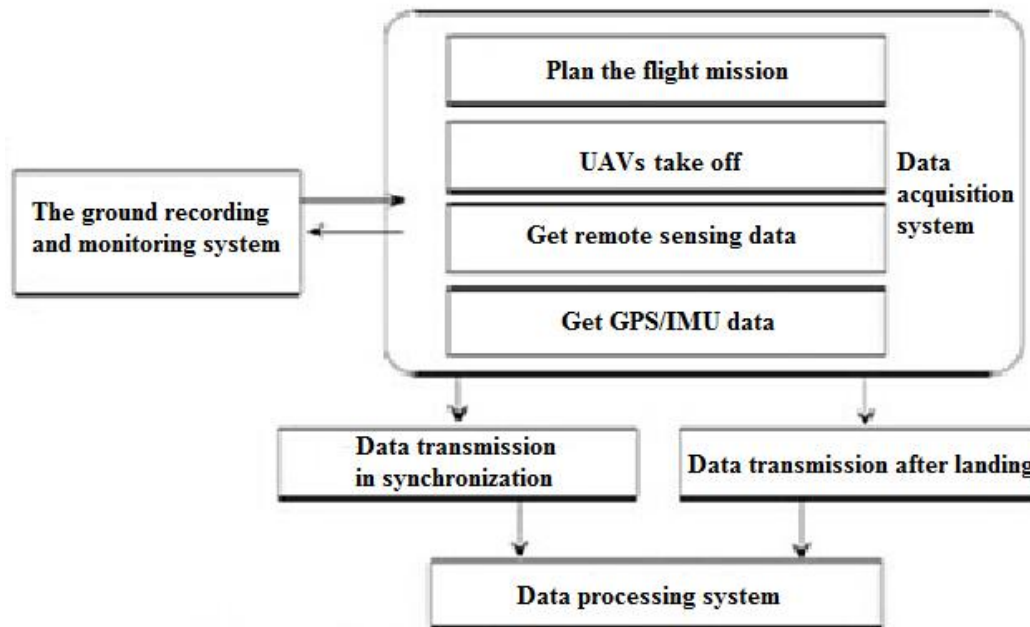


Figure 2.3 – The flow chart of remote sensing data acquisition.

Source: Compiled by the author on June, 6, 2014.

**(2) Data processing**

The data processing of remote sensing images covers the processes of geometrical rectification, mosaicing, and special analysis. For this process, nonlinear geometry distortion, image rotation and projection distortion are the primary obstacles. Nonlinear geometry distortion is a general problem in digital camera design because of arts and crafts of optical lens. Image rotation is a natural phenomena dues to the aircraft's attitude variation. In the complicated data disposal course, projection deformation is ineluctability to take place. The geometric rectification phase is a complicated process to solve these imaging problems.

Usually, UAVs carry miniature digital cameras or scanners to take pictures and film

the event. Affected by the air flow, the aircraft makes great tilt angles. As the result, image rotation and projection deformation of each images are different. Every picture needs to be corrected. This problem increases the difficulty of data processing. In general, navigation data and attitude data are used to check the image quality and flying quality rapidly. The lidar data and microwave remote sensing data can use GPS data and Inertial Measurement Unit (IMU) data to calculate point clouds and amend the geometry distorted. As the consequence, the corresponding digital elevation model and digital orthophoto map are available.
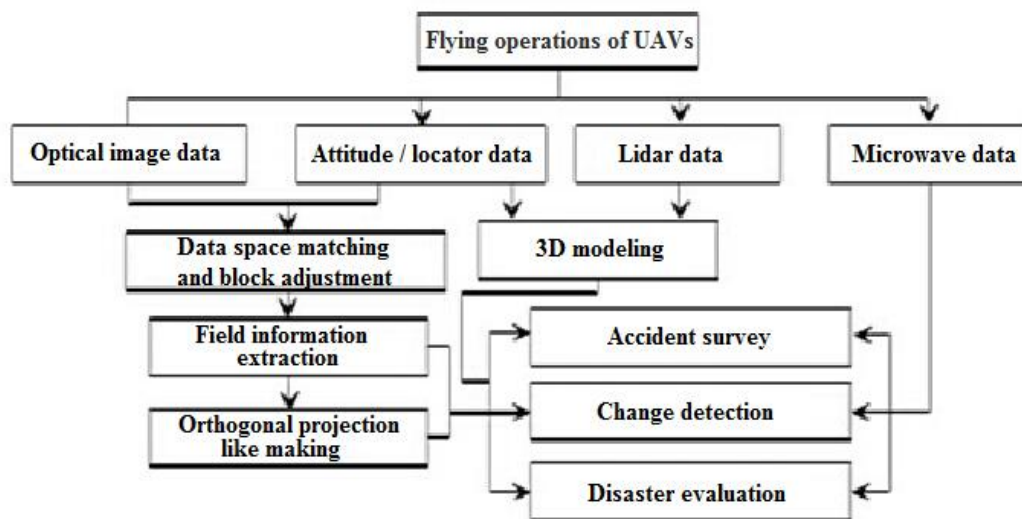


Figure 2.4 – The flow chart of remote sensing data processing.

