Swarm Optimization of Multiple UAV's for Resource Allocation in Humanitarian Aid and Disaster Relief Operations

Anant Shukla[1][0000-0002-3332-8761], Rishav Choudhary[2][0000-0002-6843-7343] and Malavika Prabhuram[3][0000-0003-4452-9275]

[1,2,3] SRM Institute of Science and Technology, Kattankulathur, Chennai, India
[1] `as4698@srmist.edu.in`
[2] `rishavchoudhary_skc@srmuniv.edu.in`
[3] `mp3602@srmist.edu.in`

Abstract: This paper presents a solution for Humanitarian Aid and Disaster Relief (HADR) using a swarm of UAV's which are capable of mapping the affected area and spotting human and livestock in the disaster stuck area. It will send the surveyed information to the ground station and relief packages can be dropped at specific locations. The swarm consists of hybrid VTOL UAV's capable of vertical take-off and landing in rough terrain and in the absence of a landing strip. The flight time achieved is greater than an hour with a range of 50 km, which is unattainable with a conventional multirotor.

The automated operation is implemented by pre-programming the system with a framework specific to the application. A learning network can be implemented to allow for better efficiency of system in multiple disaster scenarios. Flight stabilization is done with the help of a system of redundant IMU sensors computed on an on-board computer. The UAS is capable of localization and navigating in GPS enabled environments as well as, GPS denied environments with the help of a GPS, compass and inertial navigation fused with Visual Odometry. We use PSO to implement the swarm UAV's, it is required to mitigate mid-air collisions between UAV's in airspace and allocate work among them.

List of Abbreviations:

UAV: Unmanned Aerial Vehicles, **UAS:** Unmanned Aerial Systems, **HADR:** Humanitarian Aid and Disaster Relief, **LRS:** Long Range System, **VTOL:** Vertical Take-off and Landing, **PSO:** Particle Swarm Optimization, **GPS:** Global Positioning System, **IMU:** Inertial Measurement Unit, **AHRS:** Attitude Heading Reference System, **AMSL:** Above Mean Sea Level, **DOF:** Direction of Freedom, **IC:** Internal Combustion, **GCS:** Ground Control System

Keywords: Swarm Robotics, UAV's: Unmanned Aerial Vehicles, HADR: Humanitarian Aid and Disaster Relief, Particle Swarm Optimization, Wireless Mesh Topology

1 INTRODUCTION

1.1 Swarm UAV’s in an HADR Operation

There has been a shift of focus in the field of autonomous UAVs as researchers are investigating problems that involve a swarm of UAV’s rather than a single UAV. Due to this, the focus on multiple UAV system, multiple UAV and their real-time coordination in order to achieve a particular task has gained significant attention.

Since our environment and population size is changing continuously there has been an increase in cases of natural as well as man caused disaster. The disasters which occur are varied in nature and so is their complexity. To battle this, we have to be dynamic in our HADR approach, otherwise the relief measures will be ineffective. For this reason, use of UAV’s is proposed which can simplify our approach. In the case of a natural calamity, UAV’s can be deployed from a ground station to do the surveillance of the area, detect faces and create a dataset of all human faces along with their last seen location and alert the ground station controller to provide assistance. These UAV’s can provide ground assistance like deploying food packages and medical relief packages to disaster struck areas.

To implement swarm UAV’s, it is required to mitigate mid-air collisions between UAV’s in airspace and allocate work among them. The other parts of the UAS are the ground station for control and data analysis, and the communication network between the operator and drones. We use Particle Swarm optimization in order to allocate the work and coordinate between each UAV.

Moreover, in order to carry out HADR operations, the empty weight of the UAV should be less so more of the relief materials can be carried in one sortie. While being light in weight, UAVs should also be resilient enough to carry-out these tasks. To facilitate this feature UAV’s have been manufactured using materials like Carbon fibre, Glass Fibre and high-quality wood which are robust and have higher endurance value, enabling the UAV to operate in extreme conditions.

