

A smart Neural Network Based Algorithm for Landing Control of Autonomous Unmanned Aerial Vehicle

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ABSTRACT

This paper discusses the possibility of designing a flight controller to aid in the management of the onboard flight operation of unmanned aerial vehicle (UAV) autonomously during the landing approach using VOR navigation which based on artificial neural networks. Although literature review shows many research work using this techniques, yet the more intelligent algorithms are mandatory for deploying full autonomous flight operation in act. This paper focuses on the landing phase which is considered as the most sophisticated phase in the flight control and therefore requires well planning and possibility of recovery in case of uncertainties which only human pilot can do due to experience and flight rules. A proposed neural network controller algorithm was constructed and trained using Matlab neural network tool box and neural designer software. Three algorithms for landing stage were developed. These algorithms were tested and modified several times for validation with different flight scenarios using model based flight simulator. The network training results showed that the artificial intelligence base flight controller can perfectly handle the operation of autonomous landing.

Keywords: Artificial intelligence, Neural networks, UAV, Autonomous landing, VOR

I. INTRODUCTION

Unmanned aircraft control systems and theory has become one of the prominent aspect and vital issues in the scientific research , there are different control techniques and trends which are utilized to achieve the desired control objective, in the last few decades the lights has been spotted on the deployment of the artificial intelligence based techniques such as fuzzy control, artificial neural networks, expert system in addition to genetic algorithms, though classic feedback , PID and modern control approaches are still encountered in the design and implementation of control systems, each of these approach has its cons and pros and the right application to be used in [1].

Flight control systems and autopilots are integral parts of the aircraft control systems, as depicted previously they might relay on any of the mentioned control techniques, but the final decision of what approach should be used falls upon the purpose and the type of the designated controlled parameters and reliability of the control systems which are strongly related to the stability and the performance of that controller. The development of

automatic control systems has played an important role in the growth of civil and military aviation. Modern aircraft include a variety of automatic control systems that aid the flight crew in navigation flight management and augmenting the stability characteristics of the airplane. Two types of autopilots are mainly used to control the aircraft during the different phases of the flight operation, take off, cruise and landing approach, and typically they are classified as the longitudinal autopilot and lateral autopilot].

Autopilots can be used in the manned aircraft and in unmanned aircraft systems known as drones or remote piloted aircraft, hence maintains specific altitude, heading, speed, are quite difficult for human pilot, therefore and autopilot is always included, the dependability on the autopilot can be partially and it is engaged whenever the flight mode requires, this called automatic flight controller, or could be fully integrated to take the overall control during all the flight mode and this is referred to be known as the autonomous flight controller, the word autonomous controller indicates to the fact that the controller is not only programmed to follow limited rule, but it rather able to adapt its architecture to the variation of the uncertainties which are out the boundary of the expected range and maintain stable control, such systems are capable to take their own decision based on some intelligence and calculations, this intelligence is known as the artificial intelligence or machine intelligence and it resemble the same the human brain processes information and signals [1-2].

The main purpose of this paper is develop a new algorithm based on artificial neural networks to aid unmanned aircraft systems (UAS) fixed wing to achieve an autonomous landing in the presence of wind disturbance and other uncertainties, landing is most dangerous and sophisticated phase of the flight which needs a well planning and robust control to ensure smooth and safe landing operation. Researches studies on the autonomous landing techniques have recently been conducted by applying different control methods and algorithms.

An autonomous landing approach is carried out by Kotha Nagarjuna cited in [3], the study adapted an algorithm based on inertial measurement unit (IMU) outputs to control velocity and direction, the algorithms utilizes the PID control approach which is used to maintain stability during landing phase so that the drone can land safely at specific landmark, a PID controller is an ordinary compensator which is used to maintain stability and correct errors within specific boundaries, that make it a controller with limited capabilities, though the proposed algorithms has yield excellent response for the designated purpose. Referring that the controlled drone was a rotary wing type which is deploys vertical landing, the reason made the algorithm works due to its dependability on the motor speed control. Another method for autonomous landing for UAV was presented by Bruno Siely [4], the paper treated the landing for fixed wing UAV using visual protocol based on fuzzy matching and evolving clustering. the author of this work has developed a new approach for identification and color pattern recognition in image captured by UAV camera according to fuzzy rules and classify them into red, green, blue so that UAV can visually land on specific land marks, the algorithm has proved its effectiveness in image recognition but still not enough to be deployed in full autonomous landing system, since the visual landing is engaged in the final approach of the landing. another author has presented in [5] an optimal controller for fixed-wing UAV landing, based on nonlinear model predictive control, landing algorithm in this paper has