Source: Compiled by the author on June, 6, 2014.

# Chapter 3 Feasibility analysis of application of UAVs in maritime rescue activities (eapecially in Nanhai area)

Feasibility of application of UAVs and their remote sensing system in maritime rescue activities is evaluated from two aspects. One is whether the developing level of UAVs and the remote sensing system can be apply to the special maritime environment and meet the demands from search and rescue service. The other one is whether UAVs and the system have advantages in maritime rescue activities.

## 3.1 Current situation of the development of UAVs and remote sensing system

UAV remote sensing technology is an integrated system which involves in a variety of fields such as aviation, microelectronics, automation control, computer communication, navigation positioning etc. At present, most of the key technologies are still controlled in military. In terms of research and application of UAVs, the developed countries such as U.S.A. have taken the forefront in the world. A well-known product is a high-altitude and long-endurance Global Hawk which has its origins in the 1994 High-Altitude Endurance Unmanned Aerial Vehicle Advanced Concept Technology Demonstrator program initiated by the Defense Advanced Research Projects Agency (DARPA) and Defense Airborne Reconnaissance Office (DARO). Based on the RQ-4 Global Hawk, Europe produced its first high-altitude, long-endurance, signals intelligence UAV called EURO HAWK. In the current situation, it is a general trend to develop the UAV system for civil and commercial use. The growing need coming from marine safety, marine scientific research as well

as environmental monitoring and protection will be a further acceleration of this momentum.

In China, the research of UAVs and the remote sensing system has a history of more than 40 years. Since the first Chinese UAV Chang Kong-1 made a successful maiden flight On December 6, 1966, more UAVs such as Chang Hong which is a high-altitude, high-speed unmanned drone as well as T-6 which is a universal UAV etc. have developed. With the constant widening application of UAVs, China has made progress in terms of the development of the aircraft itself, the flight control system which is suitable for the aerial remote sensing and the UAV aerial remote sensing system. In the civilian field, there are several research institutions and enterprises, like Chinese Research Institute of Surveying and Mapping, China University of Geosciences and Beijing University, have put efforts into technology research about civil remote sensing based on UAVs and generate a series of remote sensing system for certain mini-UAVs. In addition, China has successfully launched seven orbiters for Beidou navigation system. The successful launch of satellites marks the favorable conditions for civil applications and development to the UAVs.

There are more than 300 kinds of UAVs with different property indexes for various purposes in the world by far. The fixed-wing UAV has a fast speed and large service radius, but it has high requirements for the landing zone because it can not take off and land vertically. Take these factors into consideration, the fixed-wing UAVs are appropriate for routine monitoring in terms of mineral resource, forestry and marine environment. For the rotary-wing UAV, it can easily take off and land in narrow space (like ship deck) and hover over the special targets for a long time. But it has drawbacks of low speed and small range. It is more suitable for dealing with unexpected incidents like maritime search and rescue as well as the surveillance of oil spill.

**3.2 SWOT analysis of UAVs in maritime search and rescue industry**

A SWOT analysis is a method used to evaluate the strengths, weaknesses, opportunities, and threats involved in a project or in a business venture. It can be carried out for a product, place, industry or person. Here it can identify the internal and external factors that are favorable and unfavorable to analyze whether UAVs are suitable for maritime search and rescue activities.

**3.2.1 Strengths of UAVs in maritime search and rescue activities**

As new equipments for search and rescue at sea, UAVs have the ability to fly over the obstacles on the ground. Compared with the army and modern weaponry by land and sea, UAVs can gather comprehensive information in a shorter time. Also, they have their own unique advantages over manned aircrafts and satellite platforms.

**(1) UAVs have high mobility but low requirements for ground support**
The accident at sea is a sudden event without omen. It needs rapid response from search and rescue department. The maritime rescue teams should get the picture clear in a very short time in order to handle the emergency rescue. UAVs have low requirements of environmental condition during take-off and landing as well as the maintenance supply because they do not need a specialized runway and ground maintenance. They have the ability to take-off and withdraw on a relatively small site, ships or oil platform. Because of the characteristics of small volume, light weight, convenient to transport, low demands on take-off and landing etc., UAVs can be sent to the site of the accident for rapid response to emergencies.

**(2) UAVs can fly for a long time and carry out the task sequentially**
First of all, UAVs do not have problems about pilot fatigue. They have the ability to

execute tasks continuously after being properly maintained and repaired. The time they stay at the air only affected by their own performance indexes. Compared with satellite remote sensing, UAVs' system breaks the limits of revisit period and response time. They are particularly well-suited for searching in solution spaces for a long time at the scene of the accident because of their characteristics of high efficiency.