This paper discusses a swarm-based solution for UAV’s which can be deployed in HADR. These disasters may vary in severity from Earthquakes, Floods, Forest Fires, Chemical spills to a wide range of disasters. This swarm of drones could be used for mitigating the disaster, searching for survivors, mapping the entire area or even dropping relief material.

2 PROPOSED METHODOLOGY

2.1 Development of Swarm System

For the final deployment platform, we have chosen a VTOL fixed wing hybrid design of 2.6-meter wingspan.

For the flight electronics, we have developed a GPS based autopilot, an AHRS and a 6 DOF Inertial Measurement Unit. We are also using a Long-Range System for providing telemetry and video communication up to 40kms. This works on 915MHz and 433MHz. This telemetry transmits data from payload sensors, position, flight information and autopilot.

A completely distributed approach is used in swarm intelligence-based strategy. Each UAV operates autonomously while collaborating with nearby UAV's to explore the disaster struck area and generate the map of the place, report the damage assessment and inform where relief is required. This occurs in three phases.

The first phase consists of a spread-out phase after take-off, that lasts for a fixed duration. This is done to ensure the planes are well placed to explore the area. Here we maximize the minimum distance between airplanes while simultaneously flying in a defined radius, which can be executed in a distributed and local way. Next comes the monitoring phase, where the planes behave the same as in the first phase. However, they also transmit the sensed data via communication link to other agents.

As soon as one of the UAV's detect damage or a human in distress, the third phase begins. This is the search stage where the planes begin collaborating with each other to search the surroundings for other humans in distress, such as humans below building rubble. To select the optimal direction for continuing, each plane uses the data received from N nearest neighbours along with its own data.

To a certain extent, group behaviour is controlled by the decision gap parameter that in turn controls the ratio of exploration to exploitation for search technique. The plane displacement between changes in direction is small for a low value of decision gap parameter, which increases its dependency on other planes in the team. If the parameter is higher, the displacement between direction change is also higher. Hence, the exploration capacity of the strategy is increased which in turn increases probability of detecting more promising areas and parameter D represents the ratio of exploration exploitation to some extent. As a result, when there is a lower number of UAV's, the algorithm is benefitted by an increased D parameter in order to increase its exploratory capabilities and avoid premature convergence to suboptima.

