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A Fully Autonomous Search and Rescue System Using Quadrotor UAV

Kheireddine Choutri[1], Mohand Lagha[1] and Laurent Dala[2]

[1]Aeronautical Sciences Laboratory, Aeronautical and Spatial Studies Institute, University Blida1, Algeria
[2]Department of Mechanical and Construction Engineering, Northumbria University, United Kingdom

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Abstract: In order to deal with critical missions a growing interest has been shown to the UAVs design. Flying robots are now used fire protection, surveillance and search & rescue (SAR) operations. In this paper, a fully autonomous system for SAR operations using quadrotor UAV is designed. In order to scan the damaged area, speeds up the searching process and detect any possible survivals a new search strategy that combines the standard search strategies with the probability of detection is developed. Furthermore the autopilot is designed using an optimal backstepping controller and this enables the tracking of the reference path with high accuracy and maximizes the flying time. Finally a comparison between the applied strategies is made using a study case of survivals search operation. The obtained results confirmed the efficiency of the designed system.

Keywords: UAV, SAR, Autopilot, Optimization, Trajectory Generation, Targets Geo-Localization.

1. INTRODUCTION

Infrastructure conditions are affected during a disaster case, when communication lines are disrupted, highways are blocked and buildings are collapsed. In this case, roads are blocked with rubble and the disaster area is totally inaccessible. Subsequently, due to the fact that the likelihood of staying alive is diminished as time progresses, the need for urgent assistance for the survivors is imperative. The need for robot assistant in crisis management is shown.

We can find UAVs for SAR apps in the literature [1]. In addition to dealing with various fields, such as: human detection/localization [2], mission planning [3], networking/data processing[4], collaborative SAR missions [5], and supported UAV assignment/trajectory planning [6]. Depending on the environment and the situation of the targets, several types of SAR missions are identified. Survivals could be on the mountains in an event of avalanche[7,8], in a marine[9], facing a fire[10], or even in a closed building [11]. Authors in [12] explain the Autonomous Unmanned Aerial System (AUAS), namely the ROLFER (Robotic Lifeguard for Emergency Rescue). The objective of this system is to provide SAR services. Fortunately, the above works describe the different parts of the SAR system, but no one has presented a fully designed autonomous system that takes into account all the components contributed (i.e. mission planning, autopilot system, search strategy and targets geo-localization).

Authors in [13] analyzed the search goals on the basis of greedy heuristics and alternative algorithms and Markov's partly observed decision. Moreover, The authors of the [14] bio-inspired, self-organized search strategy are proposed. In addition in [15] search strategies provided by the international maritime and civil aviation organization. They published annually in IAMSAR (International Aeronautical and Maritime Search and Rescue) and manual are used. Although several heuristic and probabilistic problem-solving techniques are being developed for SAR search problems, the published procedures still have estimated solutions and largely not cover the integrity of the search field and the possibility for detection/observation model to query their actual relative performance predicted.

Quadrotors are type of Vertical Take-off Landing (VTOL) systems able to hover with vertical takeoff landing. For an overview of quadrotors modeling and identification the reader may refer to [16]. Compared to the fixed-wing UAVs, the VTOL capability gives them a big facility for survivals detection. However, they are dynamically unstable, multi-variable, highly coupled systems with limited onboard energy. In order to deal with

E-mail:k.choutri@gmail.com,mlagha-aerospatiale@univ-blida.dz,laurent.dala@northumbria.ac.uk

these drawbacks, it is necessary to design an autopilot that stabilizes the quadrotor and allows it to track the desired SAR strategy trajectory. Many works have been published on the control of quadrotor [17-21], the designed controllers were for the sake of stabilization, regulation and trajectory tracking. In fact, SAR missions outdoor, critical, long endurance missions. The need of control performance, energy optimization and robustness is fundamental. Where all the previous controllers may fail to deal with this raised issues. Hence, controller design that maximizes the flying time and has a good set point tracking (meets the SAR operations requirements) is a real design problem.

This paper aims to design a fully autonomous SAR system with respect to all the requirements of a typical SAR operation. The efficiency of the designed system is proofed via a study case scenario. The contributions of the paper are:

1- The designed system will use quadrotor to scan the disaster area, collect information about any possible survivals, and send back their positions to the base station.
2- New Search strategy that combines the standard searching strategies with the probability of detection, which then, speeds up the searching process and covers the integrity of the searching area in order to detect all the possible targets.
3- Introducing a novel autopilot design using a non-linear optimal backstepping controller in order to stabilize the vehicle while tracking the search paths with good performance even in presence of disturbances and maximize the flying time.
4- Comparison between the applied SAR strategies is made using a study case of survivals detection.

Throughout this paper, a particular attention is paid to the tracking accuracy and energy consumption of the control strategy considering some performance criteria, such as the Integral Absolute Error (IAE).

This paper is structured as follows: Section 2 presents the proposed SAR method. The various SAR techniques and direction patterns are discussed in Section 3. Section 4 addresses the trajectory generation, sensor coverage and target detection algorithms used in the navigation system. Section 5 lays out the complete quadrotor dynamic model as well as the attitude and trajectory control techniques using the non-linear optimal backstepping controller. Comparison of simulations and SAR strategies is given in Section 6. At the end of the day, Section 7 ends and makes potential proposals.

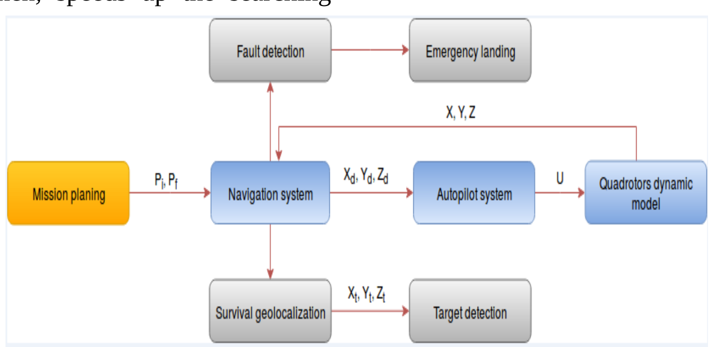

Figure.1. SAR System

2. System Design

The SAR structure built consists of the following parts, as seen in Fig.1. :

1- *Mission planning:* At this level the human operator selects the desired search strategy. Once selected, the system generates the optimal path to be tracked (i.e the coordinates of initial and final point (P_i and P_f) for every leg from the path).