In the second place, UAVs can be controlled to fly at a low altitude under the cloud. As is known to all, it is quite normal that optical remote sensing and aerial photography can not get pictures when they are blocked by clouds. UAVs can remedy these fatal flaws by their low-altitude flight and increase the utilization of images. Designed for multitasking, UAVs can carry different modules and finish the corresponding task according to the actual needs. With the combination of airborne radar, high-performance photoelectric or infrared sensor and multispectral or hyperspectral scanner, UAVs can achieve the goal of all-weather surveillance with high resolution.

**(3) UAVs can be designed in a task-focused way with strong purposiveness**
Because there is no pilot in the aircraft, when designing the UAVs in terms of safety factor, flight time, structure and so on, physical and psychological factors can be ignored. In other words, UAVs have the ability to fly for a long time according to task demand. For example, the famous UAV Global Hawk has the endurance of 41 hours. With the help of tanker aircraft, its endurance can extend to 160 hours. But in contrast, the EC225 helicopter which is a manned aircraft using in Donghai, Beihai and Nanhai Rescue Flying Service, only can fly for no more than 4.26 hours.

**(4) The safety risk of UAVs is very low**

The advantages offered by UAVs are numerous, most notably in the dull, the dirty, and the dangerous mission areas. UAVs can get to the areas that manned aircrafts can not get to. The safety risk reduces significantly. Even there is an air crash, it will not lead to the loss of human life because there is no man in the drone.

**(5) The cost of UAVs is much lower than the planes and rescue vessels in use currently**

In the first place, UAVs have the advantages of simple structure and small size, their development costs and erection costs are much lower than manned aircrafts which have the same function and rescue vessels. For example, the building cost of Nanhaijiu 101 which is one of the biggest rescue vessels in China is 260,000,000 yuan. However, the FQM-151 Pointer which is a very small hand-launched mini-UAV made by U.S.A. only costs 5,000 dollars (about 31,111 yuan today). The CL-227 Sentinel which is a remote-controlled UAV made by Canada costs 45,000 dollars (about 279,999 yuan today). There is a big gap in terms of building cost between rescue vessel and UAV. What's more, UAVs can be made from old airplanes. In this way, the production cost of UAVs is reduced greatly.

In the second place, UAVs with low weight use less oil than the classical airplanes and rescue ships, their running cost are greatly reduced.

Based on the different characteristics (including speed, service life) they have, it is supposed that, a big-size rescue vessel need 750 hours/year to complete the rescue task in a certain area and the time that aircraft needs is 200 hours/year. Also, we suppose that the service life of a ship is 25 years and the life for aircraft is 20 years. According to these basic data, we make the comprehensive cost and expenses comparison between aircrafts and watercraft which is shown in table 3.1.

Table 3.1 – The general cost and expenses comparison between the watercraft and aircraft.

| Index | Equipment | Large ship | Medium ship | Medium helicopter | Fixed-wing aircraft |
|---|---|---|---|---|---|
| Initial investment/ yuan | | 160,000,000 | 16,000,000 | 80,000,000 | 45,000,000 |
| Loiter time of one year /hour | | 750 | 750 | 200 | 200 |
| Loiter miles of one year /n mile | | 16,000 | 16,000 | 25,000 | 28,000 |
| General cost for one year / yuan | | 25,000,000 | 4,000,000 | 7,200,000 | 4,200,000 |
| General cost for each nautical mile / yuan | | 1563 | 250 | 288 | 150 |

Source: Compiled by the author on June, 6, 2014.

After a preliminary calculation it is found that, in the case of the same task, the comprehensive cost of medium helicopter and fix-wing plane is 29% and 17% of the cost of large ship respectively. In the view of the cost for each nautical mile, medium helicopter is 18% of rescue vessel and fixed-wing plane is 10% of the watercraft. In conclusion, aircraft has better value in economy than watercraft.

In the third place, there are differences between UAVs and ordinary planes in terms of operation training. For manned airplanes, pilots have to fly to the air, sitting in the cabin. It is a real flight, it costs a large amount of money. But for UAVs, operators just sit in the virtual cockpit and use the keyboard and computers for training. What's more, an operator for UAVs can control several planes at the same time, but the pilot for ordinary planes can not control two or more airplanes each time. As the result, there is fewer training costs for UAVs than for manned planes.

Last but not least, UAVs can be kept in the depot because of the small size. Unlike the airplanes which are parked outside, UAVs do not need the periodic maintenance. Their maintenance charge can be reduced as much as 80% compared with that of fixed-wing aircraft.