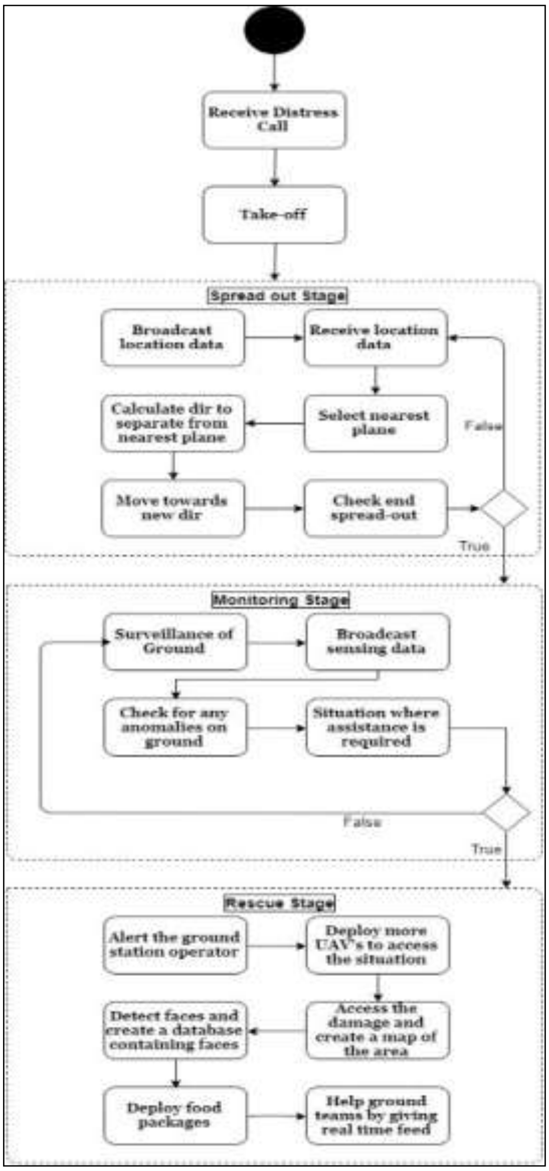

Fig. 1. The three phases in which the HADR action will be taken

2.2 Flight System and Path Planning

The objective of this project is developing an offline path planner for UAV’s that may be used for navigation in terrain that cannot be easily accessed and cause frequent accidents. For this, minimizing path length and maximizing safety from obstacles, an optimization problem must be constructed. Graph-based strategy and fuzzy-logic strategy are also implemented, but path planning is an optimization problem with multiple objectives. This is because though conflicting, it is important to minimize path length and also maximize the safety margin. We assume that the topography of the given terrain is known beforehand via data obtained from satellites or surveillance. A feasible path connecting the known starting and ending points of the flight is needed. Feasibility entails absence of terrestrial obstacles and that at any random point in the path, the curvature must not be greater than a certain limit as an aerial vehicle cannot always cover paths containing large curvatures.

To simplify the computing of collision evasion with obstacles, we assume that the airplane is a point while the boundary of ground obstacles is adjusted according to the UAV size. Here, we assume the UAV path is a B-spline curve that we can control by manipulating various control points. This addresses the following issues:

1. **The Navigation of the UAV using an offline path planner where there are no path restrictions.** Here we assume that the UAV path may cross any point in space and take any shape. This gives us a B-Spline curve path from start to end point.

2. **The Navigation of the UAV using an offline path planner where the vehicle must cross one or multiple specified points.** This may occur if the UAV is used for surveillance of a specific section of the terrain or for dropping a package at a given point. A B-Spline curve is generated here too, but the pre-specified points lie on this curve. As opposed to most approaches for path planning, the given strategy assumes a multi objective task formulation using an evolutionary algorithm. This is beneficial as it generates multiple optimal (Pareto-optimal) paths, with every path containing various trade-offs among many objective functions. With the knowledge of different options of travel in hand, the user has more flexibility and can hence choose the most suitable path given task.

We use representation of B-Spline curves for the representation for UAV paths which are detailed as follows:

1. <u>**Representation of terrain:**</u> The representation of the terrain is in the form of a meshed 3D surface, which is produced by using the mathematical function:

$$\begin{aligned} \mathrm{z}(\mathrm{x},\mathrm{y}) = {} & \sin(\mathrm{y} + \mathrm{a}) + \mathrm{b}\sin(\mathrm{x}) + \mathrm{c}\cos\left(d\sqrt{y^2 + x^2}\right) + \mathrm{e}\cos(y) \\ & + \mathrm{f}\sin\left(f\sqrt{y^2 + x^2}\right) + g\cos(y) \end{aligned} \qquad [1]$$

Equation 1: The mathematical representation of a 3D terrain

where the variables a, b, c, d, e and f are constants that were defined experimentally which simulates rough terrains with various valleys and mountains. [1]

2. <u>Representation of path of UAV using B-Spline curves:</u> UAV paths are best represented by B-Spline curves because, fewer control points are required to define a B-Spline curve, which simplifies the genetic algorithm encoding. When required, complicated paths may also be easily generated using limited control points. B-Spline curves are smooth and without kinks as they guarantee differentiability up to the first order. Change of location of any one point affects the curve shape only in the vicinity of that point.

Two control points for B-Spline curve are the starting and ending points, while the rest are produced by algorithm. The curve is created using an arrangement of discrete control points such that we can calculate curve length and further objective functions.