2- Navigation system: This sub-system is the heart of the designed system, it includes the following functions: first it provides the autopilot sub-system with the optimal path to track (X_d, Y_d, Z_d) for each time step of the path leg. The sub-system also uses a survivals geo-localization algorithm to estimate the target coordinates (X_t, Y_t, Z_t) and send back their positions to the base station based. The target detection depends on the probability of detection and the sensor range of the embedded camera. Finally the system monitors any failures that can occur such as a divergence from the desired path, an engine failure, or the battery energy consumption. Once happened an emergency landing occurred, this option would save the quadrotor from a sudden crash. Moreover the base station is informed about the mission failure.

3- Autopilot System: This sub-system has to track the search strategy path generated by the navigation sub-system. The autopilot is designed using a double loop control strategy for the position and attitude tracking based on backstepping controller. The designed autopilot aims to assure the path tracking accuracy and the quadrotor stability.

3. Mission Planning

As illustrated in Fig.2. The proposed mission planning aims to use UAVs to deploy the disaster area, detect any possibility of a victim presence, and report the collected information to the control ground station.

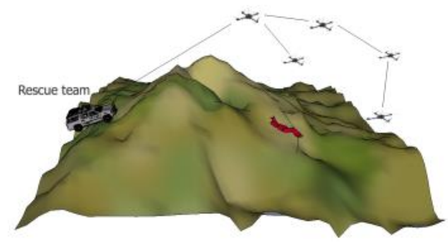

Figure 2. SAR Operation Using Quadrotors UAVs

For surface and aircraft facilities to search effectively, search patterns and procedures must be pre-planned so ships and UAVs can cooperate in coordinated operations with the minimum risks and delay. In order to meet varying circumstances, standard search patterns are defined.

A variety of search techniques are recognized by the International Maritime Organisation and the International Civil Aviation Organization. They are published annually in the IAMSAR manual. They are designed to provide easy and effective visual search patterns that can be used in a variety of contexts. Regular search patterns for the area you want are as follows:

- Scan for Parallel Track and Creeping Line
- Scan for Expanding Square
- Search for Contour

The following sections analyze the key features of the previous standard search patterns and their circumstances.

3.1. Creeping and Parallel Track scan line

Both parallel track and creeping line searches are based on covering (sweeping) the search field by preserving parallel tracks as seen in Fig.3.

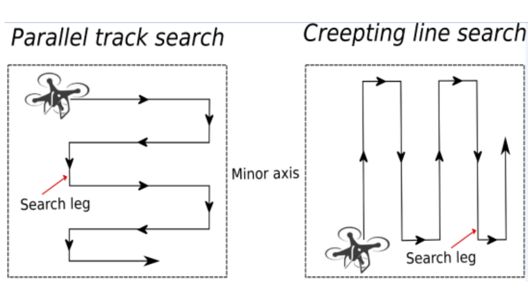

Figure 3. Parallel track search and Creeping line search pattern

One distinction between these two is the direction of the search legs, i.e. whether the search legs are parallel to the long sides (major axis) or the short sides (minor axis) of the search field.

3.2. Expanding Scan Square

The pattern starts in the middle of the search region and stretches out into concentrated pitches, as seen in Fig.4. (search technique).

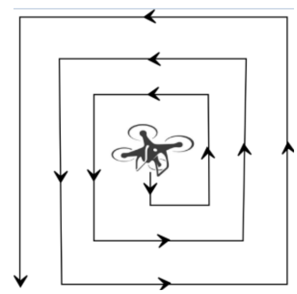

Figure 4. Expanding Square Search Pattern

3.3. Contour search

A descent spiral movement may appear as seen in Fig.5 as the pattern for the quest of this Search Strategy. This search technique is introduced around mountainous orvalleys with sharp elevation drops because in those conditions the other search models are not realistic.

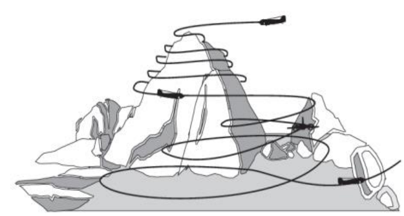

Figure 5. Contour Search Pattern

4. Navigation System

4.1. Trajectory Generation

The search trajectory generation problem can be solved by optimizing the distance between the initial and final points for each leg from the search strategy pattern.

By assuming that the running costs are proportional to average velocity, the objective function , Φ , can be defined as:

$$\Phi = \frac{1}{T}\int_0^T \sqrt{(P_1\,\dot{x}^2 + P_2\,\dot{y}^2 + P_3\,\dot{z}^2)}\; dt \qquad (1)$$

Where P_1, P_2, P_3 are weighting factors.

4.2. Sensor Coverage

The ability of the sensor to identify the victim under the prevailing conditions would greatly impact the UAV's maximum altitude.

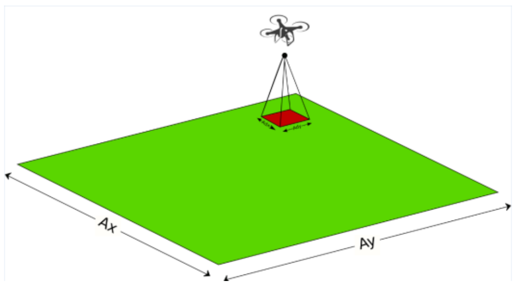

Figure 6. Sensor Coverage

Note that the sensing areas on the earth cover the surface $A = A_x * A_y$ (green area in Fig.6.) a set of $A_d(h)$ cells, where the surface $A_d = A_{dx} * A_{dy}$ (red area in Fig.6.) depends on the altitude of the UAV. With the UAV's height the measurements of the sensing zone increase.