**(6) The performance of UAVs is much better than the planes and rescue vessels in use currently**

For maritime search and rescue, time equals to life. Whether the rescue process will be success is directly related to the time that rescue members arrive at the scene of the accident. For the rescue vessel, the speed is quite slow and the vision field is quite small. What's more, it is influenced by natural conditions to a great extent. For the aircraft, the speed will be at least 7 to 10 times as much as that of rescue vessel. The fast response time of vessel and plane are shown in table 3.2. In this table, the prepared time for rescue vessel is calculated as 10 minutes, for helicopter and fixed-wing plane is 30 minutes each. The speed is about 22 n mile/h, 250 km/h and 340 km/h for rescue ship, helicopter and fixed-wing plane respectively. From table 3.2, it can be described that the reaction capability of planes is inherently better than that of rescue ships, and the gap between these two equipments gets wide with the increasing of distance.

According to the established functional relation between vision observation radius and the height of the eye, the search range of airplane is about 12 times as much as that of ship for the same long-distance voyage. In addition, UAVs have the abilities to take off in a short time, fly at low speed at low altitudes and hover in the air. For the oil spill accidents, UAVs can get the information which can not be acquired directly by rescue vessel. Compared with watercraft, UAVs have irreplaceable advantages in terms of the emergency respond time and effects of search.

Table 3.2 – The emergency respond time comparison between the watercraft and aircraft.

| Voyage/ n mile | 25 | 50 | 100 | 200 | 300 |
|---|---|---|---|---|---|
| Respond time of rescue ship /min | 78 | 146 | 282 | 554 | 826 |
| Respond time of helicopters /min | 41 | 52 | 74 | 119 | 163 |
| Respond time of fixed-wing plane /min | 41 | 51 | 72 | 115 | 158 |

Source: Compiled by the author on June, 6, 2014.

In conclusion, the advantages of UAVs are shown as follows:

(1) UAVs have better value in economy than watercrafts.

(2) While using UAVs for search and rescue activities, rescue members can obtain the relevant information at the first time, hence eliminating the blind spot and making right decisions. As the result, the loss of life and property caused by missing the best rescue opportunities can be avoided.

(3) UAVs can promote the development of maritime search and rescue activities, and enhance the science level of search and rescue. These images coming from UAVs can be used to set up databases in order to increase the accuracy of disaster risk reduction.

(4) UAVs are more environmentally friendly and cost-effective than rescue ships.

**3.2.2 Weaknesses of UAVs in maritime search and rescue activities**

Although the basic technology of UAVs brings confidence to the world, its weakness can not be neglected as well.

In the respect of the rescue capacity, UAVs can not carry persons in accident out of the scene of the accident directly. However a rescue vessel can easily bring the ship in danger or the people on board to safety.

In the respect of the performance, UAVs would be affected by the wind greatly for they are usually used in bad weather. In the case of a powerful typhoon, the images taken by UAVs may be vague.

Concerning about the operation, UAVs need a long time to train the operators. For traditional search and rescue mode using dedicated maritime rescue vessels and helicopters, there are about 3000 technical staff to ensure the safety of life and property at sea and maintain a clean marine environment. But for UAVs, there are not any professional operators who can control this complicated system for maritime search and rescue activities at this moment, even there are some cases of using UAVs in different fields such as public safety, flood control and drought relief, wildlife monitoring and so on. That means UAVs can not be used for searching targets even if we have a complete set of equipment. The operators should be trained and gain experience from simulated training at first.

### 3.2.3 Opportunities for UAVs in maritime search and rescue activities

**(1) Objective factors**

Take the responsibility area of Nanhai Rescue Bureau which covers all the South Sea of China for example. The climatic and economic characteristics of this area bring opportunities to the UAVs and their system.

The Chinese south coast area is a foggy region. Cold currents in winter and typhoons in summer are the main extreme weather which affects the South Sea. The number of tropical cyclones is decreasing, whereas the intensity of the cyclones is enhancing. Every year, there are 8-9 tropical cyclones pose a direct threat to the South Sea among the 12-14 tropical cyclones with influence.

The density of ships in the South Sea is increasing. The South Sea is one of the sea areas with large traffic density. The domestic and foreign merchant ships go through the sea frequently. The number of ships going through Taiwan Strait is 70,000 port calls per year and the number for Qiongzhou Strait and Pearl River Estuary is 11,000 port calls per year and 1,500,000 port calls per year respectively.

There are about 1,700 islands in this sea area, and there are more than 100,000 fishing boats which have registered and the number of fishmen reachs 1,700,000.

The oil and gas resources are very rich in this area. At present, there are 18 oil and gas fields which are developing with 91 platforms and facilities.

Tourism industry of South Sea is thriving. With the improved living standards, the demands for maritime transport and marine tourism keep growing. The passenger flow volume of Pearl River Estuary and Qiongzhou Strait is about 20,000 and 30,000 persons per day respectively. What's more, the marine amusements such as tours throughout the coastal, sea fishing, sailing and surfing are drawing more and more attention.

