Intelligent Tracking and Trajectory Navigation Approach for Blimp Robot

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Abstract: Recently, there has been increasing interest in autonomous navigation for the Unmanned Airship Vehicles (UAV) in indoor environments since they have the ability to navigate in low altitude and low speed for exploration applications. In this paper, we presented a two layer fuzzy approach to light-weight embedded blimp system navigates in unknown environment. The fuzzy rules base for the first layer is trained using possibilities distributions and fuzzy sets based on experimental data. This approach is able to control the main behaviors of the blimp: avoid obstacles, maintain at certain altitude, track ground robot and rotate blimp around OZ axis. It has the ability to quickly provide a possibly trajectory for the blimp in case a wall or object is detected in the path. The experiments results show that the trajectory navigation system is efficient and reliable in unknown environments.

Keywords: Blimp Robot, Fuzzy Logic, UAVs, Tracking, Computer vision.

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1. Introduction

The blimp robot is a special type of airship without rigid structure body. It has better performance than small helicopters due to some advantages such as low speed, very low noise, long time hovering, and much less energy consumed [1,2]. The autonomy systems are able to self-control and drives the important behaviors without depend on any external control. In order to design an autonomous system that is applicable for different environment conditions, a high degree of autonomy for the software system is required. As the complexity of the robotic systems in structured environments increases, the using of intelligent control approaches increases on robotics areas. However, an important navigation problem is automatic control of altitude and horizontal movement. A second important navigation problem for the blimps is obstacle detection and collision avoidance. To perform the navigation task for the blimp, it is required to maintain at constant altitude and constant velocity or pose. In order to fulfill this demand, it is necessary to measure the blimp's velocities and pose with an accurate sensor. There are several researches to handle these navigation behaviors and studied the robust control. Some of them had been used the classical controls methods, whilst others used intelligent control features [3-5]. Fengzhi Dai et al. [6] introduced the fuzzy logic algorithm for the airship. In this work they developed the hardware of the system and used fuzzy logic to control the navigation of the airship along the shortest flight path. Rao et al. [7] proposed a fuzzy logic controller which was based on the dynamics of the vehicle. The mathematical model of kinematics and dynamics using spatial vectors is presented and tested by simulation takes into account the structure of the drives in the form of two engines placed symmetrically on the sides of the object [8]. The nonlinear dynamic model of the low altitude airship with six degree of freedom is introduced and the flight conditions and the balance between forces and moments acting on the airship are analyzed [9]. Adaptive control algorithm was designed to resolve the problem of a stratospheric airship with imprecisely unknown inertia parameters [10]. The stability of the closed-loop control system was proved by using the Lyapunov stability theory. Bestaoui introduced algorithm to generate a desired flight path to be followed by an autonomous airship. The space is supposed without obstacles. However, as there is six degrees of freedom only three inputs for the airship in a low velocity flight was used. However, this study is based on simulation without any practical experiments [11]. Hiroshi introduced propose an approach to the motion planning of the blimp via the application of Markov decision process (MDP). The proposed approach consists of a method to prepare a discrete MDP model of the blimp motion and a method to maintain the effect of the unknown wind on the blimp's motion. The performance of the methods is examined by dynamical simulation of the blimp in the environment with wind disturbance [12]. In [13], a trajectory tracking controller was designed. The desired trajectories were constrained to be trimming, i.e., of constant linear and angular velocities. The method for planning six DOF trajectories for under actuated unmanned airship and for computing the open-loop controls was used. Beginning with a smooth inertial 3D trajectory to be tracked by the center of mass of the vehicle, the proposed algorithm, based on the dynamics of the system, provides the 3D corresponding body-fixed linear and angular velocities and the vehicle orientation, yielding a feasible 6 DOF trajectory. The derived trajectory is further used to compute the three available open-loop controls [14]. Then they designed a novel trajectory tracking controller for a six DOF AUV, guided by one propeller and moving surfaces. Simulations showed robustness in dynamic parameters' errors [15]. In [16], they planned dynamically feasible trajectories for an under actuated robotic airship moving in 3D. Muller presented a highly effective approach to autonomous navigation of miniature blimps in mapped environments which apply a multi-stage algorithm to accomplish strongly goal directed tree-based dynamic planning. It performs path guided sampling and optimally selects actions leading the robot towards sampled sub-goals. The approach can quickly provide a partial trajectory, which is extended and refined in the consecutive planning steps. The navigation system has been implemented and is able to reliably operate a robotic blimp in a real-world setting [17]. However, most of these blimps are with a payload of several kilograms and/or was implemented by a simulation 3D software. Besides that, most of these researches do not deal with the behaviors of the sensors during the navigation. The challenge in this project was to integrate low-weight sensors in an embedded system and to provide software architecture platform for complex behaviors like autonomous navigation and localization as well as detection and tracking ground robot. Therefore, in this paper we proposed an approach model by the possibility distribution and fuzzy sets to deal with these drawbacks and uncertainties. We design the fuzzy knowledge base experimentally. First, we test the ultrasonic sensor's behaviors. Second, we study the effect of the blimp's angle view and the distance between the blimp and the detected objects. Then, the fuzzy control takes as input the data provided by the ultrasonic sensors and delivers information for eventual obstacles or information about altitude in respect to blimp's position. Also, the blimp fuzzy approach has high significant levels of autonomy, especially the ability to change trajectory path during the flight. This autonomy systems are able to self-control and drives the important behaviors without depends on any external control. In order to design an autonomous system that is applicable for different environment conditions, a high degree of autonomy for the software system is required. For this purpose, the implementing of computer vision algorithms , which is suitable running on the limited performance of the onboard blimp system and able to provide accurate information for the control, has been developed.