The sensor model for false positive and false negative models can be modeled as follows:

- The probability of sensing a target at height h in the presence of the target = $1-\beta_h$
- The probability of not sensing a target at height h in the presence of the target = β_h
- The probability of not sensing a target at height h with no target = $1-\alpha_h$
- The probability of sensing a target at height h with no target = α_h

With α_h ($0 \leq \alpha_h \leq 1$) and β_h ($0 \leq \beta_h \leq 1$) are the false alarm and missed detection probabilities. The values accorded to α_h and β_h at the different searching heights h are summarized in Table. I.

In order to preserve an appropriate αh and βh values, a fixed scan high of 100 meters above Earth should be used to prevent the risk of missing detection and to mitigate the incorrect alerting.

TABLE I. OBSERVATION MODEL

Alttitude (m)	α_h	β_h
50	0.243599	0.000000
100	0.028369	0.000000
150	0.026099	0.046211
200	0.001110	0.046745

4.3. Target Detection

Algorithm. I. introduces the algorithm used to search the hall and records any target identification on the base station, based on the scanning technique. The mission is accomplished any time all the targets are identified (whether the number is limited) or the area in the hall is scanned, if there is any error, the base station is also informed of mission circumstances for all the instances.

Algorithm 1. Targets Searching and Detection Algorithm

Initialization
P_i (X_i,Y_i,Z_i) = Initial location
Ad (Adx ,Ady) = Detection Area
A (Ax , Ay) = Searching Area
Update(Searching Strategy)
While *true* **do**
 P=P’
 GetObservation(P)
 If *target detected* **then**
  Report Base Station
 end
 Searching Strategy (P)
 P’=NextMove(P)
end

5- AUTOPILOT SYSTEM

5.1. Quadrotor Modeling

For representing the dynamical model of a quadrotor, the following set of equations is used:

$$\dot{R}(t) = R(t)S\big(\omega_b(t)\big)$$

$$J\dot{\omega}_b(t) = -S\big(\omega_b(t)\big)J\omega_b(t) + \tau(t) \qquad (2)$$

With: J introduces the inertia matrix, R the rotation matrix, $\tau(t)$ the input torque and $S\big(\omega_b(t)\big)$ is the skew-matrix of the angular velocity $\omega_b(t)$ as in Equ.3. :

$$S\big(\omega_b(t)\big) = \begin{bmatrix} 0 & -\omega_{b3}(t) & \omega_{b2}(t) \\ \omega_{b3}(t) & 0 & -\omega_{b1}(t) \\ -\omega_{b2}(t) & \omega_{b1}(t) & 0 \end{bmatrix} \qquad (3)$$

Consequently the complete dynamic model is as follows:

$$\begin{aligned}
\ddot{\varphi} &= \frac{J_y - J_z}{J_x}\dot{\theta}\dot{\psi} + \frac{J_r}{J_x}\dot{\theta}\Omega + \frac{l}{J_x}U_2 \\
\ddot{\theta} &= \frac{J_z - J_x}{J_y}\dot{\varphi}\dot{\psi} - \frac{J_r}{J_y}\dot{\varphi}\Omega + \frac{l}{J_y}U_3 \\
\ddot{\psi} &= \frac{J_x - J_y}{J_z}\dot{\varphi}\dot{\theta} + \frac{U_4}{J_z} \\
\ddot{x} &= \frac{1}{m}\{(C_\varphi S_\theta C_\psi + S_\varphi S_\psi)U_1\} \\
\ddot{y} &= \frac{1}{m}\{(C_\varphi S_\theta C_\psi - S_\varphi S_\psi)U_1\} \\
\ddot{z} &= \frac{1}{m}\{C_\varphi S_\theta U_1\} - g
\end{aligned} \tag{4}$$

Where m and g represent the vehicle's mass and gravity vector respectively. J_r is the moment of inertia of the rotor.

The model developed in Eq.4. can be rewritten in the state-space form $\dot{x} = f(x) + g(x,u)$ with $x = [x_1, \dots, x_{12}]$, is the state vector of the system such as:

$$x = [\varphi\,\dot{\varphi}\,\theta\,\dot{\theta}\,\psi\,\dot{\psi}\;x\;\dot{x}\;y\;\dot{y}\;z\;\dot{z}]^T \tag{5}$$

From Equ.4. and Equ.5. the following state representation can be obtained:

$$f = \begin{cases}
\dot{x}_1 = x_2 \\
\dot{x}_2 = a_1 x_4 x_6 + a_2 x_4 \Omega + b_1 U_2 \\
\dot{x}_3 = x_4 \\
\dot{x}_4 = a_3 x_2 x_6 + a_4 x_2 \Omega + b_2 U_3 \\
\dot{x}_5 = x_6 \\
\dot{x}_6 = a_5 x_2 x_4 + b_3 U_4 \\
\dot{x}_7 = x_8 \\
\dot{x}_8 = \frac{U_1}{m} U_x \\
\dot{x}_9 = x_{10} \\
\dot{x}_{10} = \frac{U_2}{m} U_y \\
\dot{x}_{11} = x_{12} \\
\dot{x}_{12} = \frac{1}{m}(C_{x_1} S_{x_3} U_1) - g
\end{cases} \tag{6}$$

With:

$$\begin{cases}
a_1 = \left(\frac{J_y - J_z}{J_x}\right), a_2 = \left(\frac{J_r}{J_x}\right) \\
a_3 = \left(\frac{J_z - J_x}{J_y}\right), a_4 = \left(-\frac{J_r}{J_y}\right) \\
a_5 = \left(\frac{J_x - J_y}{J_z}\right) \\
b_1 = \left(\frac{l}{J_x}\right), b_2 = \left(\frac{l}{J_y}\right) b_3 = \left(\frac{1}{J_z}\right)
\end{cases}
\quad
\begin{cases}
U_x = (C_{x_1} S_{x_3} C_{x_5} + S_{x_1} S_{x_5}) \\
U_x = (C_{x_1} S_{x_3} C_{x_5} - S_{x_1} S_{x_5})
\end{cases}$$

5.2. Controller design

The trajectory tracking controller consists of two parts as depicted in Fig .7.

