Towards a Heterogeneous Navigation Team of Aerial-Ground Robots Based on Fuzzy Image Processing

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***Abstract*—In this paper, aerial-ground robots system has been presented that composed by ground and blimp robots. The blimp robot equipped with single camera in order to scan the environment to detect the ground robot and any obstacles in the environment. The detection algorithm has been designed based on fuzzy edge detection and shape-color features techniques. The blimp will share the environment map to the ground control station. Then, the global optimal path with avoiding obstacles is generated by enhanced genetic algorithm by modified the search A*. Several experiments were carried out in a simulation as well as indoor environments to verify the system applicability. The proposed robotic system shows good results in simultaneous navigation and mapping applications.**

***Index Terms*—fuzzy edge detection, aerial-ground, navigation, genetic algorithm, computer vision, path planning**

I. INTRODUCTION

Your goal is to simulate the usual appearance of papers in a Journal of the Engineering and Technology Publishing. We are requesting that you follow these guidelines as closely as possible.

Actually, in order to cooperate among multiple robots there is a need of an interface which addresses various issues such as communication protocols and a ground control station in order to monitor and control the multiple robots. Multi-robot systems can be used in cooperative planetary exploration, search and rescue in areas affected by disasters. Recently, the unmanned aerial vehicles UAVs have been used extensively in exploration, surveying and reconnaissance applications. In fact, a combined between UAV and ground robots have been studied and developed because such system can provide aerial imagery and perception along with ground robot GR inspection capabilities. Some of those applications are focused on using GR to help in dangerous tasks, as well as to explore large unstructured environments. Since the GR must be able to navigate from a start to target destination with suitable and collision-free motion path, then, this navigation problem consists of using the sensing capabilities to obtain the representation of unknown obstacles in such a manner that it is useful for navigation [1]. Therefore, blimp and GR have the peculiarity to be endowed with different characteristics. By merging all those capacities and characteristics together, it is possible to develop a unique sensing and perception collaborative system. In other words, as a typical lighter-than-air vehicle, the autonomous blimp robot is a unique and promising platform for many different kinds of applications, such as telecommunication, broadcasting relays, disaster guard, and scientific exploration [2]. The blimp robot not only creates a good opportunity to explore the environments, but also it increases the efficiency of the exploration since it has many advantages over the small airplanes robots such as long time hovering, much less energy consumed, very low noise and cost efficiency which made them ideal for exploration of areas without disturbing environment [3].

On the other hand, the increasing in the applications of robots has made the computer vision an important factor in such research area not only to put cameras in place of human eyes, but it is also to accomplish the entire task as autonomous as possible. Perhaps the most common way to classify the computer vision in robots depends on the complexity degree of the applications. The common process in vision system is called a visual tracking that is analyzing of sequential images to identify a reference pattern and follow a moving interest point or defined object over time on the image. There are many tracking methods in which the algorithms based on features, color and shape [4]. The visual odometry analyzed images to extrapolate the robot space movement relies on the image motion, then to estimate the position and orientation of the robot [5]. The next process is the visual navigation which uses the visual data to determine object position as well as the safe path [6]. Concerning to visual navigation, several reactive and deliberative navigation approaches have been proposed such as in structured environments using white line recognition [7], in corridor navigation using View-Sequenced Route Representation [8], or more complex techniques combining visual localization with the extraction of valid planar region [9], or visual and navigation techniques to perform visual navigation and obstacle avoidance [10]. In [11], they study a multi-robot

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system depends on a vision-guide autonomy quad-rotor and describe a methods to take off, land and track over the ground robot. However, the quad-rotor does not provide information to the ground robot about the surrounding environment. Also, [12] presents a motion-planning and control system based on visual servoing without cameras on board. In [13], they integrated and fuse vision data from the aerial and ground robots for best target tracking and for allowing leveraging of multi-domain sensing and increase opportunities for improving line of sight communications. These studies and others have been tested for several purposes such as environment monitoring [14], fire detection and fighting [15] and multi purposes collaborative tasks [16].