2. Architecture of the Blimp Robot

The main core unit is distributed among Arduino-UNO and the Gumstix-Overo-Air-COM which runs a full Linux operating system. Other sensors have been mounted on gondola such as Caspa camera, Inertial Measurement Unit (IMU), four SRF02 sensors were mounted on front of gondola to be used for avoidance obstacles as well as fifth sensor to verify the altitude distance during the flight. The aerodynamic data are displayed and plotted in real time and stored for further flight investigation and analysis in ground control center [18]. The visual system based on Speeded Up Robust Features technique SURF [19] has been used in order to localize and detect a ground vehicle based on the performance, repeatability, accuracy and speed as illustrated in Fig. 1 and Fig. 2. This visual tracking algorithm with fuzzy controller were proposed in our previous work [20]. The SURF allows having good detection with scaled invariant, rotation invariant, and robust against noise.

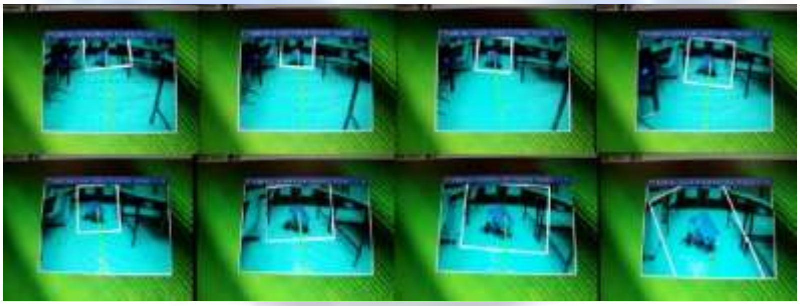

Figure 1. SURF algorithm to detect ground robot

Figure 2. Blimp Robot Follows the Ground robot

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In fact, a metallic light arc sheet had been designed in our department in order to mount the four ultrasonic sensors as shown in Fig. 3. After many experiments based on the sensor characteristics, we have found that the angle 18^o between any two adjacent sensors is the optimal value for such experiments. These sensors have responsibility to detect any object in the path for avoiding obstacles controller as well as use the possibilities of their readings in order to change the trajectory and the direction around OZ of the blimp robot.