included a method referred as deep stall landing, the advantage of the proposed method is that it can be used in landing in small space, where the UAV is in a deep stall when the angle of attack is greater than the stall angle, which cause UAV to lose height fast, an accurate control algorithm is a preliminary requirement for such method, delta wing UAV was used. while the another in work [6], has used the same optimal control; continuous model predictive control (MPC) method for landing control of UAV, the algorithm assumes the controlled plant as a multi-input system (an optimal constraint problem), in aspect of speed and descent rate which are basic concern during the landing final approach phase, a mathematical module of UAV was has been derived and an optimal problem was formulated and simulated the obtained results was compared with results obtained from simulating the same model with PID controller, and the MPC has given the best results, the approach is quite useful for autonomous landing but neglected the first phase of the landing .

A fault-tolerant auto landing controller using neural network is discussed paper [7], in which a neural control scheme is assigned to UAV automatic landing problem under the failure of control surface and severe winds, the neural network controller is designed using single hidden layer feed forward networks additive or radial basis function hidden nodes in a unified framework, the network was trained using OS-ELM algorithm, the simulation results demonstrate that the proposed neural fault tolerant controller is capable to achieve a safe landing . Another study is carried on using neural network to aid an autonomous landing of UAV on a ship. The method suggested in this paper is dependent on the visual aid landing but rather a neural network as compared to the previous in [4] which comprised fuzzy control method, three artificial neural networks were composed and trained successfully and training results was very satisfactory. many other works related to UAV have been presented by different authors, different control theories and techniques are applied to the design of UAV controller and flight controllers in general , each is featured with advantages and disadvantages, combining more than technique to control one system will greatly increase the efficiency and hence the reliability of the systems. in the head of these techniques is the artificial neural networks (ANNs), which are known for their great contribution in the recent decades in the evolution in machine intelligence and are widely used in many various disciplines [8].

The objective of this paper as stated previously is to construct an algorithm for autonomous landing of UAV during the landing phase, it is well known that the landing phase is the most difficult part of the flight and that due to various factor that may affect the landing process such as , weather conditions and manipulated variables for maintaining the desired response, therefore and instrument landing system [ILS] is always equipped into modern aircraft to aid pilot. the problem to be formulated is to replace the human pilot with flight controller able to communicate with air traffic control (ATC), and report arrival and start landing autonomously. the problems and difficulties that may phase an autonomous flight controller is required degree of the intelligence enough to enable machine deciding specific action according the variation of the conditions that cannot be programmed in form of error compensation or fault tolerant system, the significant contribution of the suggested controller in this paper is that, it proposes an algorithm for autonomous landing of UAV that includes neural network controller serves as a main command source and initiator , and includes modern control based controller that

used control actuators and some feedback technique based controller for bounded error compensation. The outcome will be a control system that capable of self-reasoning and decision making based on knowledge and experiences that resembles the human behavior and actions in sustaining higher performance autonomous systems.

Neural networks are composed of simple elements operating in parallel. These elements are inspired by biological nervous systems. As in nature, the connections between elements largely determine the network function. a neural network can be trained to perform a particular function by adjusting the values of the connections (weights) between elements. Typically, neural networks are adjusted, or trained, so that a particular input leads to a specific target output, the network are adjusted, based on a comparison of the output and the target, until the network output matches the target. Typically, many such input/target pairs are needed to train a network [9].

Neural networks have been trained to perform complex functions in various fields, including pattern recognition, identification, classification, speech, vision, and control systems. Neural networks can also be trained to solve problems that are difficult for conventional computers or human beings

II. MATHEMATICAL MODELING

this section concerns the mathematic modeling of the glide slope coupler which is engaged during the final approach landing preparation ,the geometry shown in Figure1 are associated with glide slope equation and controller modeling.