In this paper a strategy that takes advantage of mixed robotic system heterogeneity for collaborative navigation and obstacle avoidance is addressed. In other words, the GR navigation is supported by visual environment map from the blimp robot. The blimp robot will scan the environment to detect the GR and the obstacles. The fuzzy edge detection and the shape-color features technique have been used to scan the environment and detect the objects. These maps will send directly to the ground station which has the proposed approach using Enhanced Genetic Algorithm modified by the search A* algorithm to find the optimal trajectory and path for the GR.

This paper is organized as follows. First, after this introduction, fuzzy image processing based on edge detection is stated. Section III presents the navigation and the genetic algorithm. Then, we present the experiments results in IV. Finally, the conclusions and the future works are addressed.

II. Fuzzy Image Processing

As it was already mentioned, the features extracted with the camera shipped on the blimp were obtained by applying computer vision techniques. Edge detection is one of the most important algorithms in image processing and plays an important role in the higher level processing [17, 18]. Edge is defined as object border, and extracted by features such as gray, color or texture discontinuities [19]. Many of edge detection algorithms such as Sobel, Prewitt and Robert are based on gradient value [20] where the estimated gradient pixel value higher than a threshold is counted as an edge pixel. Because threshold value is often empirically determined, it is possible to lose some edges or over estimation occurs. Another important gradient based edge detection method is canny algorithm which solves an optimization problem to detect the edges [21]. The tradeoff between detection and location of edge pixels make a problematic inaccuracy. By changing threshold values, edge detection rate increases, but the accuracy of edge locating decrease. Because of noise, low contrast, and some other factor edge detection methods that have been mentioned cannot give satisfactory results [22]. In addition, fuzzy logic is a powerful problem-solving methodology with a myriad of applications in control and information processing. Fuzzy can provide a remarkably simple way to draw definite conclusions from vague information. In a sense, fuzzy logic resembles human decision making with its ability to work from approximate data and find precise solutions for the issues. Different algorithms for fuzzy based edge detection have been proposed [23]-[31]. However, all of these approaches were simulated in MATLAB or other software. In this work, we studied edge detection methods based on fuzzy logic control FLC which is developed by C++ and implemented in real OpenCV package and in the on-board the blimp robot. This FLC was designed with 9 inputs and 1 output.