In order to generate a path that passes through pre-specified points in space in Type II tasks, B-spline curve provides a simple model for generating curves. This is done as follows:

If the reference points of the B-Spline curve are S_0, S_1,....,S_n, and the UAV must pass through point S, choose a value i such that $0 < i < n$ and S_i= S. If the distance between S_{i-1} and S_i is equal to the distance between S_i and S_{i+1}, or distance(S_{i-1}, S_i) = distance(S_i, S_{i+1}) and the control points S_{i-1}, S_i, S_{i+1} are collinear, the B-Spline curve is guaranteed to pass through the point S. Hence, by use of such a mathematical model for the curve, we can tackle the problem of representation of path using B-Spline curves, by forcing UAV to follow the path and traverse through one or more points defined in the 3-D space.

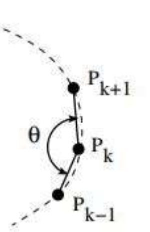

Figure 2: Representation of UAV Path as B-Spline curve

2.3 Flight Control System and Communication Stack

The Ground Control Station communicates between the ground station controller and the UAV’s and receives the visual data from the on-board cameras. The commands for UAV’s are sent from the Ground Control Station.
We are running 2 PC’s as Ground Control Computers. One of them is responsible for receiving telemetry data and running scripts for the UAV’s pertaining to path plan-

ning, etc. The second one is responsible for image and video acquisition. The script on the second running PC is responsible for image processing and facial recognition.

Figure 3: *Screenshot of Ground Communication Station*

2.4 GPS Inaccessible Environment

Aerial vehicles, whether manned or autonomous, are reliant on precise localization for navigating safely and for locating the destination. Reliance on inertial sensors alone for this purpose isn't feasible as the navigation drift gathers over time boundlessly. Generally, UAV's use GPS for complementing inertial sensing in order to provide navigation without drift. Even though this is an easy answer, GPS is not an entirely dependable sensing technique. This is because obstruction and multipaths created by skyscrapers and mountains may break down the satellite coverage. Additionally, as GPS is susceptible to spoofing and jamming, it is dangerous for navigation. Over the past decade, GPS-denied navigation is gaining increased attention, especially in indoor or underwater domains. This is problematic as without a global reference like GPS, only a drifting navigation solution containing unbounded error can be produced by the onboard sensors. Strategies such as utilizing apriori maps and simultaneous localization and mapping (SLAM) for building maps on the fly are to remain localized with onboard sensors.

Merging of development in perception with efficient mapping algorithms form stable visual based localization methods that use feature-rich environments for GPS-denied navigation. Repetitive landmark observations for loop closure is required in order to remove longer term drift errors. This dependency, as well as the payload limitations of small indoor air vehicles, limits the range with which localization algorithms can be demonstrated. [5]

3 MECHANICAL DESIGN

3.1 Overview

The UAS which we have proposed consists of a UAV which is a hybrid VTOL airplane. It combines the benefits of a fixed wing and multi rotor aircraft with transition between these two modes. The design allows for vertical take-off, change to forward flight, cruise flight to destination, and change to hover mode for landing vertically.

The characteristics of the structure include high manoeuvrability in narrow areas and flight time achieved is over an hour, that is unattainable in conventional multirotor carriers. By only using the rotors for take-off, landing, and hovering, the aircraft becomes more robust to cross winds. The drone has been designed so as to achieve a service ceiling of 4000 ft AMSL with an operating range of 50 km.

3.2 Frame

It has a customized frame of carbon fibre and glass fibre with wings made of wood. Light materials are used for reducing the weight of the aircraft and increasing the endurance of the hybrid plane. These materials also help in increasing the power to weight ratio. Hence, the shape of the aircraft body is optimized to improve lift.