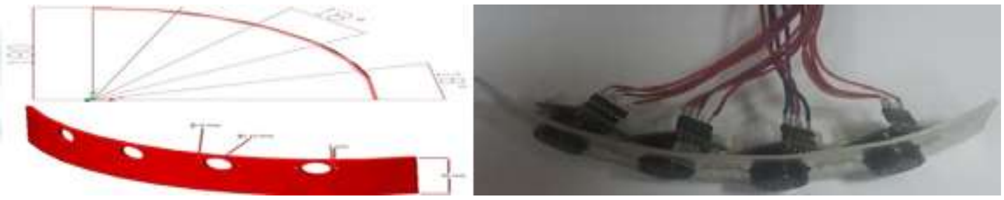

Figure 3. Sensors Arc mounted on Gondola

3. Fuzzy Sets Model

The classical fuzzy semantics are interpretations of fuzzy sets that represent cognitive categories and the system measurements are based on "linguistic variables". Joslyn Cliff [21] used interval statistics sets with their empirical random sets to develop an approach to construct fuzzy sets model based on the possibility distribution histogram. Therefore, the general measuring data were collected, then they are analyzed to propose fuzzy set model by using frequency distribution and possibilities distribution. By studying and analyzing the frequency distributions of these data, someone can find the random set values (S). Then, possibility histograms and distributions (π) which depends on the core **C** and support **Supp** of the measurement record sets can be calculated as shown in Fig. 4. Therefore, the fuzzy set model can be designed. The two-layer fuzzy controllers 2LFC have been designed based on possibilities distribution and frequency distribution and it was implemented in our previous work [22]. Actually, in practice we need to control the rotation around the OZ axis in order to change the trajectory of the blimp during the navigation to be a full autonomous robot. Hence, we updated our controller to have another combined controller which deals with this issue. Fig.5 shows the structure of the fuzzy free trajectory approach. It has a sub-controller in the first layer and a combined controller in the second layer. The first layer is based on possibilities distributions and fuzzy sets. Through empirical studies, we tested the effect of the blimp's angle view and the distance between the blimp and any object in the path. Then, we introduced fuzzy sets approach to control the blimp behaviors. After estimated the shortest distances (SD_i) and the incidence angles (β_i) between the blimp and obstacles based on the sensors, the sensors readings (SR_i) become more precisely. The data from the sensors are directly inputted to sub-controllers . The second layer uses the outputs of the sub-controllers as inputs and to generate the main trajectory behavior of the blimp. As a result, the control can identify the possibilities of the free-trajectories to perform rotation around OZ axis.

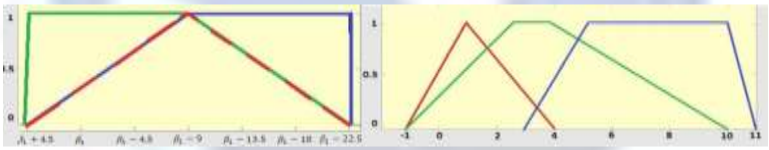

Figure 4. Experimentally Membership function.

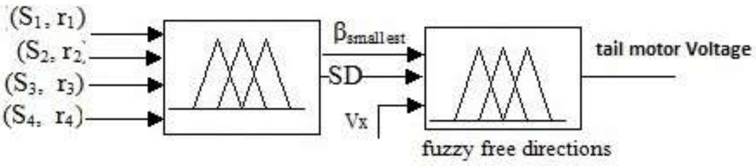

Figure 5. Structure of the 2LFC.

For more precisely, the four sensors S with their readings r: {(S1, r1), (S2, r2), (S3, r3), (S4, r4)} have their own trapezoidal membership functions based on possibilities distributions (πr1, πr2, πr3 and πr4) as shown in Fig. 6. The algorithm starts by finding the incidence angles β and the shortest distances based on possibilities and frequency distributions then transfer the possibilities distributions to fuzzy membership functions without any change. Then, the three possibilities of initial fuzzy free trajectories $\mathbf{FFT_{Initial}}$ could be calculated based on any two adjacent sensors as given in (1). In this step the controller is searching for all the possible free trajectories with minimum incidence angle. The final fuzzy free trajectory $\mathbf{FFT_{Final}}$ can be obtained by (2) in order to find the final possible free trajectory.