As the features shown above, this sea area is a developing area. The development of marine economy increases the possibility of maritime accident and heats up the

attention that the government and people pay to the marine safety. As the result, the government and relevant departments need to enhance searching techniques and equipments in order to meet the increasing demand for maritime security. Besides, the hydrologic and weather conditions which are constantly changing will cause more accident at sea and increased the difficulty of the search and rescue. These objective factors provide opportunities for UAVs using in maritime search and rescue activities. With the help of UAVs, the specific information which holds great significance for assisting rescue crew in risk assessment and plan making can be get to improve the initiative, reliability and pertinence of rescue plan. As the result, the rescue success rate will be improved. That means the ships or persons in danger will be rescued in a shorter time while the rescue crew will confront less danger.

**(2) Subjective factors**

The search and rescue force plays a vital role in the development of shipping industry. Table 3.3 shows the data of search and rescue operations from 2003 to 2013. It is found that the rescue success rate maintains at a certain level even the number of rescued persons increases. There is a certain gap compared with developed countries such as U.S.A. In order to improve the rescue effect, the requirement of adapting the environment of maritime search and rescue should be taken into account when allocating the search and rescue forces. Fortunately, UAVs can meet the above needs.

Table 3.3 – The data of search and rescue operations from 2003 to 2013.

| Year | Number of maritime accident | Number of persons in danger at sea | Number of rescued persons | Rescue success rate |
|------|------|------|------|------|
| **2003** | 1889 | 14912 | 14243 | 95.50% |
| **2004** | 1492 | 16491 | 15597 | 94.60% |
| **2005** | 1582 | 17806 | 16969 | 95.30% |
| **2006** | 1620 | 17498 | 16753 | 95.70% |

| | | | |
|---|---|---|---|
| **2007** | 1861 | 25087 | 24227 | 96.60% |
| **2008** | 1784 | 20280 | 19565 | 96.50% |
| **2009** | 1964 | 19128 | 18397 | 96.20% |
| **2010** | 2218 | 24513 | 23555 | 96.10% |
| **2011** | 2177 | 19352 | 18712 | 96.70% |
| **2012** | 1954 | 16952 | 16392 | 96.70% |
| **2013** | 2169 | 21399 | 20712 | 96.79% |

Source: Compiled by the author on June, 6, 2014.

Maritime search and rescue work is the final and key line of the maritime traffic safety guarantee system. It is the most direct way to avoid or lighten perils of the marine accidents. It contains 5 stages: discover the maritime issues, take an initial operation (information collection and rescue risk assessment), set an action plan, carry out the rescue plan, and complete the rescue operation. As can be seen from the process, after the SOS messages are received, information collecting and risk assessment are the priority for all. They relate to the rescue plan and the success of the rescue action. Only under the guidance of a comprehensive plan which is based on timely and clear information, every rescue force can work cooperatively with each other and maximize their potential to fulfil the rescue task.

As a general rule, a ship would send out its location by satellite or its panalarm when it gets into trouble. The rescue department can find the ship's position when rescue members receive the information. But actually, some information sent by the ship in distress is not coincident with actual facts. Some people even exaggerate the risks dues to their lack of ability to correctly assess risk. Facing with these problems, UAVs are good problem solvers.

In this case, UAVs can be sent to the targeted location with the aim to see the matter clearly, get detail information about the location and nature of distress, the traffic

density of the specified waters, the meteorological hydrological conditions of the scene, the description, loading condition, the equipment status of the ship in danger, as well as the number and the state of the persons in danger. These data make significant contributions to rescue risk assessment and operation plan.

What's more, UAVs can pay sustained attention to the issue with the aim to complete the rescue plan which should change with time and environmental condition. The work environment is dynamic for the ships at sea are moving and the marine risk is constantly changing. As the plan unfolds, the condition of weather, the visibility, the latest information of the target ship is likely to change. These call for the improvement of the rescue plan. UAVs can help to perfect the design scheme in a certain extent. They can focus on the targets and follow up the drifting direction of the targets as well as the vital signs of the person in distress. They have great effects on the implementation of the rescue work.

The experience of development in advanced countries shows four development trends of maritime search and rescue: equipments are more and more modern, work pattern is more and more stereoscopic, response is more and more rapid, information is more and more integrated. But there are some defects in current search and rescue system. These offer opportunities for UAVs to carry on forerunner and the explorer role in maritime search and rescue activities. Using UAVs can increase the accuracy, reliability and efficiency of the basic information and provide technical support for rescue work.

### 3.2.4 Threats to UAVs in maritime search and rescue activities

From the perspective of external threats, there are about 10 dedicated maritime

rescue vessels stand by at the South China Sea. With the increased emphasis on traffic safety at sea, more and more professional equipments (such the rescue ships) will put into the maritime search and rescue activities. What's more, with the help comes from other departments, for example, Maritime Safety Administration of Guangzhou and Hong Kong Government Flying Service, the search and rescue work will be shared.

