Multi-robot Collaborative Platforms for Humanitarian Relief Actions

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Abstract — **In this paper we describe the main components and technical challenges required for the implementation of a multi-robot collaboration platform towards supporting humanitarian relief actions. The platform supports collaborative work between a fleet of UAVs, mobile stations and light-weight fast-speed robots. The platform can be used on both land or marine environments allowing a wide diversity of rescue, surveillance and relief operations. The paper presents the entire robotic system of the platform along with some mobile station-base collaborative tasks, inter UAVs and fast-speed mobile platform collaboration. Finally, we present potential application scenarios where these platforms can be deployed.**

INTRODUCTION

Natural disasters, as well as large-scale man-made hazards are calamitous events that can seriously affect the well-functioning of a community causing huge human, economical and environmental damages. In the recent years, advances in science and technology made possible the use of high-tech devices in disaster relief operations. Moreover, the new technology, such as mobile phone, crisis mapping, online volunteering and social media became of central importance to relief efforts in humanitarian crises. For example, victims of the earthquake in Haiti were able to assist in their own rescue by sending text messages to explain their locations. The messages were further plotted by online volunteers around the world into a crisis map that was used by relief workers to find victims trapped under rubble [1]. Social media is often used to assist disaster victims to communicate where assistance stations are located, which areas still have power or how the relief efforts are scheduled. Examples include assistance provided to the victims of the Hurricane Sandy in New York and New Jersey or to the flood victims in Indian and Bangladesh during usual monsoon season.

Additionally, unmanned aerial vehicles (UAVs) and field robots seem to be a promising solution to be deployed in crisis situation, such as monitoring disasters from the air, deliver supplies, relay Wi-Fi and cellular phone service or detecting land mine [11].

Recent disasters like the Thailand tsunami 2004, Fukushima nuclear accident in 2011 or the Aircraft maritime crashes along 2014 call for a rapid and effective solutions ready for tasks such as search and locate, aid supplies delivery or communication networks deployment. Multi-robot collaboration can be an effective and fast way to asses these problems providing the area with a physical and digital transport network on those early moments when time is critical.

We propose a multi-robot collaboration platform composed by three different robotic systems. First land and maritime mobile stations base to deploy, coordinate and support UAVs and light-weight fast-speed moving systems. We also explain some coordination tasks between UAVs and mobile stations and inter UAVs/moving systems collaboration, respectively. Also some potential scenarios are presented as a prove of the usability of our proposal.

I. ROBOTIC SYSTEMS

As pointed by [1] (Saffiotti, 2004) most of the robots used for rescue tasks can be classified in 5 types depending on their type of locomotion: (a) wheeled, (b) tracked, (c) legged, (d) airborne, and (e) serpentine. We separate our collaboration platform in three groups. The first group of robotic systems involves mobile stations, either land, mostly wheeled or tracked, or maritime. The second group of systems involves airborne devices (UAVs, commonly known as air drones); and the third group involves light-weight fast-speed moving robots, again either land (wheeled, tracked, legged or serpentine) or maritime, capable to provide fast response capabilities for rescue and saving operations, as well as efficient and quick delivery of small items.

A. Mobile Stations

This type of robotic systems includes either land or maritime mobile stations. Their main function is to

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provide energy supplies and centralized coordination to the other robotic systems, as well as to mobilize heavy equipment and/or bulk emergency supplies. They are big and should be able to support heavy payloads. Therefore land ones would be mostly wheeled or tracked as these movements provide a robust locomotion system able to support the heavy loads they would carry around.

These mobile stations serve as a centralized base for logistics and operations. Due to this they are the first vehicles to be deployed. More than one station can be used in a deployment depending on the requirements of the disaster area to cover and the objective task to conduct.

B. Unmanned Aerial Vehicles

UAVs are aircrafts without a human operator on board. Their flight would have autonomous capabilities although they would be partly managed from the main mobile stations. However they should also be available for remotely flying if the need arises. It is very important that base stations obtain accurate information regarding the UAVs position so they can send proper directions to the UAVs in order to properly manage the deployment of the fleet.

They provide the means to overcome the hard terrain scenarios from disaster environments rapidly moving around the area. This constitutes a key factor as they become a very fast way to set up links for ether physical transportation of items or a quick setup for emergency communications. These systems provide exploratory and search capabilities to the full multi-robot platform. They can also be responsible for the transportation of light-weight items to locations that are inaccessible from, to and between mobile stations, as well as for the setting of dynamic communication networks to facilitate human-human as well as robot-robot communication.

C. Low-weight fast-speed moving systems

These types of systems involve, again, either land or maritime robots, this time able to provide fast response capabilities for rescue and saving operations, as well as efficient and quick delivery of small items.