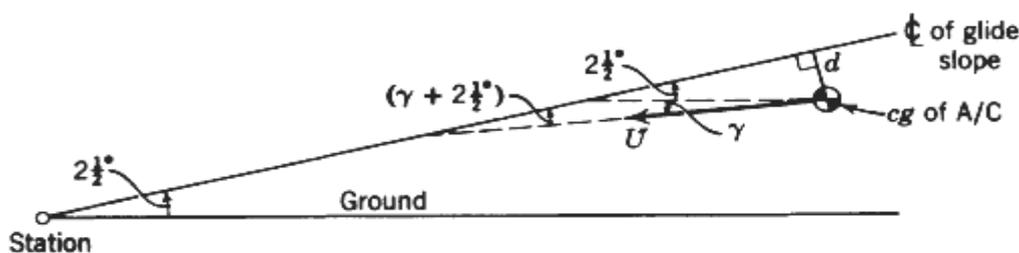


Fig 1: geometry of the glide slope

$$\dot{u} = U \sin \left(\gamma + 2 \frac{1}{2} \right)^{\circ} = \frac{U}{57.3} \left(\gamma + 2 \frac{1}{2} \right)^{\circ} \quad (1)$$

Where d is the glide slope angle, and could be positive or negative with respect to VOR transmitter beam angle, the distance from d to the station (R) is slant distance therefore the deviation from the intended slant distance (E) is given by:

$$\Gamma = \frac{57.3d}{R \text{ deg}} \quad (2)$$

The block diagram of the automatic glide slope is shown in fig 2 bellow, it is always engaged to guide the aircraft vertically toward the runway center with specific descent rate



fig 2: block diagram of the glide path controller [1]

The final phase of the UAV landing requires the transition from the glide slope to the actual touchdown point , typically referred to as the "flare" . Flight test data has shown that during performing the flare from the approach glide to the final touchdown, the descent rate is decreased in an exponential manner. in order to make aircraft to fly an exponential path. then the altitude above the runway (h) decrease according to the equation:

$$h = h_0 e^{-\frac{t}{\tau}} \quad (3)$$

Where h_0 is height at the start of the flare

The geometry of the flare path is demonstrated if fig 2 bellow from which the descent rate \dot{h}_r during the flare path is given by the equation:

$$\dot{h}_r = -0.8h \quad (4)$$

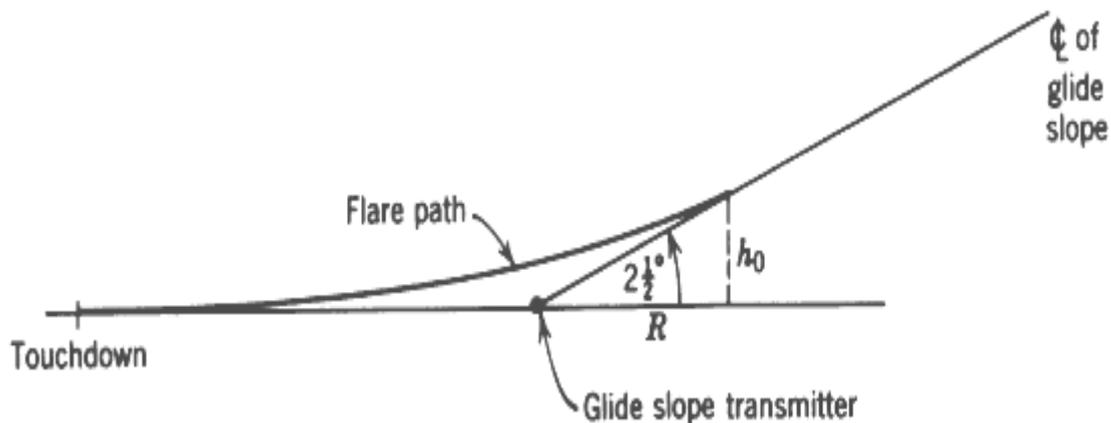


Fig 3: Geometry of flare path

Automatic flare controller is shown in fig 4, it is automatically control the flare altitude rate \dot{h}_r with proper adjustment to pitch angle according to equation 5.

$$\frac{\dot{h}(s)}{\theta(s)} = \frac{U}{57.3} \left[\frac{\gamma(s)}{\theta(s)} \right] \quad (5)$$

