Flooding Disaster Oriented USV & UAV System Development & Demonstration

Jimin Zhang  
School of Mechanical Engineering  
Shenyang Ligong University  
Shenyang, China  
zhangjimin@sia.cn

Junfeng Xiong, Guangyu Zhang  
University of Chinese Academy of Science  
Beijing, China  
xiongjunfeng@sia.cn, zhangguangyu@sia.cn

Feng Gu, Yuqing He  
Shenyang Institute of Automation  
Chinese Academy of Science  
Shenyang, China  
fenggu@sia.cn, heyuqing@sia.cn

Abstract—Flooding disasters have led to heavy costs including enormous property losses and casualties. The biggest challenge lies in rescue operation is the low efficiency and the high security risk of rescuers, which is also a problem focused on by this work. Unmanned system is one of the solution that replace people in the rescue operation. However, there are still some obvious defects of unmanned system that are difficult to overcome, such as the limited perspective of the Unmanned Surface Vehicle (USV) and the short flight endurance of a micro multi-rotor craft also called little Unmanned Aerial Vehicle (UAV). At the same time, they both have other advantages that the other one does not have, for instance, the long cruising ability of the USV and the broad horizons of the UAV. Thus in this paper we try to combine the superiorities of the USV and the UAV to make up for their defects, as a result, the whole system will be able to own a broad vision and a long cruising power.

Keywords—USV; UAV; Cooperation; Air-surface robot system

I. INTRODUCTION

Floods have seriously impacts on populations worldwide in terms of both loss of life and property [1]. In 1998, China suffered the heaviest basin-wide flood disaster which had cost great casualties and losses [2]. So far, many of the rescue and monitoring operation have been completed by unmanned vehicles [3-5], such as USVs and UAVs. There are lot of applications of USVs which include bathymetric mapping, defense and general robotics research [6], and we mainly use it to do rescue operation and some cooperative research. In Hurricane Wilma, 2005, USVs and UAVs were used for emergency response by detecting damage of seawalls and piers, locating submerged debris, transportation infrastructure inspection and determining safe lanes for sea navigation [3]. After the Fukushima nuclear accident in 2011, the United States and Japan had used multi-robot systems to assess the damage jointly [4]. Obviously the USVs and UAVs have a lot advantages over other manned vehicles. The smaller size allows the USVs to get access to narrow and small space to get detail information. Remote operation can avoid casualties of the rescuers caused by the unexpected potential dangers. Also, the UAVs provide a bird’s view to help the USV operator to have a good visual field. However, it is indeed very hard for the operators to control USV and UAV beyond-visual-range. With no communications between the USV and UAV, it is not easy for the UAV to locate the USV from a low-resolution global photo. And another well-known defect of UAV is the short flight endurance, which means that the UAV has to return to change battery for about every twenty minutes or less. Heterogeneous robots system usually possesses complementary perception of environment [7]. On the other side, the USV can usually keep working for at least two hours and it is easy for UAV to reach the designated place to acquire detailed information. To bring all the capabilities of the unmanned vehicles like USV and UAV to full play, we come up an aerial-surface system.

The air-surface system conception is that the USV carries a UAV into a complex stricken area for information acquisition and rescue operation. The UAV will take off from the USV while the USV arrives at the designated area. Then the UAV start to hover over the USV at an appropriate height to take global photos or videos and send them to the USV. The reason why the USV needs such photos and videos is that it is very hard to manipulate once the USV is out of vision. Another reason is that USV can only generate a local path which may not be an optimum one obviously, while the system is under autonomous control. So global information is needed to achieve the global trajectory planning. Meanwhile global trajectory planning can be modified by the information of laser and camera installed in the USV.
To achieve fully autonomous function, the UAV should be capable of taking off and landing on the USV automatically. So the whole system can be split into three functional subsystems.

The first subsystem is the USV, the mother ship, which is mainly used to carry the UAV, collect local environmental information with laser and camera, release rescue equipment, pull the survivors back to the bank and to do most calculation like generating map from a photo and navigation planning.

The second subsystem is the UAV, whose main function is to get the global information of the environment like photo and video and export it to the USV. Besides, the UAV must also complete the auto take-off and landing function, when the mother ship is drifting on water surface.

The last subsystem is the auto take-off and landing system, it is composed of landing assist mechanical structure and autonomously take-off and landing algorithm that also has function to auto track mother ship. The algorithm is completed in the computer of UAV in assist of the data of the USV status which is used to assess the take-off and landing condition of the USV.