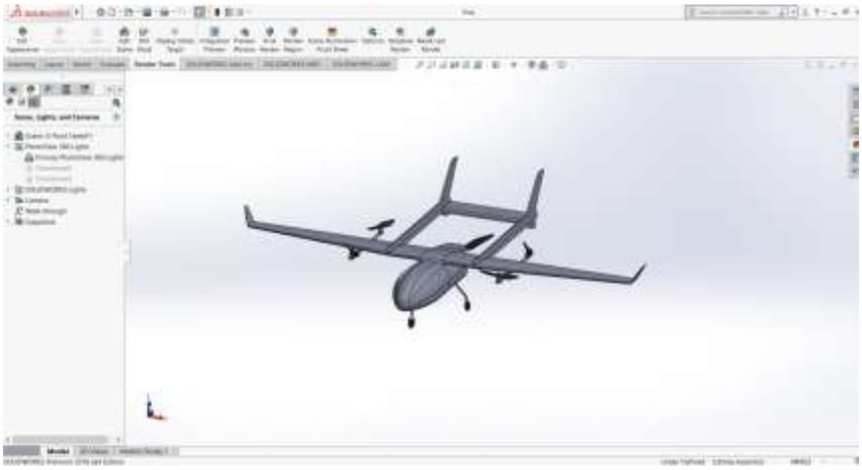

Figure 4: The proposed design of UAV

3.3 VTOL System

The UAV utilizes a VTOL (Vertical Take Off Landing) system which facilitates take off from a level surface and there is no requirement of a landing strip which makes this UAV ideal to be used in HADR region. VTOL is facilitated by incorporating a combination of four rotors in H configuration and an overhead boom for flight stabilization.

3.4 Propulsion

The four motors are mounted below the fuselage to provide a vertical thrust and a single 30cc IC engine is mounted on the fuselage in a pusher configuration to provide the necessary forward thrust.

3.5 Modes of Operation

The aircraft operates in three modes, VTOL, Transition and Fixed wing.

i. **VTOL**: In this phase, the UAV uses the set of four motors to lift, which are powered by lithium polymer batteries. 20” propellers are used which provide the required thrust to lift the UAV.

ii. **Transition phase**: In this phase, the UAV switches from vertical to forward flight and vice versa. This helps to save up the liquid fuel which is required by the UAV for take-off.

iii. **Fixed wing**: Once the engine starts, it propels the UAV in the forward direction and the four rotors are stopped. We are using a high wing aircraft with higher wing loading. It helps to attain more stability while carrying the loads.

3.6 Electronics Housing

Electronics components will be housed in fuselage and all components have been placed accordingly for the proper weight distribution. The bottom of the fuselage will have the holder for camera gimbal which help to aim, record as well as give live feed of the area under surveillance. Another bracket is designed which houses the drop mechanism to drop the relief materials in the desired area.

The UAV has been provided with landing gear to keep the bottom mounted components safe as well as to ensure smooth landing and take-off from the ground. The distinctive characteristics of the hybrid UAV is that it can perform vertical take-off and landing and cover long distance at high cruising speeds. Overall, it is a suitable design for performing aerial surveillance and package delivery.

Table 1. UAV Specification Chart

Parameter	Value
Wingspan	2600 millimeters
Wing Area	0.88 square meter
Empty Weight	6.5kg
Engine	30cc gasoline engine
Propeller	19-inch 8-pitch
Maximum Takeoff Weight	15kg
Payload	4kg
Cruse Speed	120 km/h
Stall Speed	35 km/h
Endurance	2hr
Service ceiling	4000ft AMSL
Power System	Gasoline Electric Hybrid

4 CONCLUSION

This paper presents a UAV swarm solution for coordinating multiple UAV’s that can be deployed for Humanitarian Aid and Disaster Relief. With the help of this system, we can deploy a swarm of drones which can do the surveillance of the disaster struck area, broadcast their status to surrounding UAVs and the ground station and determine the most promising direction to move in.

These UAV’s can be deployed in various situations like Earthquakes, Floods or other calamities and relief packages of weight up to 2 kg can be dropped to the people needing assistance. The system is capable of detecting faces and creating a database consisting of all human faces detected with their last known location.

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