$$\mathbf{FFT_{Initial}} = \{\min(\pi_{r1}, \pi_{r2}), \min(\pi_{r2}, \pi_{r3}), \min(\pi_{r3}, \pi_{r4})\} \quad (1)$$

$$\mathbf{FFT_{Final}} = \min\{\pi_{Si}, \pi_{ri}\} \quad (2)$$

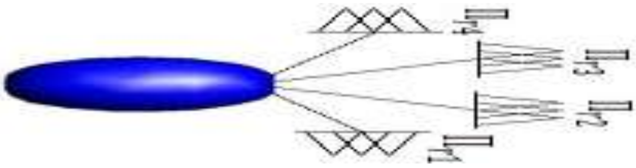

Figure 6. **The Trapezoidal possible fuzzy free directions**

The combined controller aims to change the blimp trajectory path and direction if it detects frontal obstacles. The combined controller system should cause the blimp to change the direction of the blimp when the front sensors detect an obstacle in a certain distance. The controller has three inputs: first, the error which describes the difference between the required distance and the smallest shortest distance (**SDsmallest**) and it has 5 linguistic variables (NH: negative high, NL: negative low, Z: zero, PL: positive low, PH: positive high). The second input is the horizontal velocity (out2 with 5 linguistic variables). The third input is the smallest view angle **βsmallest** with three linguistic variables. The output is the voltage of the tail motor. The summarized algorithm is shown the following paragraph.

Algorithm:

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Input
Sensor readings      (S1, r1), (S2,r2),(S3,r3),(S4,r4):
                     Determine μ_i for angles view
                     Determine μ_j for radial error
                     Obtained the shortest angle view βs
                     Calculate shortest distance SDs
                     WHILE : Navigate
                         IF : SDs <= safety distance
                             THEN Change vectorization angle
                         Else: find FFT_initial.
                             Then estimate the FFT_Final
                         END IF
                     END WHILE
                     Return Fuzzy trajectory
                     Control the tail motor voltage.
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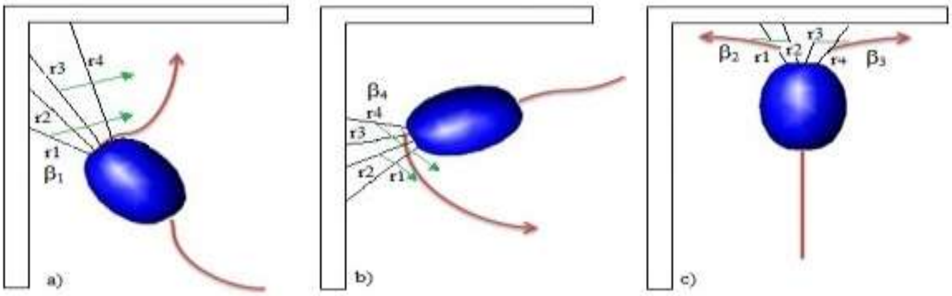

Figure 7. **Wall examples of possibilities FT**

Fig. 7 shows three examples of possibilities for free trajectories. In Fig.7a the controller could detect the smallest incidence angle β1 which is related to r1 and as a result the blimp will rotate to increase the β1 and navigate away from the wall. In Fig.7b the smallest incidence angle is β4 and the smallest distance is r4. Hence, the blimp changes the direction of navigation and will not collide with the wall. The most interesting case is shown in Fig. 7c when the algorithm detects two smallest incidence angles (β2, β3). In this case the controller has ability to use one of them. We should note that when the blimp detects these walls or any objects in the path the avoidance controller will decrease the speed of the blimp and perform the rotation around OZ axis. In the emergency cases, the avoidance controller can rotate the vectorization angle up to 180^o only if the distance between the blimp and the object small than a safety distance.