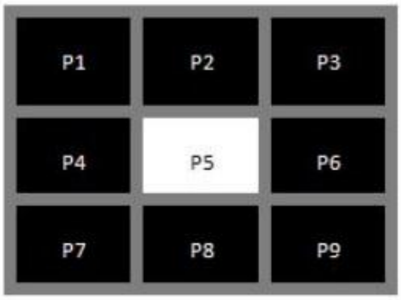

Figure 1. 3*3 fuzzy filter mask

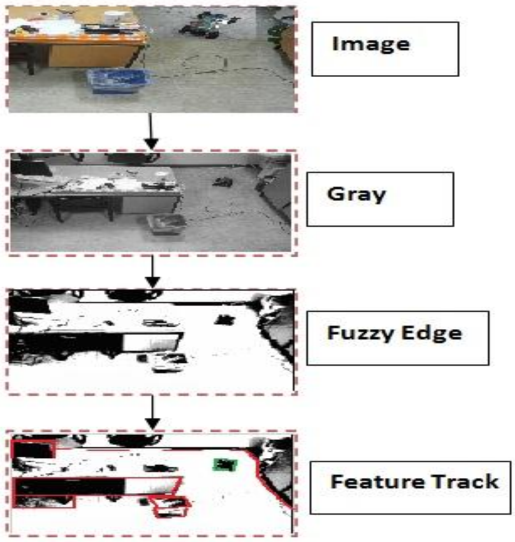

Figure 2. Image processing algorithm

The task starts by detecting the edge points of the image by taking every pixel with its eight neighbors as it is shown in Fig. 1. This whole structure is tuned to function as a contrast enhancing filter to segment the taken images. Then, each pixel is processed with fuzzy rules base in order to consider the pixel as edge or not (under consideration as black, white or edge). The collection of all these edge points is taken as the final edges of the image. The image processing algorithm sequence is shown in Fig. 2. The whole procedure is accomplished by two steps. First, define a set of contours in order to address the ground robot shape and color. The square features are extracted similarly to the aforementioned procedure to define the obstacles. The algorithm has 9 inputs with two linguistic variables (B: Black, W: white) and the output has three linguistic variables (B: Black, E: Edge, W: White) as it is shown in Fig. 3 and Fig. 4. In fuzzy reasoning, the most important fuzzy implication inference rule is the generalized modus ponens (GMP), which uses an IF-THEN rule that implicitly represents a fuzzy relation. The use of fuzzy rules is important when the causal link between domains is not known. Usually partial knowledge about the relation between these domains exists in the form of fuzzy rules. The fuzzy rules define the connection between input and output fuzzy (linguistic) variables. The rule consists of two parts: an antecedent and a consequence part. In this work we have 52 base rules. A typical rule, which describes this simple fact as:

IF $Input_1$ is B_1 AND $Input_2$ is B2… AND $Input_9$ is B_9 THEN Output is E

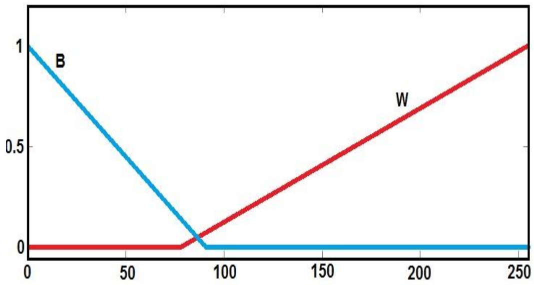

Figure 3. The membership functions for inputs

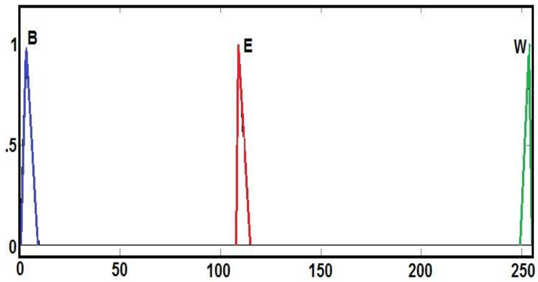

Figure 4. Output membership functions

III. Navigation and Genetic Algorithm

Figure 5. Blimp robot

This section describes the algorithms used for the navigation of both the ground and blimp robots. The blimp robot had been designed and developed in our previous works [32]-[35].It has control system to provide the blimp with the main behaviors such as the height (altitude), stabilization around the Z-axis as well as the ability to avoid obstacles. The control system also provides a pose stabilization algorithm that attempts to keep the blimp as steady as possible in order to obtain a better image as it is shown in Fig. 5. Also, the blimp robot could detect the ground robot and follow it in the environment.