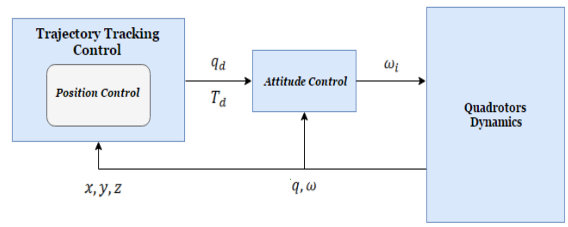

Figure 7. Block diagram of the proposed control structure

The inner loop for attitude control and the outer loop for the position control. The position controller generates the desired attitude vector q_d and the desired trust T_d for the attitude controller.

Let's consider the tracking error:

$$e_i = \begin{cases} x_{i_d} - x_i & i \in \{1,3,5,7,9,11\} \\ \dot{x}_{(i-1)_d} - x_i + k_{(i-1)} e_{(i-1)} & i \in \{2,4,6,8,10,12\} \end{cases} \tag{7}$$

Using the Lyapunov functions as:

$$V_i(x) = \begin{cases} \frac{1}{2} {e_i}^2 & i \in \{1,3,5,7,9,11\} \\ V_{(i-1)} + \frac{1}{2} {e_i}^2 & i \in \{2,4,6,8,10,12\} \end{cases} \tag{8}$$

By applying the following algorithm:

For i =1

$$\begin{cases} e_1 = x_{1_d} - x_1 \\ V_1 = \frac{1}{2} {e_1}^2 \end{cases} \tag{9}$$

And:

$$\dot{V}_1 = e_1 \dot{e}_1 = e_1(\dot{x}_{1_d} - x_2) \tag{10}$$

Thee_1 stability is derived using the Lyapunov function as follow:

$$x_{2_d} = \dot{x}_{1_d} + k_1 e_1 \tag{11}$$

With $k_1 > 0$ the Equ.17. is then: $\dot{V}_1 = -k_1 {e_1}^2$. Let consider a variable change by making:

$$e_2 = x_2 - \dot{x}_{1_d} - k_1 {e_1}^2 \tag{12}$$

For i = 2:

$$\begin{cases} e_2 = x_2 - \dot{x}_{1_d} - k_1 {e_1}^2 \\ V_2 = \frac{1}{2} {e_1}^2 + \frac{1}{2} {e_2}^2 \end{cases} \tag{13}$$

And:

$$\dot{V}_2 = e_1\dot{e}_1 + e_2\dot{e}_2 \quad (14)$$

Finally:

$$\dot{e}_2 = a_1x_4x_6 + a_2x_4\Omega + b_1U_2 - \ddot{x}_{1_d} - k_1\dot{e}_1 \quad (15)$$

The control signal U_2 is obtained such that $\dot{V}_2 = e_1\dot{e}_1 + e_2\dot{e}_2 \leq 0$ as follow:

$$U_2 = \frac{1}{b_1}(-a_1x_4x_6 - a_2x_4\Omega + \ddot{\varphi}_d + k_1(-k_1e_1 + e_2) + k_2e_2 + e_1) \quad (16)$$

In order to extract the control signals the same steps are followed:

$$\begin{cases} U_3 = \frac{1}{b_2}(-a_3x_2x_6 - a_4x_2\Omega + \ddot{\theta}_d + k_3(-k_3e_3 + e_4) + k_4e_4 + e_3) \\ U_4 = \frac{1}{b_3}(-a_5x_2x_4 + \ddot{\psi}_d + k_5(-k_5e_5 + e_6) + k_6e_6 + e_5) \\ U_x = \frac{m}{U_1}(\ddot{x}_d + k_7(-k_7e_7 + e_8) + k_8e_8 + e_7) \\ U_y = \frac{m}{U_2}(\ddot{y}_d + k_9(-k_9e_9 + e_{10}) + k_{10}e_{10} + e_9) \\ U_1 = \frac{m}{C_{x_1}C_{x_3}}(g + \ddot{z}_d + k_{11}(-k_{11}e_{11} + e_{12}) + k_{12}e_{12} + e_{11}) \end{cases} \quad (17)$$

With: $U_1 \neq 0$ and $k_i > 0$ $\quad i \in \{2, \dots, 12\}$

All the control parameters are obtained using Multi-Objective Genetic Algorithms such as in [29], and shown on Table.II.

Table II. Control parameters

Controller	k1	k2
Attitude	[0.8 0.8 0.5]	[0.1 0.1 1.2]
Position	[0.2 0.2 3]	[0.1 0.1 1.5]

6. Simulations Results

The second part discusses the track of the different SAR strategies patterns and compares them over a case study of survivals SAR operation. Three types of search areas are designed for the SAR strategies in order to simulate different scenarios: a flat, mountainous and a hybrid area for the study case. All the areas are supposed to be with a total surface of 1000m * 1000m.For the mountainous simulation environment. The major challenges to UAVs in the experiment are an exponential mechanism that emulates mountains:

$$z(x,y) = \sum_{i=1}^{n} h_i * \exp\left(-\left(\frac{x - c_{x_i}}{g_{x_i}}\right)^2 - \left(\frac{y - c_{y_i}}{g_{y_i}}\right)^2\right) \quad (18)$$

This function gives altitude of the given coordinate (x, y) in the simulated terrain. Where, h_i controls height of peak i; c_{xi} and c_{yi} mark central position of peak i; g_{xi} and g_{yi} control peak gradient in x and y orientation respectively.

The integral absolute error (IAE) is used to judge the controller's performance. The index IAE is expressed as follows:

$$IAE = \int_0^t |e(t)|\, dt \quad (19)$$

6.1. SAR strategies path tracking

6.1.1 Expanding Square Search (ESC)

Let's suppose that the quadrotor scans a flat surface from a departure point $P_0\{X,Y,Z\} = \{500, 500, 0\}$ then track the reference trajectory generated by strategy.

As shows Fig.8. the quadrotor UAV was able to pass over all the prescribed waypoints, and track the reference path using straight lines without any oscillations and with a high accuracy. The control outputs are shown in Fig.9. where a good accuracy of the path tracking is presented specially for the altitude hold. High attitude degrees (up to 1 rad) are used during curving movements when passing from a waypoint to another. Fig.10. shows that the control signals are within the limits of the actuators. These results show that all the constraints and the assumptions considered during the modeling and the control design are successfully respected.