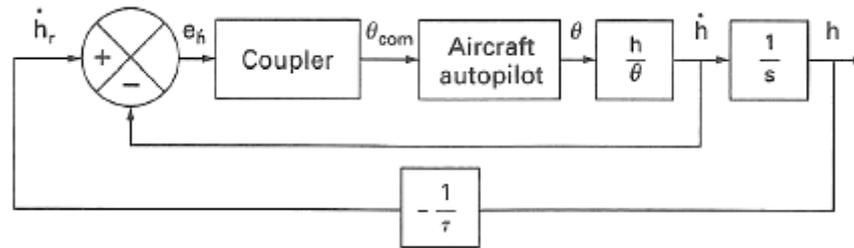


Fig4: automatic flare control system [1]

III. FLIGHT CONTROLLER ARCHITECTURE

Figure 5 depicts the general architecture of the proposed neural network based controller which manages all the flight phase and direct the control commands to the autopilot system assigned to actuate the aircraft control surface, the aircraft dynamic are sensed and fed back to the flight manager, data from onboard weather radar and the navigation instrument are also provided so that the controller may decide the right action for any uncertainties that may affect the flight stability.

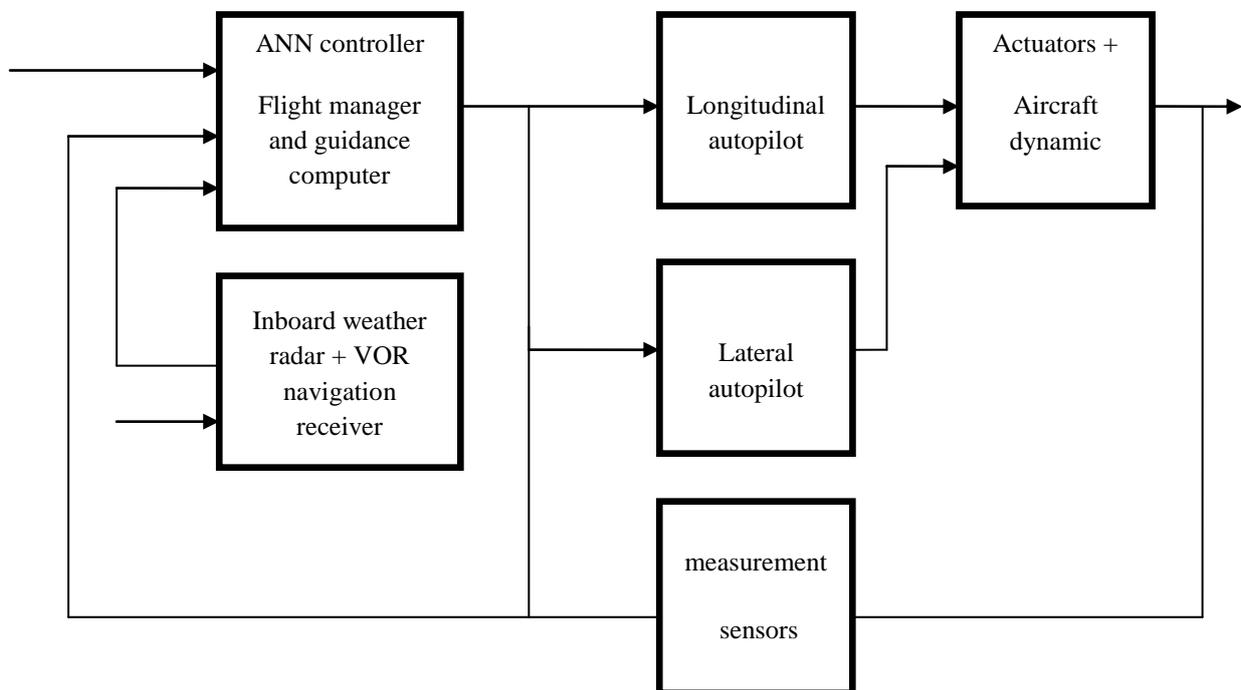


Fig 5: Block diagram of flight control system

3.1 Transition Phase Algorithm

The proposed algorithm is constructed to provide full autonomous navigation to guide UAV toward safe landing. Accordingly the algorithm divides the landing phase of the UAV flight into in three sub-phases, the first

phase is called transition phase ; in this stage the aircraft is vectored to descent fromcruise altitude (Top Descent Point) TDP to an altitude of 3000ft (referred to as the standard transition altitude) above sea level at specific descent rate in feet under the constraints of wind factor and temperature, this done before known distance to the final destination (airport) and an arrival is reported to the ATC.