For this type of robot wheels would provide a fast motion on flat and smooth surfaces, but not on uneven or rough ones. Tracked robots would be slower but can be used in a large variety of rough or slippery terrains or in the presence of steps and stairs. Finally serpentine-like robots would provide promising methods to move quickly in narrowed spaces or quickly reach people in collapsed building scenarios.

In the literature we can find, several example of such robots or tools that can be used for creating them. For instance, [3] (Kohlbrecher et al, 2014) presents hector_slam an open source software module for self-localization and mapping in a degraded urban environment that has been used during several editions of the RoboCup Rescue competition and which has been re-used by different international research groups in a wide variety of tasks.

In [4] (Hirose and Fukushima, 2004) present different kind of “snakes and strings” robots used in rescue operations. Here, snake-like robots are intended to gather useful information thanks to their capabilities for moving through the narrow spaces under collapsed buildings, and the hyper-tether robots are used to assist the snake-like robots as recharging units, or to build mobile robot systems that can move and work around the disaster sites. In addition, the use of the tethers is extended so they can be used as means for power transmission, control, cooperative material transmission and communication, stability, or even anchoring.

II. UAV-MOBILE STATION COORDINATION

In this section we describe the two main collaborative tasks between the mobile stations and UAVs, which are related to the problems of localization and landing, and UAV battery replacement.

A. Localization and Landing

UAVs when in outdoor environment where GPS signal is consistently available the problem of localization is simplified to a great extent. However, localization and mapping is still a complex problem in indoor or other environments where GPS signal is unavailable. Another means of localizing UAV systems is by tracking through external sensors. In such configuration and multiple cameras track the position of the UAV through marks on the UAV or using model based tracking [5]. This approach if well suited for small indoor scenarios but it does not scale well to larger areas.

Active research is being conducted in the area of indoor localization and navigation using on-board cameras and other sensors such as IMU and GPS if available. 3D Visual SLAM [12] and Visual Odometry [13] are the two primary technologies being used to solve this problem. [14] present an interesting approach of localizing UAV with a single camera under uncertainties in outdoor environment. The work in [15] presents efficient camera based pose estimation in real-time using SLAM through visual feature. Using these technologies it is possible for a UAV to map its surrounding and localize itself using on board cameras without relying completely on GPS signals. This gives a major boost to the possibilities of navigation, exploration and manipulation in hazardous environments. Once the UAV is able to localize its position and orientation within the surrounding; this information can be used to execute motion control strategies for landing on stationary surface of a moving platform such as another service robot within the shared workspace. This opens the doors for several possibilities of collaborative task execution between UAVs and other robots with different capabilities.

A. UAV Battery Replacement

A major problem with current UAV technology is autonomy [16]. Even top military devices can only fly for about 40 minutes to one hour. This problem has not a direct solution as augmenting battery power affects the weight of the battery, which requires more energy consumption from the UAV engines and, at the end, the result is faster power consumption rather than increased autonomy time.

The only feasible solution to this problem is by replacing the UAV battery before it completely runs out of power. This is where mobile stations perform one of its most important roles in our proposed multi-robot collaboration platform. The mobile station constitutes a central base for UAV battery changing, which recharges used batteries for a continuous replacement operation as permitted by its own internal power supply. The UAV battery replacement mechanism comprises a rotator cylinder with several docking-socket compounds around its periphery.

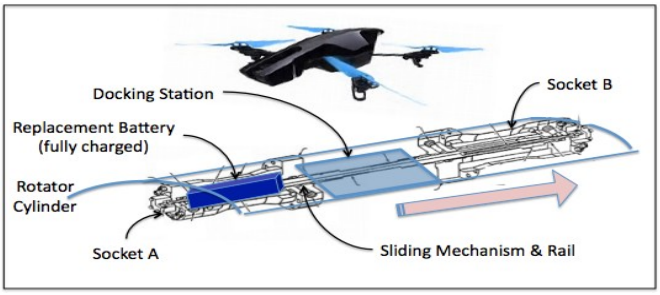

Figure 1. UAV Battery Replacement Mechanism

A seen from Figure 1, the UAV battery replacement procedure is a follows. Let us assume socket A contains the replacement battery (i.e. the one that is fully charged). After the UAV lands in the docking station, the UAV battery is unlocked mechanically. Then, the linear motor moves the sliding mechanism in the direction illustrated in the Figure. As a result, the charged battery is displaced from socket A into the UAV chassis and the uncharged battery is displaced from the UAV chassis into socket B. Afterwards, the replaced battery is mechanically locked and the UAV can leave the mobile station. Meanwhile, the disposed battery starts its recharging process and the sliding mechanism remains in its new position until next battery change is performed (next replacement will occur in the opposite direction bringing back the sliding mechanism to its original position). Finally, the overall cylinder structure rotates to place the next docking-socket compound on top, ready for the next UAV to land in the docking station and proceed to battery replacement.

