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Air-ground multi-agent robot team coordination

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Abstract— In an indoor search and rescue mission, the two main tasks are detecting the location of survivors or broken equipments and recovering them from a building full of danger. For the outdoor robots, they can use GPS to get the path information. But in a GPS-denied environment, the robots cannot get the support from satellites. We design an air-ground robot team to provide a solution to this problem. It consists of a micro aerial vehicle with a vertical camera and a horizontal camera, and two micro ground vehicle with an ultrasonic sensor and a colour sensor. Experimental results are presented demonstrating this air-ground robot team's ability to operate successfully in indoor environments.

Keywords- multi-agent, air-ground, robot team

I. INTRODUCTION

Unmanned vehicles are major focus of autonomous researches, since they can finish the tasks in a dangerous environment ([1]-[5]). Using of a group unmanned vehicles in the search and rescue mission can be a great benefit to people, since they can extend our capability [3], [4]. In order to provide better communication network performance [3] or speed up the search [4], aerial and ground vehicles are chosen to work in a three-dimensional network. Most of the approaches for autonomous air-ground search focus on systems for outdoor or urban operations; they need the support from the satellites to get the GPS position. But when the situation happened indoors, for example in a building full of poison smoke that people cannot go inside, these systems may not work properly. Some of the works [2], [4] choose to use micro helicopter for the navigation purpose, but the helicopter are two small to carry suitable equipments in order to provide rescue support properly. Others [1] choose to use ground vehicles because they can carry more equipment, but the speed cannot compare to the aerial vehicles.

In this project, we aim to overcome this challenge by designing an air-ground robot team. It consists of a Micro Aerial Vehicle (MAV) with vertical and horizontal wide-angle cameras, and two Micro Ground Vehicles (MGV) with various sensors and with the possibility to carry light weight equipment such as oxygen masks or first aid kits.

We propose a solution for the chemical (poisonous gas) accident. The MAV will first fly into the hazardous zone and check the suspect location. When the MAV pin points the broken point, MGVs will follow the path of the MAV to the location and carry on the rescue mission.

The rest of the paper is structured as follows. In section II we present the system overview, including aerial team, ground team and control station. In section III experiments results are provided. Conclusion and future work are discussed in section IV.

II. SYSTEM OVERVIEW

The entire system, which is shown in Fig.1, consists of three sub-teams: aerial team has a quadrotor helicopter with two cameras, multiple sensors and an on-board processor; ground team has two unmanned vehicles with multiple sensors and two on-board processors; control station has a portable PC with wireless and Bluetooth communication, and a desktop PC with internet communication and powerful processor.