4. Experiments Results

Some experiments were carried out to check the behaviors of the blimp. The behavior of the vectorization controller is shown in Fig. 8. When the sensors detect an obstacle the controller will change the direction of the blimp robot by changing the vectorization angle. Fig. 9 showing the estimated distances between the blimp and the tracking ground robot. The feedback of the visual data will be inputted to the vectorization vision controller in order to change the angle and track the ground robot until the distance between the blimp and ground vehicles becomes small. Fig. 10 shows the accelerations along with axes X, Y and Z. The acceleration along with axes Y equals to zero because of the fact that the plan OXZ is the symmetric plane of the blimp. The velocities in x and z axis are shown in Fig. 11 and Fig. 12. The blimp navigates with constant velocity in x-axis and when it reaches to the certain altitude the velocity in z-axis approximately goes to zero. The behavior of fuzzy direction algorithm (Directions in blue, Voltage in red) is shown in Fig. 13. If the algorithm detects an object at a certain distance, it will estimate the shortest distance and the smallest incidence angle. Hence, the fuzzy direction algorithm will find the crisp value and convert it to a pulse width module PWM for the tail motor. It is clearly obvious that the amount of voltage depends on the incidence angle and distances which means when the blimp rotate the motor will stop working and the blimp could navigate on other direction. The 3D path trajectory during the navigation of the blimp is illustrated in Fig. 14.

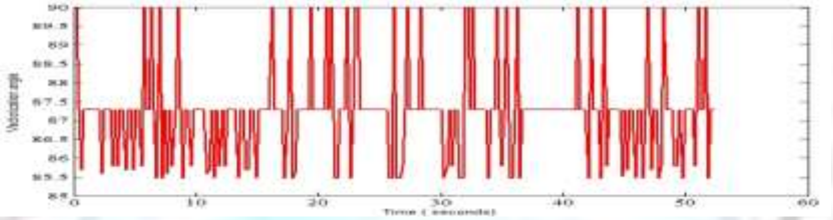

Figure 8. **Vectorization angle**

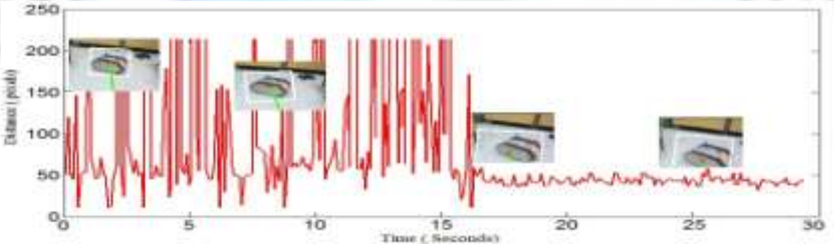

Figure 9. **Estimated distance between target and blimp**.