III. UAV / MOVING SYSTEM COLLABORATION

In this section we describe some inter UAV collaborative tasks of superlative importance in humanitarian relief actions and emergency operations, as well as UAV fast-speed mobile platform collaboration. More specifically we focus our attention in the problems of dynamically establishing a communication network, target identification and localization, and low-weight item transportation.

A. *Dynamic Communication Networks*

A very important issue during emergency situations is the reliability of communication networks. Regardless of the situation, the prompt and efficient setting up of a reliable communication network is of fundamental importance during emergency situations and humanitarian actions in general.

Recent studies have already addressed the problem of communication network reliability during emergency situations [17], [18]. Although not exactly the same problem, but certainly related, several studies have also addressed the issue of delivering communication services to rural areas [19], [20]. Some recent examples include, among others, the use of balloons to deliver communication services to rural areas in America [21].

In our proposed multi-robot collaboration platform, we use UAVs to dynamically provide mobile self-configurable networks for both human-human and human-robot communications. Major technical issues to be accounted for are fault tolerance, self-configuration and energy efficiency, for which proven solutions have been already proposed and implemented [22], [23], [24], [25]. Figure 2 illustrates the proposed configuration for the dynamic communication network.

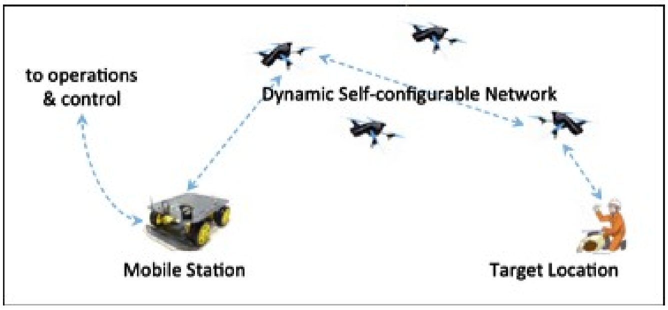

Figure 2. Dynamic Communication Network

As seen from the figure the mobile stations are responsible for linking the dynamic communication network created by the UAVs with the operations & control station. This link can rely either on radio or satellite communications. On the other hand, the dynamic UAV based network provides communication between the mobile stations and the target location. For this, conventional Wi-Fi technology can be used, which can provide about a hundred meters of span for each individual UAV station.

D. *Target Identification and Triangulation*

Self-localization is one of the most important problems to be considered in autonomous robotic navigation [26], [27], [28], which becomes especially important in the case of autonomous rescue robots [29]. In the specific multi-robot collaboration platform presented here, UAVs are the ones responsible for target detection and triangulation. In our proposed approach, UAVs can use GPS information to get a rough estimate of their own position, but will rely on visual information in order to detect and properly localize the targets.

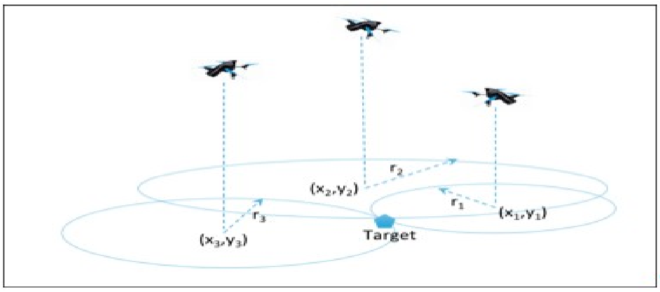

Figure 3. Visual triangulation of target with UAVs

Localization cannot be directly solved by means of any single UAV localization. This is mainly because UAV can estimate their position by using GPS but for orientation, additional compass information is required for determining the bearings. If the UAV system is equipped with a compass, the target localization problem can be easily solved by just referring the current target location on the camera image to the corresponding UAV localization and bearing. On the other hand, if not compass information is available, triangulation of the target position by using tat least two, or more, UAVs will be needed. Figure 3 illustrates this procedure.

As illustrated in the Figure 3, target triangulation can be used for both target localization and UAV bearing estimation. In this problem, a set of values (x,y,r) are to be collected for each anchor point (i.e. UAV), where (x,y) correspond to the estimated coordinates of the UAV and r its distance to the target location. While the coordinates (x,y) can be directly provided by the GPS location system, the distance r has to be estimated based on the current location of the target in the camera image and the current height of the air UAV. By combining the evidence from different UAVs, which must contain the target in their visual field, localization can be conducted by following a standard triangulation algorithm [30].