From the perspective of internal threats, there are 7 key technologies for the development of UAVs and their remote sensing system.

(1) Aerodynamic problems about low Reynolds number;

(2) Micro power systems high thrust-weight ratio;

(3) Structured design technique of large bulk;

(4) Stability and operability of flight and the control technology;

(5) Information-passing techniques with weak power signal;

(6) Multidisciplinary design optimization for UAV system;

(7) Processing and manufacturing technology based on micro electro mechanical system.

For UAVs, these techniques are the main issues that have to be solved. In other words, these are the treats to UAVs.

# Chapter 4 Applications of civil UAVs

## 4.1. Application abroad

National Aeronautics and Space Administration (NASA) has set up a UAV Applications Center with the aim to carry out research for different civilian purposes. Work with National Oceanic and Atmospheric Administration, this center makes scientific researches on weather forecast, global warming, glacial ablation and so on.

During the 2007 wildfire season, NASA used Ikhana for assessing the severity of the fire and damage from the forest fire. Ikhana is a modification of Predator B. It is used for civil and environmental monitoring purposes.



Figure 4.1 – UAV Ikhana of NASA.

Source: The website of National Geographic.

(http://news.nationalgeographic.com/news/2012/09/pictures/120921-hurricane-drones-nasa-usgs-environment-science/#/news-drones-ikhana-flight_59339_600x450.jpg)

By reconstructing the UAVs which used to be used for military affairs, NASA launched its own drone mission to understand and predict storms on September 19, 2012. The UAV launched by NASA is called Global Hawk. It can travel up to 17,700 km as well as stay in the air for up to 30 hours.



Figure 4.2 – A Global Hawk turns hurricane hunter.

Source: The website of National Geographic.

(http://news.nationalgeographic.com/news/2012/09/pictures/120921-hurricane-drones-nasa-usgs-envir

onment-science/#/news-drones-global-hawk_59341_600x450.jpg)

Figure 4.3 – A set of monitors for UAVs in the control center.

Source: The website of National Geographic.

(http://news.nationalgeographic.com/news/2012/09/pictures/120921-hurricane-drones-nasa-usgs-envir

onment-science/#/news-drones-control-station_59342_600x450.jpg)

Not only NASA, but also United States Coast Guard (USCG) wants to improve itself and enhance the comprehensive strength by using UAVs.

USCG is one of the oldest coast guards in the world. Some of its equipments have past or near their original retirement ages. To fill the gap, USCG set up the Integrated Deepwater System Program whose missions are to protect maritime safety. In this program, USCG planned to purchase 76 UAVs. The news on December 18, 2013 said that USCG would accept about 20 micro UAVs (Wasp III) given by Marine Corps.

Figure 4.4 – Equipments for Deepwater Program.

Source: Tao, R. (2003). *Deepwater programme of USCG.* Modern Ships, China.

For a wide range of monitoring at sea which is one of most important part of Deepwater Program, UAVs, such as high altitude endurance UAV and Vertical Take-off and Landing (VTOL) UAV, are the important components of aviation division. In other words, UAVs can cover the shortages of patroling the coast in the air. UAVs and their systems are useful for maritime safety.

## 4.2. Application in China

Since 2013, UAVs have been used in marine environmental monitoring in Liaoning Province. It is the first application in maritime management in China. The images of island area and its adjacent sea area taken by UAVs provide accurate information for the divisions of the sea and marine protection.

Tianjin Maritime Safety Administration (MSA) is the first MSA which uses UAVs as

the assistant of cruise control in order to enhance the emergency command ability and the capacity for emergency management of oil spilling.

The UAV in Tianjin MSA is HSE-LY-001 of Longyan. Its flight altitude is 1,000 m. Equipped with digital cameras, Longyan takes on the work of surveillance on water pollution as well as maritime search and rescue. According to Tianjin MSA, Longyan works 2-3 times a week. It is on call for 24 hours and takes off at any time if there is an accident happened in the area under the administration of Tianjin MSA. By January 4, 2013, Longyag has flown 76 sorties safely. Its work efficiency exceeded expectations.



Figure 4.5 – The UAV using in Tianjin MSA.

Source: Compiled by the author on June, 6, 2014.

Figure 4.6 – The control center of UAV in Tianjin MSA.

Source: Compiled by the author on June, 6, 2014.

Even though there is no precedence for UAV using in the real maritime search and rescue activities, from the SWOT analysis and the use cases in other areas in and out of China, the conclusion can be get that using UAV in maritime search and rescue activities is feasible.

**Chapter 5 Targets of UAVs in maritime search and rescue activities**

Based on the present development situation of search and rescue, UAVs are suited for targets searching, locale information transporting and pollution monitoring because they have the certain advantages over manned planes and vessels.