With the global environment information from UAV, the USV can complete the identification, search and map-building mission and achieve global trajectory to the target location for rescue work. After that, the UAV will continue to send back videos or photos back so that the USV can get some feedback to rectify the trajectory planning. Then, if the UAV is temporarily unnecessary or running out of power, it can land on the USV for power saving or power recovery.

II. USV

So far different kinds of USVs have been created to conduct a series of research and experiments [8-11]. This part mainly introduce our USV platform.

A. Hardware System

The USV system designed and implemented in SIA, CAS as shown in Fig. 1. Its basic performance parameters are provided in TABLE I.

| length | width | height | max velocity | load |
|--------|-------|--------|--------------|------|
| 280cm  | 70cm  | 37cm   | 35 km/h      | 70 kg|

The water-jet propulsion USV is made up of five subsystems, including the on-board control computer sub-system, power supply sub-system, communication sub-system, sensor and perception sub-system, and ground station sub-system. The computer is an Adventech® PC104+ industrial embedded computer. Power supply is composed of two CSTK12V17AH lead-acid batteries and a small lead-acid battery. Two lead-acid batteries are used to power the whole computer, sensors and other equipment, the small battery is used to start the engine and keep the engine running. Besides, the engine can generate electricity to recharge the two lead-acid batteries. The sensor sub-system contains a GPS/IMU system, which is used to locate the USV and obtain some inertial states such as attitude, velocity and acceleration. The ground station was wrote by C++ and installed in an industrial portable computer. It is mainly used to monitor the main data of the USV, receive video information from the USV and the UAV, complete manual trajectory planning and control the USV by a maneuvering handle. The on-board control computer in the USV can be used to record the experimental data and do most calculation like local environment information perceiving, map generation and trajectory planning.

It is cable of replacing different kinds of loads and external sensors according to different mission. If survivors are trapped on a small highland or a roof, then the USV can be equipped with a rescue rope throwing equipment to throw the rope to the survivors. If a boat or a house in water catches fire, or a life signal need to be detected, then the USV can use infrared camera and other detecting instruments to get more detail information. Besides, the USV can be used to collect water sample of the flood area especially those around the chemical industries.

B. Software System

To ensure the safety of navigation, the USV requires real-time obstacle avoidance capability. The software structure of Computer Control System (CCS) is implemented using QNX V6.5.0 real time operational system (RTOS), which is known as a real-time, high stable and good portable OS. It includes the following modules, Gi5631 (receive and process GPS/IMU signals), Communicator (TCP communicate and data transmit), Tracker (realize GPS tracking), Protocol, Controller, PWM (send PWM wave to servos), and Engine module. The software structure diagram can be seen in Fig. 2.
C. Application Experiments

To improve and demonstrate the performance of the USV system, we have done a serious of application experiments such as rescue rope throwing, dragging survivors in the water, water sampling and local environment information collection using laser imaging as shown in Fig. 3.

The performance of USV can satisfy our demands and we are now working on solving the problem of side slipping to achieve more accurate position and trajectory control. At the same time, we also need to separate some energy to do some picture processing in the CCS to generate a feasible map.

III. UAV

We have assembled a hexacopter using Pixhawk, open-source flight control system, carbon fiber frame, six rotors and a landing assist mechanism. Fig. 4 is the UAV sub-systems. Pixhawk runs a very efficient real-time operating system, which provides a POSIX-style environment. And it mainly includes mission management, MAVLink, RC input, Trajectory Control, Position Control, Attitude Control, etc, as shown in Fig. 5. Our next focus is the USV tracking algorithm and auto landing algorithm. The landing assist mechanism will be introduced in the next part.