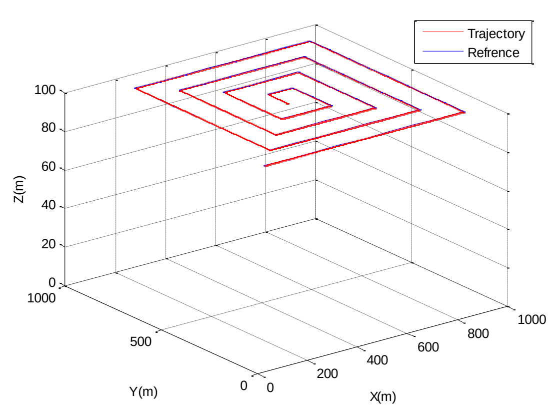

Figure 8.ESC Trajectory Tracking

6.1.2 Parallel Track (PT) and Creeping line Search (CLS):

For this strategy the quadrotor is supposed to scan the same flat area used in the precedent strategy but this time from two different departure points $P_{0C}\{X,Y,Z\} = \{50, 50, 0\}$ for the CLS and $P_{0P}\{X,Y,Z\} = \{950, 50, 0\}$ for PT strategy. The obtained results for both CLS and PT 3D trajectory tracking are shown in Fig.11. & Fig.12. respectively.

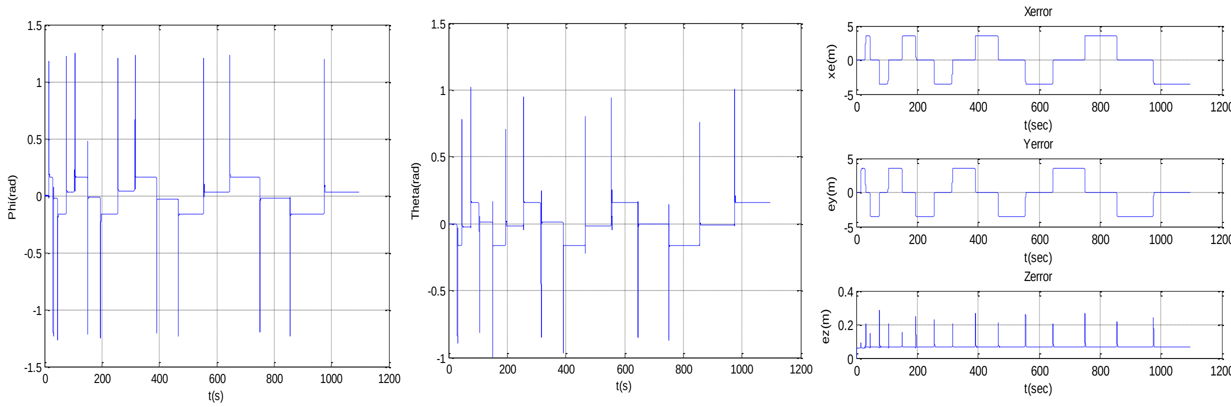

Figure 9. ESC Control Outputs

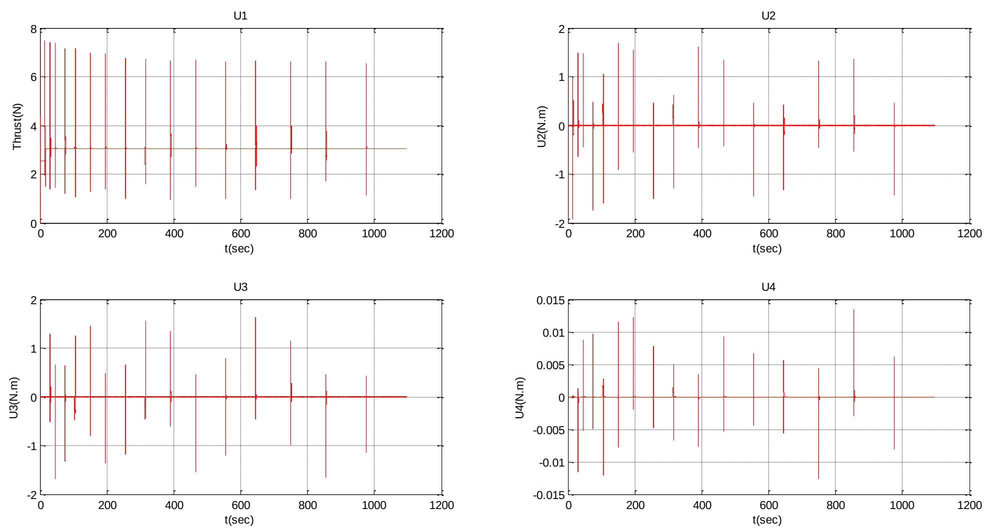

Figure 10. ESC Control Inputs

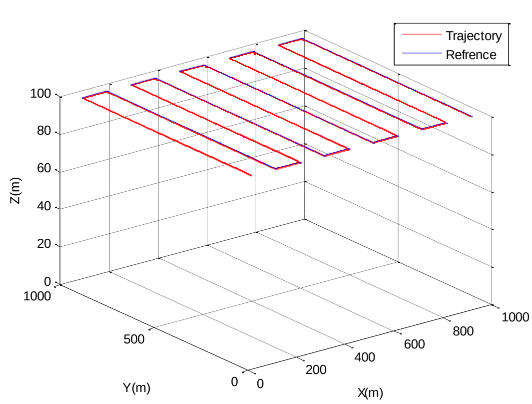

Figure 11. CLS Trajectory Tracking

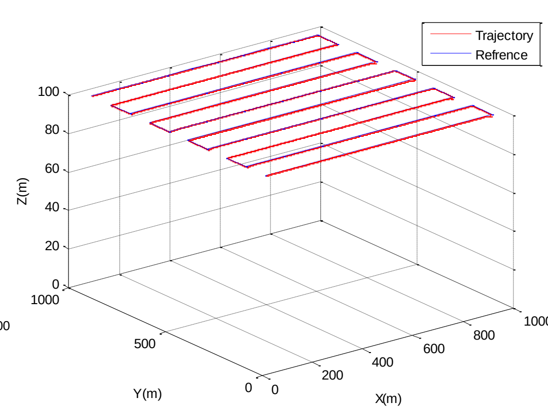

Figure 12. PT Trajectory Tracking

From Fig.11. & Fig.12. it is clear that the quadrotors was able to track the waypoints with high accuracy in both cases and scan all the desired area. Fig.13.&Fig.14. decipate the control outputs, where the controller was able to maintain the quadrotors stability during the path tracking and spetially on curving corners when changing the waypoints.