Before the transition phase, the distance to the bottom descent point (BDP) which is attitude of 3000ft above the ground, mustbe calculated using the equation :

$$\frac{H_c (ft) - H_d (ft)}{R_d (ft/min)} \times \frac{V_g (NM/hr)}{60 (min/hr)} = NM \quad (6)$$

Figure.6 represents the flow chart of the proposed transition stage.

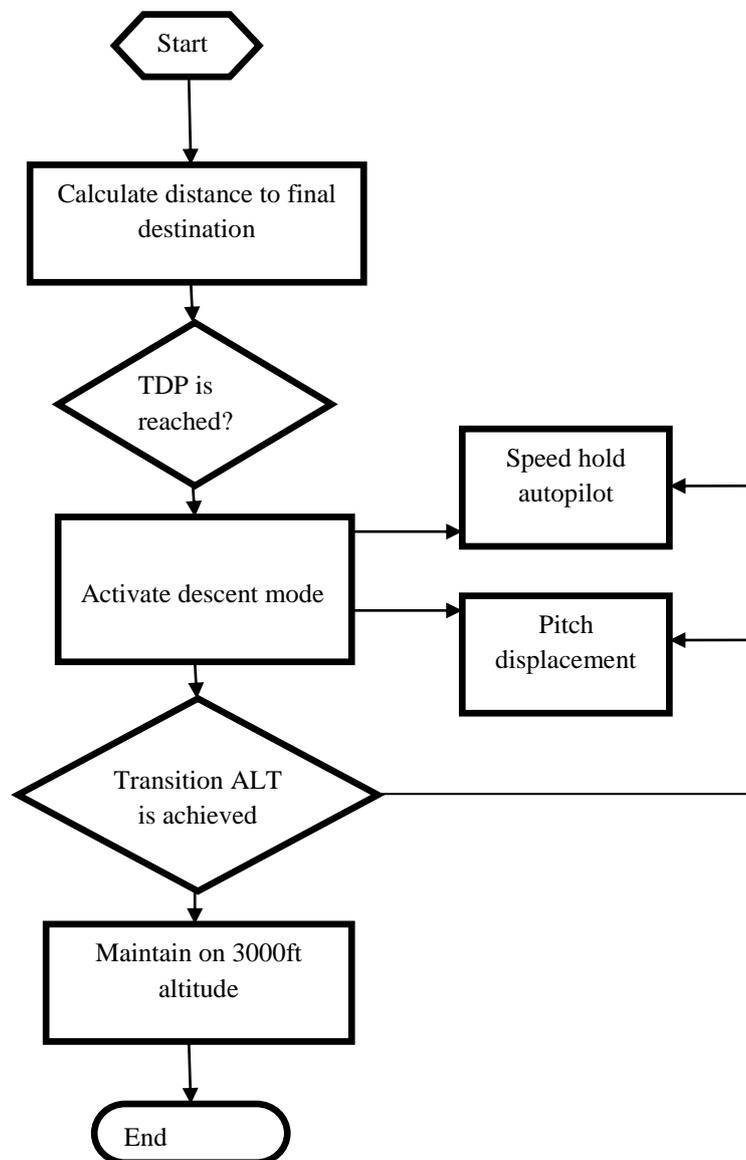


Fig 6: Transition phase flow chart

The second phase of the landing shown in Fig7 is localization phase, upon reaching the transition altitude (3000ft) the guidance system vectors the aircraft to intercept a localizer at distance of at least 6 nautical miles from the runway. The autopilot positions the aircraft so that it is on heading toward the runway centerline; the guidance type in this phase is lateral.

Figure.7 represents the flow chart of the proposed localization stage.