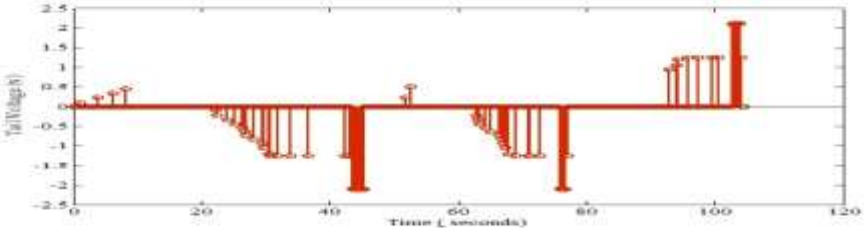

Figure 10. **The accelerations of the blimp**

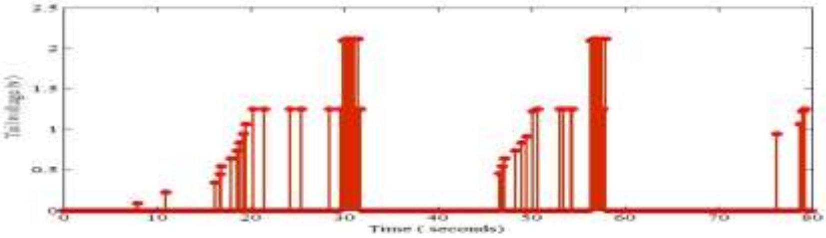

Figure 11. **Velocites behavior of the blimp**

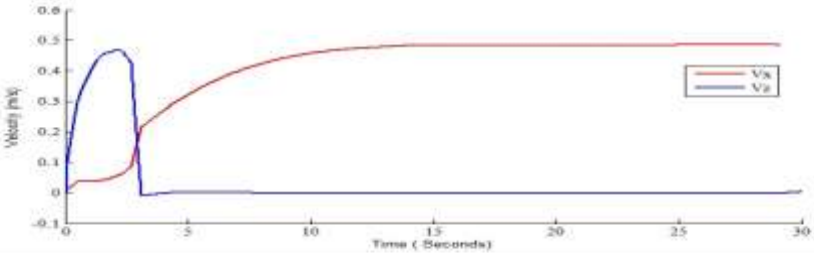

Figure 12. **The velocities during the fly**

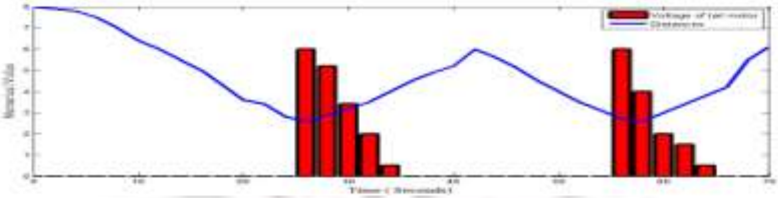

Figure 13. **Behavior of FD controller**

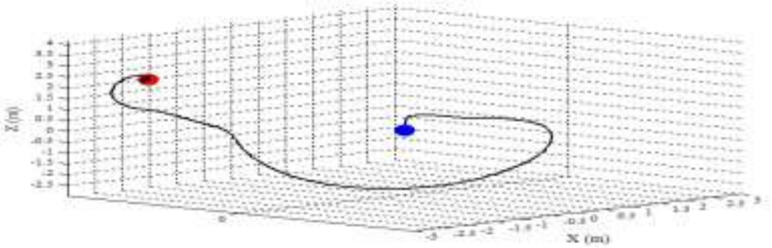

Figure 14. **3D Path planning of the blimp robot**

5. Conclusion

In this paper, we proposed fuzzy sets model for free trajectory path which is applicable for autonomous blimp robot. The approach based on the possibilities distribution and frequency analysis of imperial data in order to build such model and to solve the main issue in fuzzy logic which is (how to design the fuzzy knowledge base). We studied and analyzed the sensors characteristics to reduce the drawbacks in the sensors readings. The experiment results demonstrated the feasibility and advantages of this fuzzy approach on the trajectory of the blimp robot. they showed a good performance of the blimp main behaviors

References

[1]. T. Xu, X. Zhang, and Y. Lu, Onboard controlling system design of unmanned airship, International Conference on Electronic & Mechanical Engineering and Information Technology, Proceedings of the IEEE , August 2011, vol. 6, pp. 3028- 3031.

[2]. A. Elfes, A. Bueno, and M. Bergerman, Robotic airships for exploration of planetary bodies with an atmosphere: autonomy challenges, Autonomous Robots Journal, 2003, vol. 14, pp. 147-164.

[3]. L. He, W. Huang, and Y. Wang, Study of variable structure control technology on stratospheric airship attitude, Measurement, Information and Control (MIC) Conference, 2012, vol. 2, pp.1023 – 1026.

[4]. Y. Yueneng, Z. Wei, and W. Jie, Sliding mode control for a near space autonomous airship, ICEICE 2011, pp. 3576 - 3579.

[5]. M. Yamada, H. Adachi, and Y. Funahashi, Robust control of an uncertain under actuated airship with asymptotic rejection against wind disturbance, IEEE International Conference on Control Applications, 2010, pp. 1844 – 1849.