The obtained control inputs illustrated in Fig.15. & Fig.16. for the CLS and PT strategies are the same and remain within the desired functional range of the quadrotors engines.

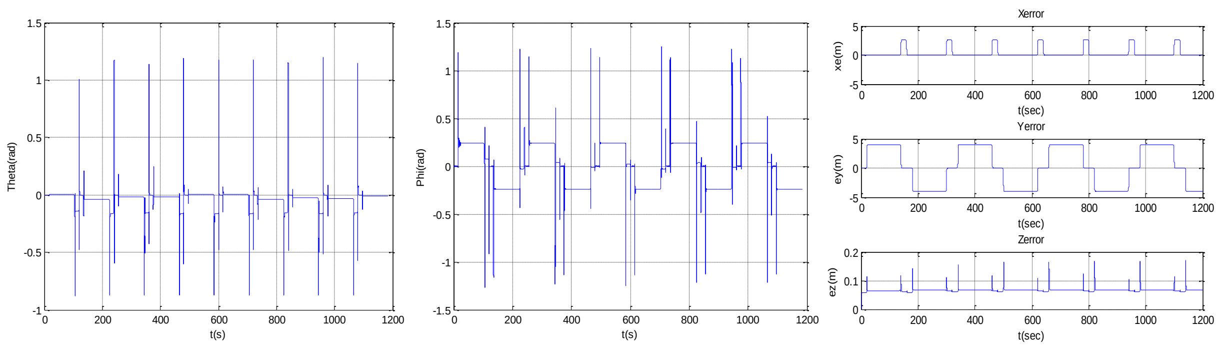

Figure 13. CLS Control Outputs

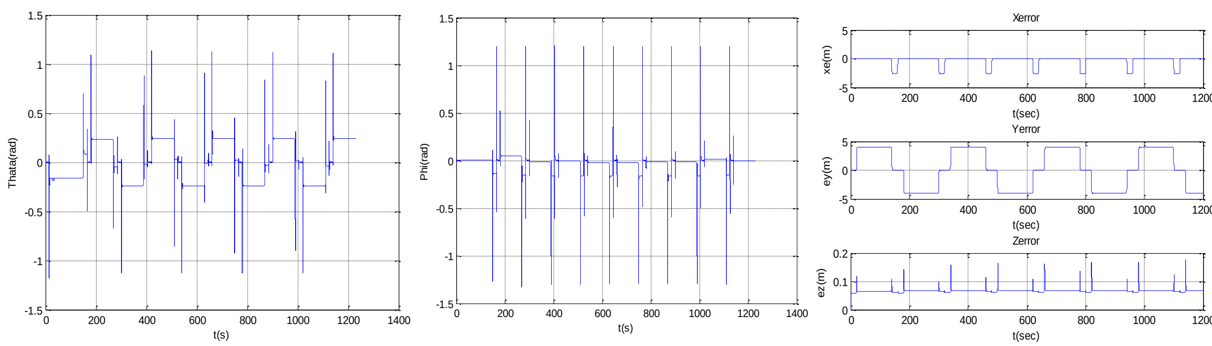

Figure 14. PT Control Outputs

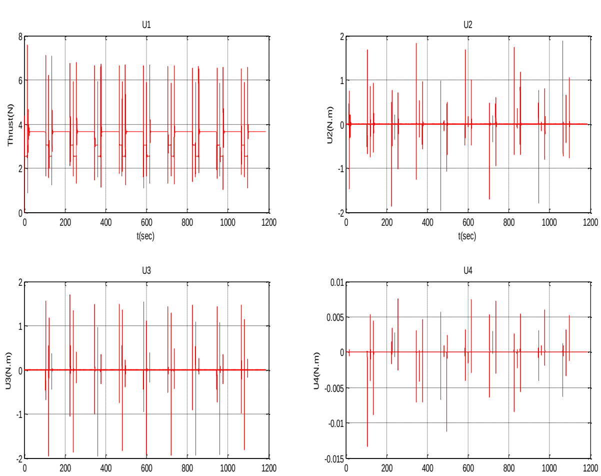

Figure 15. CLS Control Inputs

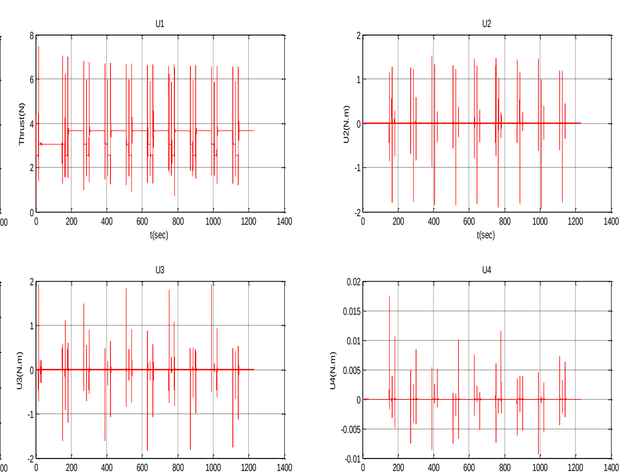

Figure 16. PT Control Inputs

Table .III. shows the comparison between the different SAR strategies.

From the obtained results it is clear that the controller was able to optimize the energy consumption and with high accuracy for all the strategies, but the PT strategy is supposed the best since it offers a more complete covered area with an acceptable searching time and controller path tracking accuracy.