**5.1 Collecting field data**

When a marine accident happened, the rescue at scene is the most critical aspect of the whole work. Often triggered by complex sea environment and extreme weather, manned vehicle are not convenient to use. In this case, UAVs can utilize their skills. UAVs can hover in the specified airspaces for a long time without rest. Also, their air routes can be constantly adjusted in order to fulfill temporary tasks. The staff on land can get the real time images with high quality from the emergency scene and order the rescue vessels to rush to the right location. Using UVAs instead of manned aircrafts can greatly reduce the risk caused by harsh conditions, being complement in superiority for rescue vessel. Accordingly, the success rate of search and rescue will be vastly improved.

For some special cases, like oil spill accidents and ship-collision, command center makes the most accurate rescue plan only after evaluating the level of the accident. In that case, UAVs can fast react and arrive at the certain place required by the command center in the shortest time, taking pictures of sea condition, sending the real-time information back to control center by teletransmission. On the other hand,

the staff working at the center can make the UAV hovering over the sea surface in order to collect accurate and detail information which is the basis of emergency plans.

## 5.2 Airlifting small necessaries

When accidents happened at sea, it is very important for people in danger to have enough fresh water and food to sustain life. As is known to all, seawater is undrinkable, and the persons who are trapped in an island or at sea may not have enough food to eat. In that case, UAVs can give necessary assistance to those people. Before taking-off, operators can equip the UAVs with a small amount of necessary supplies such as bottles of fresh water, compressed biscuits, and even some drugs. After UAVs arrive at the scene of the accident and find the targets, they can airlift the supplies which are attached to a parachute at the right time, helping the people to keep themselves in a relatively good condition before they are rescued.

## 5.3 Detecting accidents and monitoring pollution

Marine accidents are often unpredictable and may produce a chain reaction. The situations of the disaster and pollution change at every moment so that the true and reliable information is needed. UAVs have different characteristics of quick speed, low energy consumption, zero casualt and real-time, they can be used to monitor and detect key areas and key targets to ensure the emergency decision is fast and effective.

**Chapter 6 Design scheme of UAVs and their system in maritime rescue activities**

**6.1 Detailed working procedures**

When a distress message received, UAVs can take specific rescue actions according to the message. They fly to the scene from the nearest rescue base first. The rescue ships goes to the accidental site at the same time and take the next steps according to the information sent back by UAVs. When UAVs arrive at the scene and find the targets, they use their high-definition cameras to take images of the ships (or air vehicles, submersibles) and persons in distress as well as the sea conditions, and then send the information back to the control center and the nearest rescue ships. Also, the controllers can use the Very High Frequency (VHF) and loudspeaker on UAVs to communicate with persons in danger to understand the details of the accident such as the kind of the rescue work should be provided, the speed and the course of the ship in danger and so on. If UAVs do not find the persons and ship in distress, they can send real situation back to the control center and help the decision maker to work out a new rescue plan.
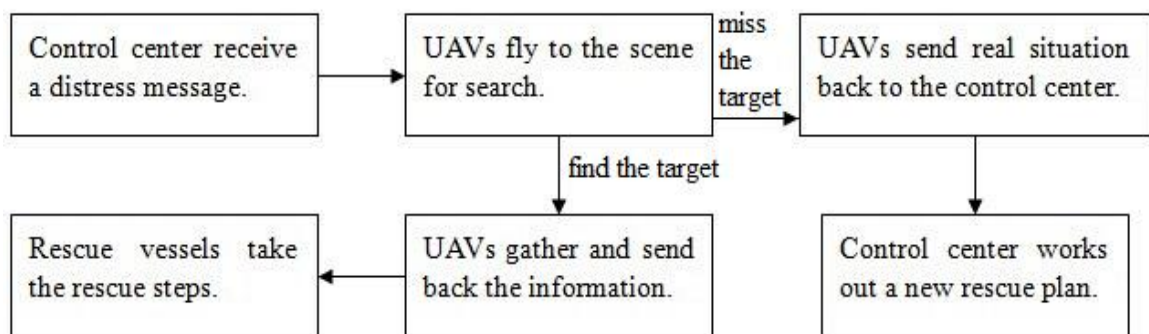


Figure 6-1 Working procedures of UAVs using in maritime search and rescue.

Source: Compiled by the author.


## 6.2 Inherent requirements of UAV platforms

In order to meet demand comeimg from the marine safety, the selection of UAVs using in search and rescue activities should consider the following factors:

### (1) Performance of wind resistance

The external meteorological environment such as wind, cloud, rain etc. has a great influence on UAVs' flight paths and flying qualities. As new equipments in maritime search and rescue activities, UAVs are applied to abominable environments such as a hurricane. The wind-resistance design is especially important for UAVs because it determines whether UAVs can arrive the site of accident smoothly and quickly. More than that, the wind-resistant performance is bound up with the stability of aircraft and the definition of the images. The stronger wind resistance UAVs have, the higher stability they have, the clearer images they take. In conclusion, UAVs using in maritime search and rescue work should possess certain anti wind capacity and be equipped with shock absorber to ensure the images are available and useful.