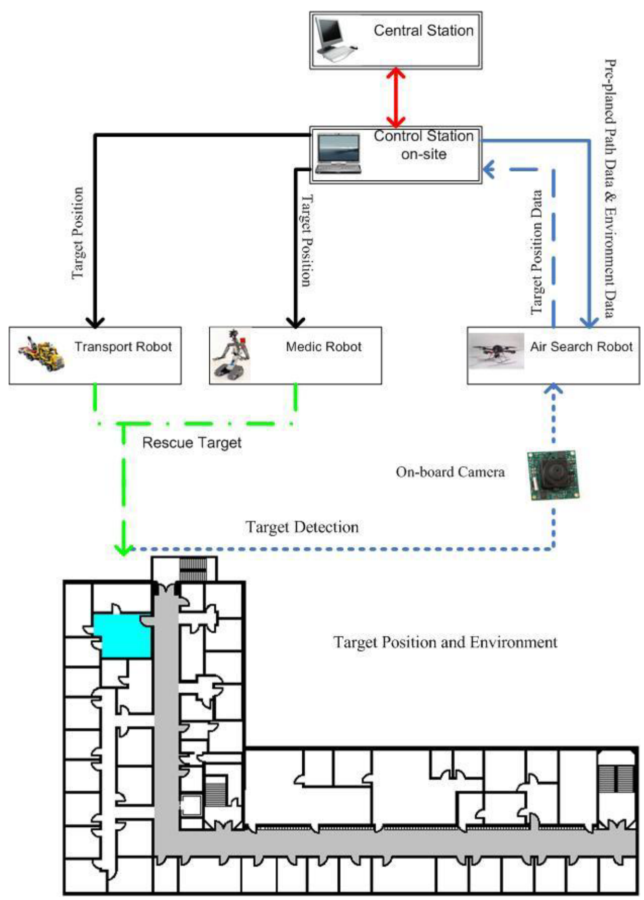

Fig.1. System architecture

A. *Aerial Team*

The MAV applied in this work is an AR.Drone quadrotor helicopter with one 93° wide-angle front camera, one 64° wide-angle vertical camera, one ultrasound altimeter (6 metres) and embedded computer with 468 MHz processor as shown in Fig.2. The running speed of the helicopter is 5m/sec.

Fig.2. Ar.Drone Micro Aerial Vehicle

The quadrotor present the following advantages.

- Simple design and low maintenance time [6]. Unlike normal helicopters, quadrotor do not need mechanical linkages to verify the rotor blade pitch angle.
- Smaller rotor diameter [7]. Requires less kinetic energy stored during flight.
- High manoeuvrability [6], [7], [8]. Owing to their small size (45 x 29 cm), quadrotor can easily fly indoors and outdoors.

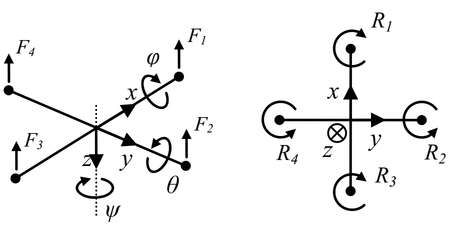

Fig.3. Quadrotor kinetics

Basic motion of a quadrotor can be shown in Fig.3. The quadrotor is controlled by the four independent inputs – roll, pitch, yaw and thrust, and has six outputs – position vector (x, y, z) as in (1) and 3 Euler angles (θ, φ , ψ) as in (2). Each pair is turning clockwise and the other is turning anti-clockwise to balance the moments.

$$\ddot{x} = u_1 (\cos\varphi \sin\theta \cos\psi + \sin\varphi \sin\psi) - K_1\dot{x}/m$$

$$\ddot{y} = u_1 (\sin\varphi \sin\theta \cos\psi - \cos\varphi \sin\psi) - K_2\dot{y}/m \qquad (1)$$

$$\ddot{z} = u_1 (\cos\varphi \cos\psi) - g - K_3\dot{y}/m$$

$$\ddot{\theta} = u_2 - l\,K_4\,\dot{\theta}/I_1$$

$$\ddot{\psi} = u_3 - lK_5\,\dot{\psi}/I_2 \qquad (2)$$

$$\ddot{\varphi} = u_4 - K_6\,\dot{\varphi}/I_3$$

where x, y, and z are three positions; θ, φ and ψ are the three Euler angles, representing pitch, roll and yaw respectively; g is the acceleration of gravity; l is the half length of the quadrotor; m is the total mass of the helicopter; I_i are the moments of inertia with respect to the axes; and K_i are the drag coefficients.

The virtual control inputs to the system are defined as following in (3) [9]:

$$u_1 = (F_1 + F_2 + F_3 + F_4)/m$$

$$u_2 = (-F_1 - F_2 + F_3 + F_4)/J_1 \qquad (3)$$

$$u_3 = (-F_1 + F_2 + F_3 - F_4)/J_2$$

$$u_4 = C\,(F_1 - F_2 + F_3 - F_4)/J_3$$

u_1 affects the altitude of the quadrotor, u_2 affects the rotation, u_3 affects the pitch angle and u_4 affects the yaw angle.

Roll movement is obtained by varying left and right rotors speed the opposite way. Pitch movement is obtained by varying front and rear rotors speed the opposite way. Yaw movement is obtained by varying each rotor pair speeds the opposite way.