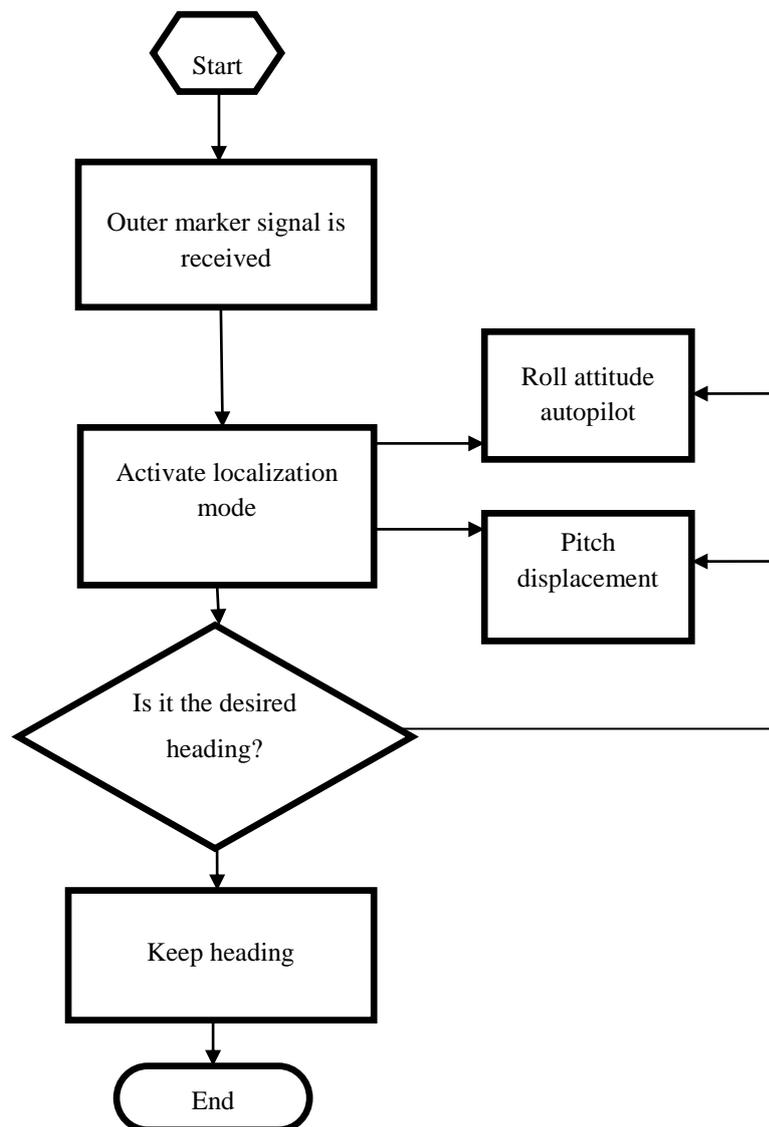


Fig 7: Localization phaseflow chart

The third phase shown in Fig 8 is glide slope or glide path, it is automatically engaged when the aircraft approaches the inner marker of the (VOR) navigation unit a glide path slope is intercepted which guides the aircraft vertically with angle 3 degree to the horizontal, in this stage the final approach speed should be

maintained which is determined by aircraft operation manual (AOM) before getting 50ft above the runway touch and the engagement of flare mode.

Figure.8 represents the flow chart of the proposed glide slope and flare stage.