### (2) Endurance

From the practical work it is found that the radius of search and rescue service should be no less than 200 km, the loiter time of UAVs should be more than 1 hour. That means the endurance of UAVs using in rescue work should be more than 3 hours. The endurance of Eagle Eye and Fire Scout which are two types of UAV purchased by USCG are 5 hours and 6 hours respectively.

### (3) Flexibility

As mentioned before, fixed-wing UAVs need a special runway for both take-off and landing. This is a problem for fixed-wing UAV using on rescue vessels. By contrast, rotary-wing UAVs have their unique advantages in using on rescue ships for it can

take off and landing without runways. In addition, the rotary-wing UAVs can hang steady in the air, fly close to the rescue area which other platforms are difficult to reach as well as follow and monitor the targeted ships closely. In the grand scheme, rotary-wing UAVs are ideal options to the existing rescue force.

**(4) Instruments onboard**

Besides the basic equipments such as remote control apparatus, radar, differential GPS, high definition cameras of 360 degrees, autopilot and so on, UAVs should carry on some rescue equipments that match with the rescue vessels, for example, ECDIS, Air Speed Indicator (ASI), VHF, anemograph, night vision instrument, Electro Optical Targeting System (EOTS) and so on. With the help of these devices, UAVs can transmit the maritime search and rescue information around the clock and render timely help to the ships and persons in distress.

Table 6.1 - Equipments on UAV and their contribution.

| Name | Contribution |
|------|--------------|
| GPS | Locating the target's positions quickly and save the rescue time. |
| AIS | |
| Cameras | Shooting pictures of the scene. |
| Anemomete | Gathering information about the direction and speed of wind. |
| Radar | Searching the persons in distress automatically. |
| Autopilot | |
| Night vision | Accomplishing the search task at night and auto-follow-up the target. |
| EOTS | |
| VHF | Communicating with the person on ship, helping them to prepare for the rescue work. |

Source: Compiled by the author on June, 6 2014.

**6.3 Arrangement of the control system**

Besides the UAVs themselves, the control system about the equipments of

monitoring and command should be taken into consideration. At present, Nanhai Rescue Bureau has a master-control centre in Guangzhou and 8 sub-control departments in the rescue bases in Haikou, Guangzhou, Yangjiang, Shenzhen, Zhanjiang, Shantou, Sanya and Beihai. All of the existing systems are connected with each other as well as the ships on call. The control system of UAVs can be integrated into existing systems, setting an operation room in the master-control center. When the master-control center receives a distress signal, the professional rescue staff will give commands and instructions to the relevant rescue base to fly UAVs control by the operator working in the main center. The images gathered by UAVs are sent back to the master-control center, sub-control center and the rescue ships at the same time, helping the rescue staff to have a clear understanding of the accident and make a right decision. During the whole process of search and rescue, UAVs are always controled by the operators in the master-control center.

## 6.4 Storage of UAVs

Rotary-wing UAVs are the best choice for maritime search and rescue activities, they can land on the rescue vessels and parking there in a short term. For the long term, they must be placed into storages. The UAVs with small bodies can be parked in the modified area in the existing garage and equipment stores. For the aircrafts which are relatively larger, they could be stored in the rescue flying bases of Nanhai NO.1 Flying Rescue Service which is a professional team carrying out air rescue missions in China.

**Chapter 7 Conclusion**

The development of UAVs has a long history for nearly a hundred years. The technology of UAV is relatively mature. The result of SWOT analysis shows that using UAVs in maritime search and rescue activities is feasible. It is necessary for the professional rescue team to use UAVs and the remote sensing system as a new rescue force for they can arrive at the scene in a short time, collect the in-time data, search the targets as soon as possible, keep track of an event in real-time and airdrop aid to the persons in danger.

At present, the application of civil UAVs is in the practical period. It still has some important things to perfect. From the perspective of working time, the application of UAV is bound by air traffic control. This is the biggest problem that UVAs are facing at present. The rescue force should communication with relevant departments in order to save the rescue time. From the perspective of design, UAVs using for marine safety should follow the regulations of aircraft provided by International Aeronautical and Maritime Search and Rescue Manual. The airline should be designed and controlled according to the requirements in the manual. From the perspective of allocation, since the application of UAVs in maritime activities is in the early phases of development, rescue department had better choose one or some rescue bases as pilot and use a few UAVs for experiment before the widespread application. The development experience of UAVs should be learned from advanced countries and a comprehensive strategy should be outlined in order to make full use of domestic technical conditions and material foundation to develop the UAV system. UAVs will play an important role in maritime search and rescue activities in future.

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