TABLE III. FLAT AREA SAR STRATEGIES COMPARISON

Stratigie	Search Time (min)	Battery Consumption (%)	Covered area (%)	Fitness (IAE)
ESC	17	76.31	80	0.1584
PT	20	81.22	100	0.1534
CLS	20	80	100	0.8161

6.1.4 Contour Search (CS)

This strategy is often used when scanning a mountain area because of its spiral path that creates a contour.

A virtual mountain with a 100m of altitude is simulated, where the quadrotor is starting from a departure point $P_0\{X,Y,Z\} = \{50 , 50, 0\}$ and track the desired path around the mountain. Fig.17. & Fig.18. & Fig.19. illustrate the simulation environment as same as the obtained trajectory generation and tracking of the quadrotor. The obtained results are shown in Table IV.
Fig.17. shows that the quadrotor was able to track the generated path and cover the entire mountain with a very high accuracy, and a minimum of battery consumption (Table IV) in less than 6 min.

The control outputs dissipated in Fig.18. are validating the controller effectiveness and optimality where a high accuracy is reached with low attitude degrees. The obtained control inputs shown in Fig.19. oscillates with low frequency supported by the quadrotor engines.

TABLE IV. CS STRATEGY SIMULATION RESULTS

Stratigie	Search Time (min)	Battery Consumption (%)	Covered area (%)	Fitness (IAE)
Spiral	6	13.44	-	0.0046

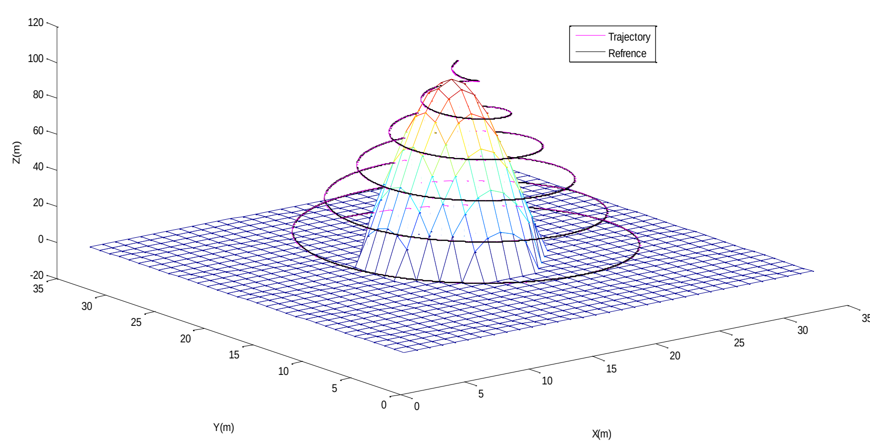

Figure. 17. CS Trajectory Tracking

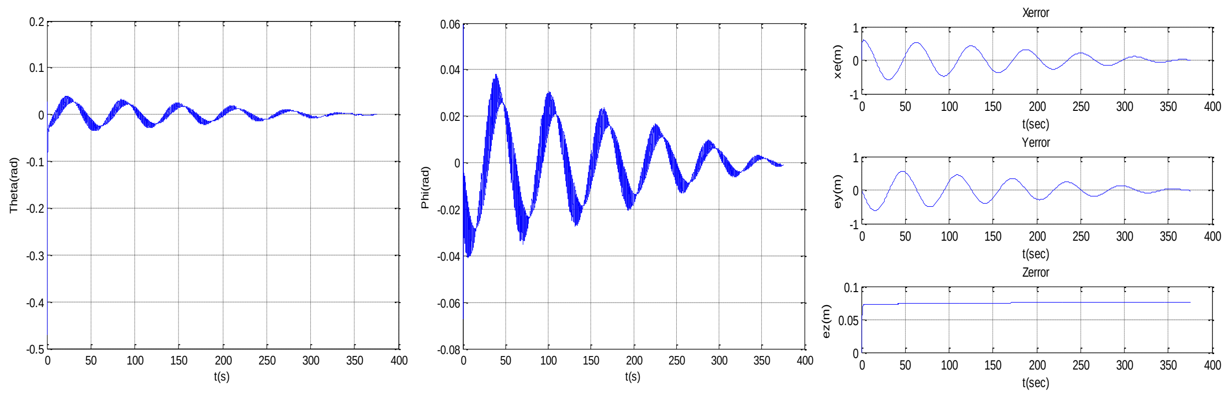

Figure. 18. CS Control Outputs

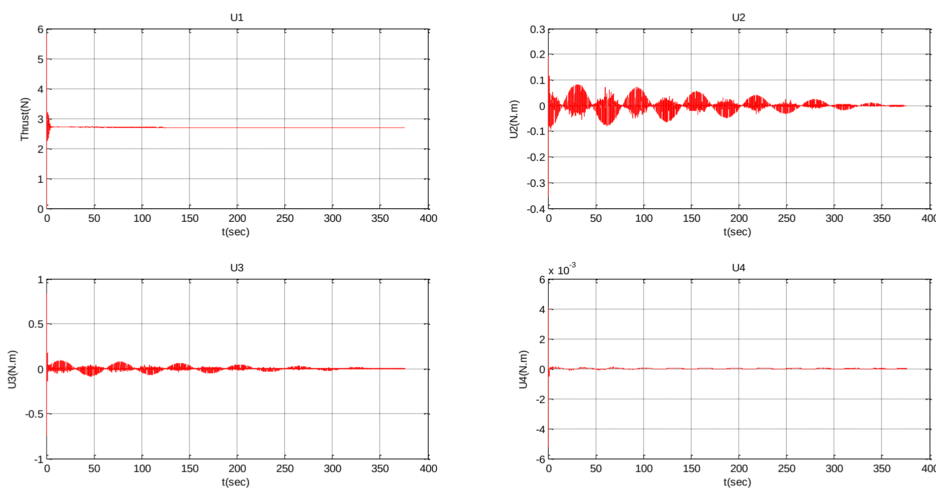

Figure. 19. CS Control Inputs

6.2 SAR STRATEGIES COMPARAISON

In this section the study case is to scan a hybrid flat and mountainous area and search for possible survivals. The surface is of 1000m * 1000m and contains two mountains of 100 m of altitude. All the previous SAR strategies are applied in order to find 10 persons (red dots in Fig.20.) that are randomly distributed all over the area.