To achieve the desired target position, the Control Station sends the pre-defined path to the helicopter control unit. This pre-path is a set of flying instructions that allows the aerial vehicle to arrive to the desired location. Examples of flying instructions are: go straight for 4 seconds at 5m/sec or turn right 45° clockwise. The quadrotor is internally controlled with the assistance of an on-board sensor that modifies the Euler angles (θ, φ and ψ) as shown in Fig.3 and the motor's rotation speed.

After finish the search mission and arrive at the target position, the MAV will use the on-board camera to recognize the target (we use different colour to identify different target in this project), then the control station decides which MGVs is needed to be send to accomplish the mission.

B. *Ground Team*

The MGVs used for testing were LEGO mindstorms NXT. The NXT bricks have two processors and various sensors. Different robots were designed to address the different tasks since the robots are built on the basis of the role they play in the mission. LEGO's flexibility was important to increase the effectiveness during the preliminary tests. However, for the final implementation two Oto Melara Unmanned Vehicles (OTO-TRP3-FROG) will be used as shown in Fig.4. These MGVs present equivalent possibilities as the NXT in addition to more specific functions, such as the ones present in the Reconnaissance, Intelligence, Surveillance and Target Acquisition (RISTA) version [10].

Fig.4. Oto Melara Micro Ground Vehicle

In these tests, the MGVs are designed to move in two modes as shown in Fig.5: straight forward mode and turning mode. These two modes will help the vehicles following a chosen path with predictable movement, as needed when following smooth sharp corners [11].

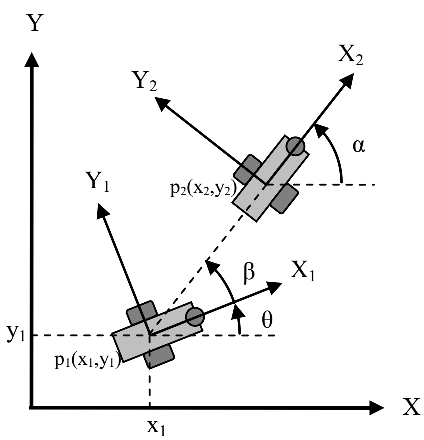

Fig.5. Ground robot kinetics

Global reference frame is used to represent the location of the vehicles relative to a fixed coordinate system as shown in Fig.5, the angle data and real-time speed can be obtained by the internal sensor of the ground vehicles as in (4)

$$\begin{aligned} \dot{x}_i &= v_i \cos\theta_i \\ \dot{y}_i &= v_i \sin\theta_i \\ \dot{\theta}_i &= \omega_i \end{aligned} \qquad (4)$$

where X_i-Y_i is the reference frame of MGV_i.

The location of MGVs can be estimated by:

$$\begin{pmatrix} \hat{x} \\ \hat{y} \end{pmatrix}_{t+\Delta t} = \begin{pmatrix} \hat{x} \\ \hat{y} \end{pmatrix}_t + \begin{pmatrix} \Delta s \cos(\hat{\theta} + \Delta\theta/2) \\ \Delta s \sin(\hat{\theta} + \Delta\theta/2) \end{pmatrix}_t \qquad (5)$$

With the position information provided by the MAV, the Control Station converts the 3D path into a 2D path and sends the latter one to the ground vehicle. The MGV follows the received path to the target position and finish the rescue mission with their role-based design equipment.

C. Control Station

A portable PC is used as the on-site control station. It is used for the image processing, object detection and robot team controlling [12].

The communication between the aerial vehicle and the portable PC is based on the IEEE802.11b/g network communication standard. All sensor data coming from the MAV (like controlling, configure, status, position, speed and engine rotation speed) is requested by sending attention commands (AT) through UDP messages. The images of the target location are sent by the MAV back to the Control Station also using UDP messages.

The ground vehicle communicates with the portable PC via Bluetooth network. The MGVs send all data from their sensors back to the PC and receive the control command from the control station at a rate of 100 Hz via Bluetooth Class II equipment.

Another desktop PC is used as the centre station. It is used to control multiple on-site control station in different location at the same time through internet.