E. Low-weight Item Transportation

(D'Andrea, 2014) [5] proves technically and economically that UAVs can carry packages of up to 2 kg in a range of 10 km with headwinds of up to 30 km/h. Companies like Amazon, DHL or Google have tested with success the possibility of using UAVs in large cities. However, several issues related with security and law regulation (Rivera et al, 2014) [7] are restricting their full deploy. Meanwhile, and may be due to the high necessity, UAVs are being adopted and improvised to deliver medications, custom 3D printed implants and biomedical devices to remote locations and in resource constrained settings. For instance, the American start-up company Matternet[1] in partnership with Médecins Sans Frontières in Papua New Guinea and Haiti are developing autonomous UAVs to help transport medicines, food, and water to areas afflicted by natural disasters. Besides, in Bhutan, where the ratio of physicians is around 0.3 per 1,000 people, this same company is working with the World Health Organization (WHO) to deliver medications to healthcare providers in spite of the difficult weather conditions and mountainous terrain. However, strong weather conditions like the ones produced by the heavy rains during the monsoon period are current challenges that have been left for a next generation of UAVs (Ghoshal & Medina, 2014) [8].

In a similar manner, DHL is using their "parcelcopter" drone (see Figure 4) to deliver medications and emergency goods daily to the Juist Island located 12 km from Germany's shores. (DHL press, 2014) [9].

Figure 4. Image of the parcelcopter used by DHL to deliver medicines

Finally, UAVs can be used to monitor spread of pathogens and to track land-use changes and disease incidence in real time [10] (Scutti, 2014). In this project, the researchers use UAVs to collect data and map changes in mosquito and monkey habitats in remote areas of Malaysia. Here, UAVs can overpass some problems with satellites such as skipping cloud contamination and low spatial resolution, and are able to produce "stereo" images used for 3D visualizations as well as the generation of digital elevation models. Finally, they are not yet capable of gathering data provided by remote-sensing methods such as radar.

IV. POTENTIAL APPLICATION SCENARIOS

In this section, we focus our attention on two potential application scenarios, in which the proposed multi-robot platform can be of significant help to existent human forces from both the operational and logistic points of view.

A. Emergency Delivery on Land Operation Scenario

A network of UAVs can be a key asset to provide supplies in disaster scenarios where areas are difficult to reach. Depending on the properties of a node (a single aerial vehicle) in the network, it can serve in one or more roles.

A rotorcraft can serve two purposes in such disaster scenarios. One is to act as the informant and another to act as the deliverer. The informant role enables the rotorcrafts to explore an area and communicate what it perceives to the network of aerial systems. In the role of the *deliverer* a rotorcraft would deliver various packages depending on the maximum payload it can handle. At any given time the role of a rotorcraft can be decided dynamically depending on its and the other aerial systems' state.

Figure 5. Fixed-wing UAV

The fixed-wing, Figure 5, aircrafts can serve multiple roles. A fixed-wing aircraft can transport the relief packages from a land-based station to the disaster area. Replacement batteries for rotorcrafts can also be transported using a fixed-wing aircraft. These items can be transferred to the various rotorcrafts when needed similar to mid-air refueling in which fuel is transferred between two military aircrafts - the tanker to the receiver. These fixed-wing aircrafts can also play the role of rotorcraft carriers in which they act as the docking station for multiple rotorcrafts and manage the deployment. They can also be used as antennas for long-range

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[1] http://mttr.net/

communication between the disaster area and a land based station.

F. Life Saving at Maritime Disaster Scenario

This scenario considers the situation in which there is a needed for recovering survivors from the water. In this scenario, the multi-robot collaboration platform includes autonomous maritime robots as mobile stations, a fleet of UAVs and a fleet of robotic rescue buoys, such as the EMILY lifeguard robot [31], which is depicted in Figure 6.

The fleet of UAVs will play a key role on target detection and localization. For identification of human bodies in the seawaters, heat detectors have been proved to provide much better results than conventional image or video. For localization, a triangulation approach, as the one described in section IV.B, is needed. A fleet of UAVs can quickly explore the disaster area identifying victims and reporting their coordinates to the mobile station, from which a fleet of robotic rescue buoys can be deployed one to each of the identified target locations. As each rescue buoys approach its assigned target location, UAVs can continue monitoring the victims to update possible drifts of the original target location and assist the rescue buoys on successfully reaching their targets.

Figure 6. EMILY E.R.S. Lifeguard Robot

V. CONCLUSIONS AND FUTURE WORK

We have described the main technological components and technical challenges for the implementation of a multi-robot collaboration platform for conducting humanitarian relief actions. The proposed platform supports collaborative work and coordination among a fleet of air UAVs, mobile stations and light-weight fast-speed robots at either land or marine environments allowing for the execution of a wide diversity of rescue, surveillance and relief operations.

The main collaborative tasks between the mobile stations and air UAVs, as well as among air UAVs and other fast-speed moving systems, were described in detail. Finally, two potential application scenarios were presented and the utility of the proposed multi-robot platform in such specific scenarios was described.

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