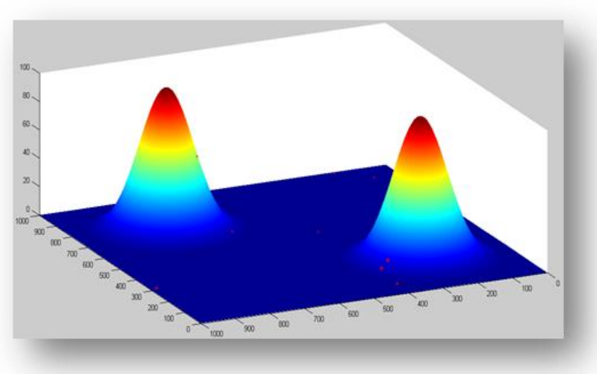

Figure. 20. SAR Study Case Environment

A comparison between the different SAR strategies is made, the obtained results are shown in Fig .20. From Fig .21. it is clear that only the CLS and PT strategies were able to cover the desired area and detect all the 10 survivals but after a long time (about 25 min). For the ESC strategy only 70% of the survivals was detected in less than 20 min. For the CS strategy, 60 % of the survivals are detected in only 9 min, which is a very interesting time when comparing with the other strategies for the same percentage. The explication behind these results is that the CS is local concentrated searching strategy that covers the surfaces with a high detection probability which means a less searching time, where the other strategies are more generalized searching strategies that cover the entire area and detect all the possible survivals but with a long searching time. The departure searching point is also an other comparison parameters that must be cited, because generally it is so critical from a point and not from the other due to the complicated nature of the SAR operations.

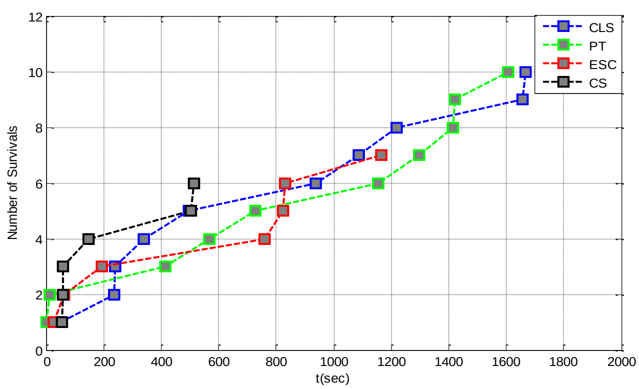

Figure. 22. SAR Strategies Comparaison

7 Conclusion

This paper studied the design of a fully autonomous SAR system that includes all the necessary elements during a typical SAR operation.

For the autopilot system a double loop control structure based on a non-linear optimal backstepping controller was applied. The designed controller was able to deal with the SAR operations requirements such as:vehicle stability, searching trajectories tracking with good performance. The obtained results of the trajectory generation and the path tracking were judged to be satisfactory since the quadrotor has successfully followed the desired SAR strategy generated path within the functional range and with respect to all the limitations.

A study case of an area scanning for possible survivals geo-localization and detection was simulated. Different SAR strategies were applied and compared; the final results speed up the searching process and cover the integrity of the searching area in order to detect all the possible targets.

The next step for this research will focus over the use of a UAV swarming as a multi-agents system to reduce the research time and improve the efficiency. A combination of the different SAR strategies can also applied to benefit of the advantages of every strategy.

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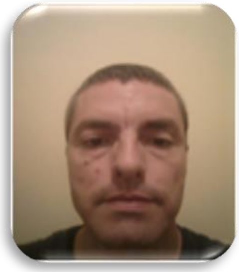
Kheireddine CHOUTRI was born in Constantine, Algeria, on 26 February 1992. He received the Master degree in Aeronautical Engineering from the Aeronautics Institute of Blida, Algeria, in 2015. In this same year, he started his doctoral studies in the field of Aerial Robots in the Aeronautics and spatial studies Institute of SAAD DAHLAB Blida 1 University - Blida, Algeria. His current research activities include UAV Guidance, Navigation and Control , Multi agents system.



Mohand LAGHA was born in Tizi-ouzou, Algeria, on 30 June 1976. He received the Engineer Diploma in Aeronautical Engineering from the Aeronautics Institute of Blida, Algeria, in 2000, the M.Sc. in Aeronautics Sciences from the SAAD DAHLAB University of Blida, Algeria, in 2003. He received the Ph.D. degree (with honors) in Aeronautical Engineering at the Aeronautics Department of SAAD DAHLAB Blida University on 3rd July 2008, and the habilitation (HDR) on September 2010. At present he is Full Professor in Aeronautics and spatial studies Institute of SAAD DAHLAB Blida 1 University - Blida, Algeria. His current research activities include estimation theory, radar signal processing, weather radar signal analysis and UAVapplications.

Laurent DALA received his PhD in Aerospace Engineering from the University of Manchester. He also graduated from the French Grandes Ecoles in Aerospace Engineering (Ecole Superieure des Techniques Aerospatiales-ESTA) and in Mechanical and Electrical Engineering (Ecole Speciale des Travaux Publics, du Batiment et de l'Industrie-ESTP). He is a Fellow of the Royal Aeronautical Society, a Chartered Engineer (CEng and Eur-Ing) and the Past President of the Aeronautical Society of South Africa (AeSSA). Laurent was titular of the Chair in Aerospace Engineering and Head of the Aerospace Research Group at the University of Pretoria (South Africa) till October 2016. He has a very long and successful experience in applied and fundamental research in international aerospace projects, such as in the FP6 European project NACRE (New Aircraft Concepts Research), where he was the Chairman of the Advisory Group. His research is based on a multi- and cross- discipline approach, combining analytical/engineering (using Asymptotic Theory for instance), experimental and computational methods. In 2016, Laurent joined Northumbria University where he is the Head of Mechanical Engineering. His fields of expertise are Aerodynamics, Aeroelasticity, Aeroacoustics, Flight Mechanics and Multidisciplinary Optimisation Methods.