IV. TAKE-OFF AND LANDING ASSIST SYSTEM

The take-off and landing assist system plays an important and fundamental role in the whole system. The wind-wave disturbance is always a big challenge for the UAV to land onto the USV, for the reason that the USV keep swaying and drifting in the water environment which make it more difficult to take-off and land automatically. And the UAV is also risking a danger of crashing into the water during a landing process. Besides, the UAV may fall off, while the USV is taking a sharp turn or disturbed by the wind and wave. To overcome the problem, we had done some simple experiments shown in Fig 6. And a simple landing assist device had been completed which is shown in Fig. 7. This set of landing assist device is composed of a servo, a telescopic holding rod which is connected to the servo, a small aluminum alloy board which is connected to the rod and the basic frame. Also, another flat board is fixed on the USV. Both surface of the boards are pasted with sticky material, so the small board can affix onto the flat board. We hope that the UAV could land onto the USV by pasting on the flat board. Before taking off, the servo will separate the small board from the flat board. According to some experiments, the reliability cannot satisfy the demands of the safety landing. Because sometimes the sticky material cannot paste so well that the material will separate from the board under server disturbance. So a new set of modified landing mechanical device called “double-harpoon system”, as Fig. 8 shown, has been designed. It is totally based on mechanical connection and both undercarriages are equipped with a set of “harpoon”, which make the system more reliable. Besides the “harpoon system” is much smaller and lighter, so the UAV has more load capacity for camera and other communication devices. All the parts of the “double-harpoon system” are now under processing. To improve and modify the design of “double-harpoon system”, a series of experiments...
will be conducted, manual take-off and landing, auto take-off and landing, tracking and communication test included.

There are kinds of methods of autonomous landing for the UAV, such as GPS based method and computer vision-based method [13]. We might use a combined method, which both methods will be adopted.

![Fig. 6. Preliminary experiments: Manual landing](image)

![Fig. 7. Landing assist mechanism: first generation and simple test](image)

![Fig. 8. Modified mechanism: second generation](image)

V. CONCLUSION

This paper introduces a new system named Aerial and Surface Combined Robot System, which consists of a USV, a UAV and a take-off and landing assist system. A lot of experiments have been conducted so far, the feasibility and validity of the USV system, UAV system have been tested and intensified. Based on the work above, our next step will focus on the environment modeling, tracking, cooperative map building, navigation and the autonomous taking off and landing.

REFERENCES

[1] P. Adhikari, H. Yang, “A digitized global flood inventory (1998–2008): compilation and preliminary results,” Nat Hazards, vol. 55, pp. 405–422, May 2010.

[2] B. H. Zeng, Y. S. Xia, “Chinese floods in 1998 and strategies,” Journal of Catastrophology, vol. 1, pp. 57-61, Mar 2000 [in Chinese].

[3] Murphy R., Steimle E., Griffin, Gullins C., Hall M., and Pratt K., “Cooperative use of unmanned sea surface and micro aerial vehicles at Hurricane Wilma” Journal of Field Robotics, vol. 3, pp. 164-180, Oct 2008.

[4] Murphy R., Karen L., Dreger N., Jesse R., Brian S., Richard s., and Eric S., “Marine Heterogeneous Multirobot System at the Great Eastern Japan Tsunami Recovery,” Journal of Field Robotics, vol. 5, pp. 819-831, 2012.

[5] Scerri P., Kannan B., Velagapudi P., Macarthur K., Stone P., Taylor M.c., Dolan J., “Farinelli A., Chapman A. C., Dias B., and Kantor G., Flood disaster mitigation: a real-world challenge problem for multi-agent unmanned surface vehicles,” in 1996 proc, AAMAS Workshops Conf, pp. 252-269.

[6] J. E. Manley, “Unmanned surface vehicles, 15 years of development”, Oceans 2008, pp. 1-4, 2008.

[7] Mei Y G, He Y Q. “A new spin image based registration algorithm of 3D surrounding model in low-dimensional feature space,” Sci Sin Tech, vol. 1, pp. 108-118, 2014 (in Chinese).

[8] J. Corneliussen. “Implementation of a guidance system for cybership II”, Master’s thesis, 2003.

[9] J. Curcio, J. Leonard and A. Patrikalakis, “SCOUT – a low cost autonomous surface platform for research in cooperative autonomy,” Oceans 2005, pp.725–729, 2005.

[10] H. K. Heidarsson and G. S. Sukhatme. “Obstacle detection and avoidance for an autonomous surface vehicle using a profiling sonar”, 2011 IEEE International Conference on Robotics and Automation, pp.731-736, 2011.

[11] W. Naeem, T. Xu, R. Sotton and J. Chudley. “Design of an unmanned catamaran with pollutant tracking and surveying capabilities”, UKACC Control, 2006. Mini Symposia, pp. 99-113, 2006.

[12] M. Li, Y. He, Y. Ma, and J. Yao, "Design and implementation of a new jet-boat based unmanned surface vehicle," International Conference on Automatic Control and Artificial Intelligence (ACAI 2012), in ACAI, New York, pp. 197-200, 2012.

[13] G. Xu, S. Ji, Y. Cheng, “Research on computer vision-based for UAV autonomous landing on a ship,” Pattern Recognition Letters, vol. 6, pp. 600-605, 2009.