The main objective of the blimp robot in this research is to detect the ground robot and obstacle in the environment by using fuzzy edge detection algorithm. Then, the environment data will send to the ground control center GCC which has the ability to communicate with the blimp robot as well as the ground robots in the system in order to make the system heterogeneous. Fig. 6 shows the GCC. This interface was used to receive all flight data acquired onboard and supervised explicitly and the aerodynamic data are displayed and plotted in real time and stored to provide the information for further flight investigation and analysis. The command editor could be used in case of emergency events which could not be automatically solved, so the operator has ability to change the control parameters during mission. In this work, the data transfer from the blimp to the GCC. Then, GCC will transfer the data to PC that generates the trajectory by using the enhanced approach (Genetic Algorithm and A*). Moreover, the optimal trajectory needs long time to be designed, thus, the PC that running MATLAB approach will generate it. Then, the final map trajectory could be transferred to the ground robot in order to improve the robot navigation system in the environment as it is shown in Fig. 7. Whilst the trajectory means a time-based profile of position and velocity from start to destination target, the paths are based on non-time parameters. This helps to have smooth movement during the parametric Cubic Spline function of trajectory and it must give continuous velocity and acceleration. Basically path planning problem is a form of geometrical problem which can be solved by geometrical description of mobile robot and its workspace, starting and target configuration of mobile robot and evaluation of degrees of freedom (DOF) of mobile robot. Trajectory planning in general requires a path planner to compute geometric collision free path. This free path is to be converted into a time based trajectory [36]. The optimal trajectory has many characteristics such as collision-free, short, smooth, security, short time to minimize the energy consumption of the robot. In fact, the new hybrid approach based on performing modification of A* and GA has been introduced in our previous works [37]-[39]. This approach has ability to increase the searching ability greatly of robot movement towards optimal solution state. In addition, the approach can find a multi objective optimal path for mobile robot navigation as well as to use it in complex static environment. However, when the environment is complex and the number of the obstacles is increasing, the basic GA may face some difficulties to find a solution or even it may not find one. The classical method and modified A* search method in initialization stage for multi objectives has been proposed to overcome these drawbacks. Therefore, in order to avoid fall into a local minimum complex static environment, the proposed approach has several genetic operators such as deletion operator and enhanced mutation operator by adding basic A* to improve the best path. In addition, the approach could reduce the energy consumption of the ground robot since it takes into account the time as an objective.

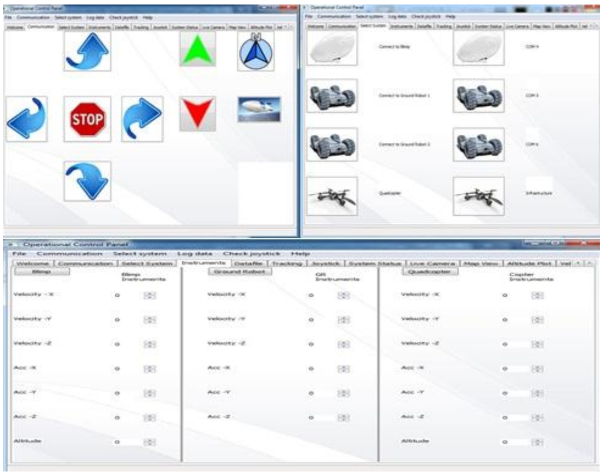

Figure 6. Ground control center

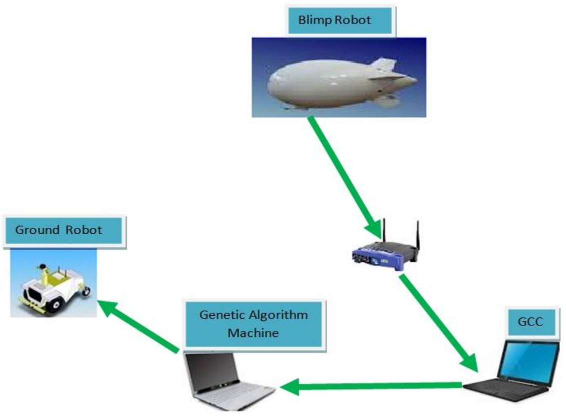

Figure 7. The whole process and communication

IV. The Experimental Results

In order to verify the complete proposed system, some experiments were conducted. During these experiments the blimp robot was flying at a certain altitude (2 meter) as it is shown in Fig. 8. The experiments were done in lab in where the background is very clear and there is not any disturbance except for the illumination variance. The ground robot and the obstacles would be identified and detected in the video sequence by the fuzzy edge detection and the shape-color features algorithm.

The mobile robot velocity profile in x and y direction is shown in Fig. 9. Fig. 10 shows the velocity of the robot with respect to time for optimum and it starts increasing from 0 to maximum 0.75 m/s and the robot might reduce its speed in case there is a static obstacle close to its path in order to turn left or right. Also, the optimal trajectory generating of mobile robot navigation is illustrated in Fig. 11. Therefore, the optimal trajectory (red) and path (blue) that have been simulated and generated are shown in Fig. 12.