III. CONTROL STRATEGY AND EXPERIMENT EVALUATION

Fig.6 shows the environment map and the pre-planned path for the MAV. The test missions are designed to run as follows: The MAV sends out first to search for the targets following the path at the speed of 18km/h. The control station on-site controls the MAV using the (1) and (2), and the MAV sends the navigation data at 5Hz including speed, direction and altitude back to the control station on-site. The control station on-site uses the navigation data to plan the paths of MGVs with the help of (4) and (5). After finding the suspect target, the MAV uses a Wi-Fi network to send the position data and image data through UDP port 5554 back to the control station. The control station confirms which object it is, on the basis of its colour and decides which MGV should be sent out. After arrival at the location of the object, the MGV completes the task using their agent-based design. All the information and data is sent to central station by the control station to record the mission data for the future use.

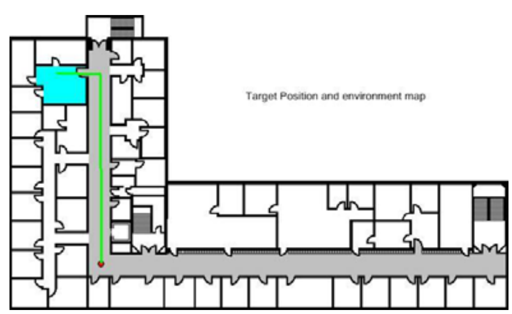

Fig.6. Start point (red dot), Target position (blue area) and map

The whole system has been tested with a total of 18 trials at 5, 10 and 20 metres range in two different light conditions; full light and half light illumination. Missions were considered completed if all vehicles accomplished their individual tasks in a positive way. All trails were successful except 1 that failed at the range of 20 meter under half illuminate condition because the MAV cannot detect the target. In Fig.7 (MAV path) and Fig.8 (MGV path) the result at 10 meters range under full illumination condition is presented.

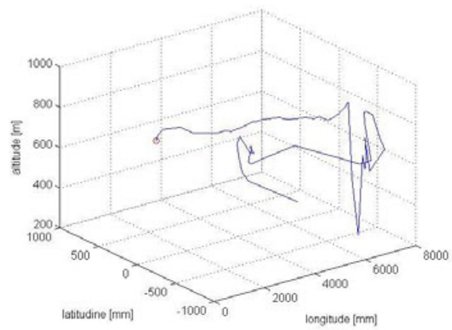

Fig.7. MAV path in 3D (red dot is the start point)

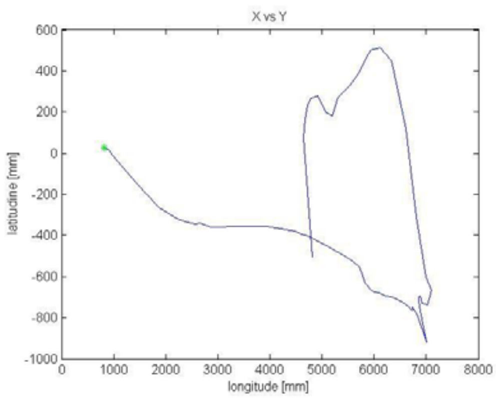

Fig.8. Path of MGV follows in 2D (Green dot is the start point)

It can be seen from the above figures that the MAV could follow the pre-planed path to check if there is a target in that area and MGV can follow the path of MAV to the target position.

IV. Conclusion and Future Work

In this paper, we present the concept and design of a new approach for a search and rescue robot team able to work in an indoors (GPS-denied) environment. The team is divided into an aerial team (AR.Drone helicopter), a ground team (two LEGO or Oto Melara vehicles) and a control station (computer with wireless communication). The results show that the aerial team is capable of searching a suspected area using a pre-planed path and send the precise target location back to the control station. The ground team is able to follow the path provided by the aerial team to find the target and finish the rescue mission. In the near future, the size of the robot team will be increased to be able to accomplish more difficult search and rescue tasks under different environment conditions. The project comprises the test of vehicles equipped with other type of sensors that would give the possibility to cope with missions like hostage situations and intruder surveillance.

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