[6]. F. Dai, W. Gao, N. Kushida and L. Shang, " Fuzzy Control for the Autonomous Airship," 2011 6th IEEE conference on ICIEA, pp. 784-788, 21-23 June, 2011.

[7]. J. Rao, Z. Gong, J. Luo and S. Xie, " A flight control and navigation system of a small size unmanned airship," In Proc. of the IEEE Int. Conf. Mechatronics and Automation, vol. 3, pp. 1491-1496, Niagra Falls, Canada, 2005.

[8]. W. Adamski, P. Hennan, Y. Bestaoui and K. Kozlowski, "Control of airship in case of unpredictable environment conditions," 2010 Conference on Control and Fault Tolerant Systems, pp. 843-848, Nice, France, October 6-8, 2010.

[9]. D. Qiufeng, C. Li and D. Dengping, "Trim and controller design of low altitude unmanned airship,"System Simulation Journal, vol. 21, pp. 3035-3038, 2009.

[10]. Y.Wu, M. Zhu, Z. Zuo and Z. Zheng, " Adaptive Trajectory Tracking of Stratospheric Airship Based on Input-output Stability Theory " 2011 Fourth International Symposium on Computational Intelligence and Design . IEEE Trans. 2011,pp. 301-305.

[11]. Y. Bestaoui, " Characterization of non trim trajectories of an autonomous underactuated airship in a low velocity flight , " Proceedings of the 2005 IEEE International Conference on Robotics and Automation , Barcelona, Spain, April 2005, pp. 2259- 2264.

[12]. H. Kawano, " Three Dimensional Obstacle Avoidance of Autonomous Blimp Flying in Unknown Disturbance". Proceedings of the 2006 IEEE/RSJ , International Conference on Intelligent Robots and Systems. October 9- 15, 2006, Beijing, China. pp.123- 130.

[13]. L. Beji and A Abichou,, "Tracking control of trim trajectories of a blimp for ascent and descent flight maneuvers," in International Journal of Control, vol. 78, pp. 706-719, July 2005.

[14]. F. Repoulias and E. Papadopoulos, " Dynamically Feasible Trajectory and Open-Loop Control Design for Unmanned Airships," Mediterranean Conforence on Control Automation, July 27-29, 2007, Athens- Greece. IEEE Trans.

[15]. F. Repoulias, and E. Papadopoulos, "Three dimensional trajectory control of underactuated AUVs," Proc. European Control Conference (ECC 2007), Kos, Greece, July 2007.

[16]. F. Repoulias, and E. Papadopoulos, "Dynamically feasible trajectory and open-loop control design for unmanned airships," Proc. IEEE Mediterranean Conf. on Control and Automation (MED 2007), Athens, Greece, June 2007.

[17]. J. Muller, N. Kohler and W. Burgard, " Autonomous Miniature Blimp Navigation with Online Motion Planning and Re-planning,". 2011 IEEE/RSJ Intrnational Conference on Intelligent Robots and Systems. September 25-30, 2011. San Francisco, CA, USA.

[18]. R. Al-Jarrah and H. Roth, Design blimp robot based on embedded system and software architecture with high level communication and fuzzy logic, Proceedings of the 9th International Symposium on Mechatronics and its Applications (ISMA13), Amman, Jordan, April 9-11, 2013.

[19]. H. Bay, A. Ess, T. Tuyelaars and V. Gool, Speeded up robust features, Computer vision and image understanding, 2008, pp. 346-359.

[20]. R. Al-Jarrah, R Ait-Jellal and H. Roth, Blimp based on embedded computer vision and fuzzy control for following ground vehicles, 3rd IFAC Symposium on Telematics Applications, Seoul, South Korea, 11-13 November, 2013.

[21]. C. Joslyn, Measurement of Possibilistic Histograms from Interval Data, International Journal of General Systems, 1997, vol. 26(2-3), USA. 1997a.

[22]. R. Al-Jarrah and H. Roth, Developed blimp robot based on ultrasonic sensors using possibilities distribution and fuzzy logic, Journal of Automation and Control Engineering, March 2013, vol. 1, pp. 119-125.