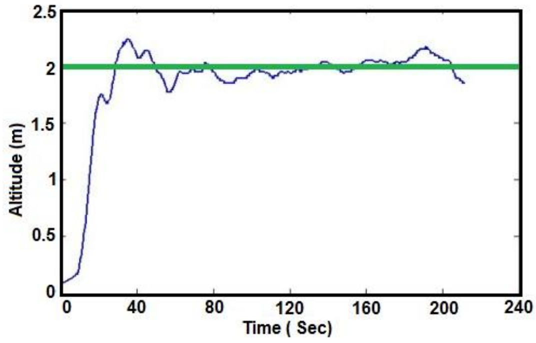

Figure 8. Altitude of the blimp robot.

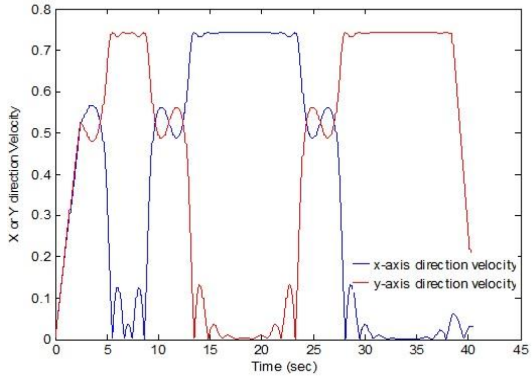

Figure 9. Mobile robot velocity profile in x and y direction

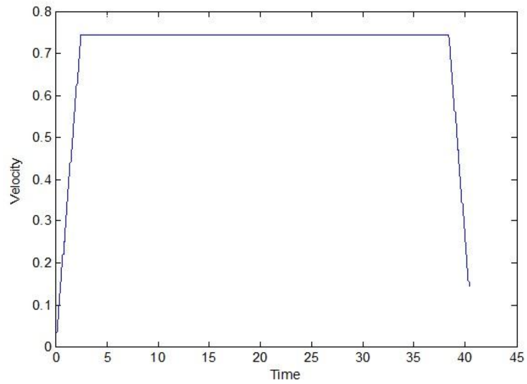

Figure 10. Mobile robot velocity profile of optimal trajectory

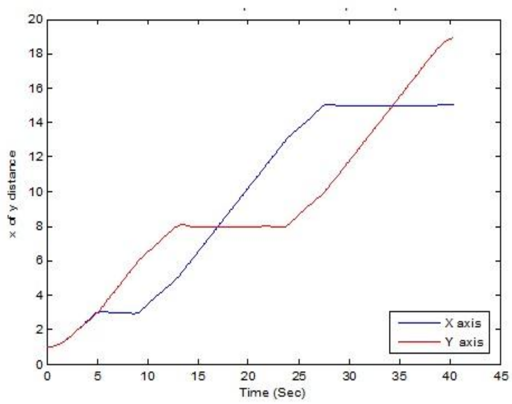

Figure 11. Optimal trajectory generating of mobile robot navigation

Figure 12. Trajectory and path for the ground robot

V. Conclusion

In this paper, a project towards a heterogeneous system has been presented based on blimp and ground robots. The blimp will explore the environment and detect the objects based on the fuzzy based edge detection algorithm. The fuzzy system includes appropriate defined membership function and fuzzy rules, decide about pixel classification as edge or non-edge. Then, these data were simulated to find the optimal path and trajectory for the ground robot by using an simulation approach that combines enhanced genetic algorithm and modified A*. The proposed approach also provides the robot with the optimal velocity based on the optimal trajectory and path. Also, these obstacles are memorized and a global map with all obstacles was built to enable the system to merge reactive and deliberative methods. In the future, more extensive tests and more complex control are needed to create more complex architecture which allows in next phases to build local-maps. Also, the robot will run the genetic algorithm by itself and communicate with the blimp robot without using GCC in the future.

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