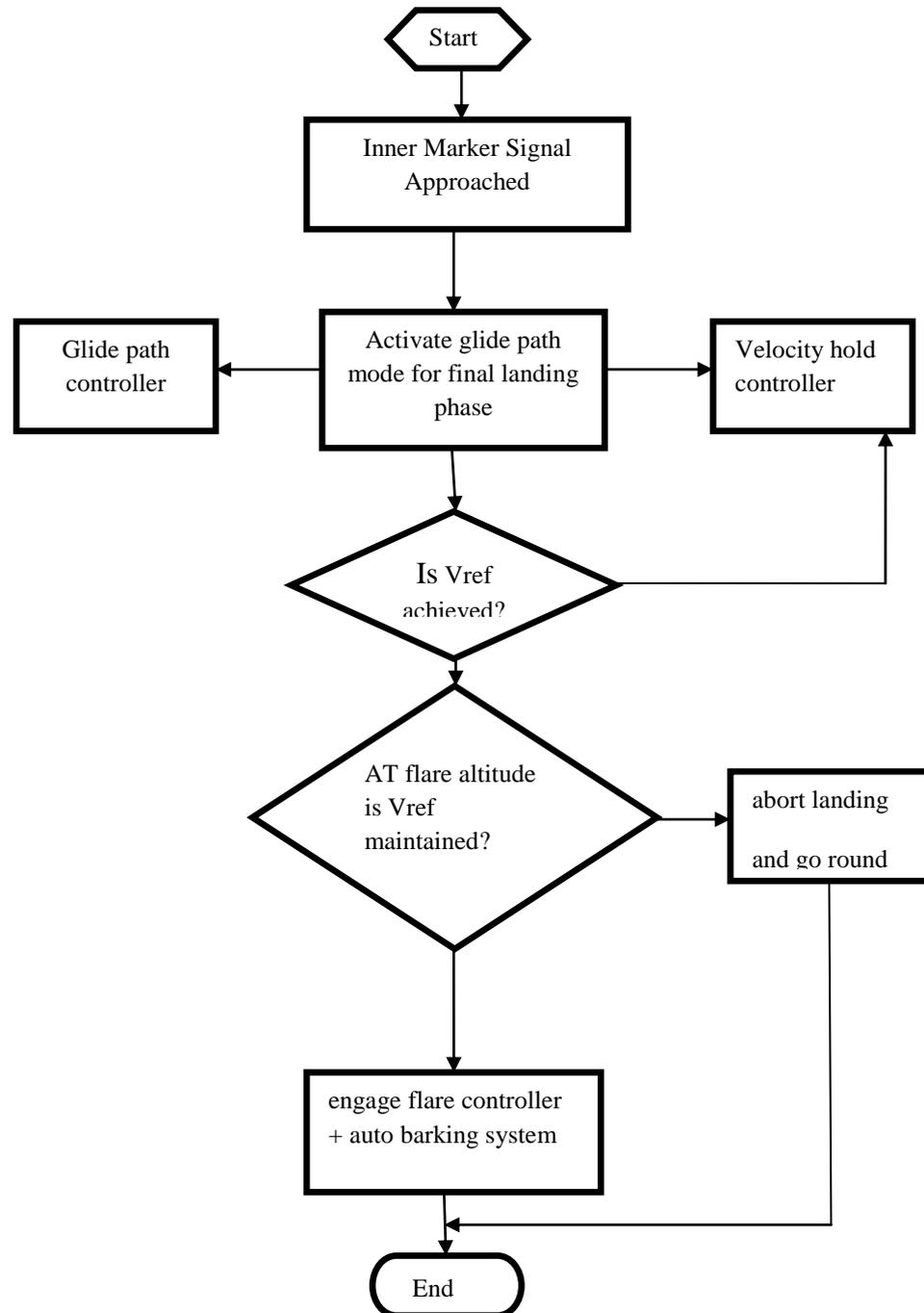


Fig 8: The Glide slope and flare phase flow chart

IV. SIMULATION RESULTS AND DISCUSSION

for an aircraft to lose and specific altitude and maintain desired heading, the guidance system is provided with data required ensure highest possible performance, the data provided in table 1 [10] are used to train neural network to maintain certain descent ratio for a given ground speed and vertical deflection slope to the horizon during landing phase from the standard TDP to the desired to BDP.

a neural network is developed which is composed of two layer with 10 hidden neuron , the inputs to the network are the matrix which consist of the different ground speed and standard glide slop angle and target output is the desired descent rate to be maintained by the autopilot, the network is a simple feed forward with sigmoid hidden neurons, Bayesian regularization training algorithm is used , This algorithm typically requires more time for laerning [10], but result in good generalization for difficult, small or noisy datasets. Training stops according to adaptive weight minimization (regularization). 65% of data will used for tarining and 20 % for validation while 15% of the data is utilized for testing , the resultig resposnes and performnncce is discussed in figure 9.

Table (1): descent rate at specific ground speed

ground speed/knots	90	110	130	150	170	190	210	230	250	270	300
Angle to horizontal (°)	3	3	3	3	3	3	3	3	3	3	3
Descent Rate ft/Min	470	585	690	795	900	1005	1110	1215	1320	1425	1530

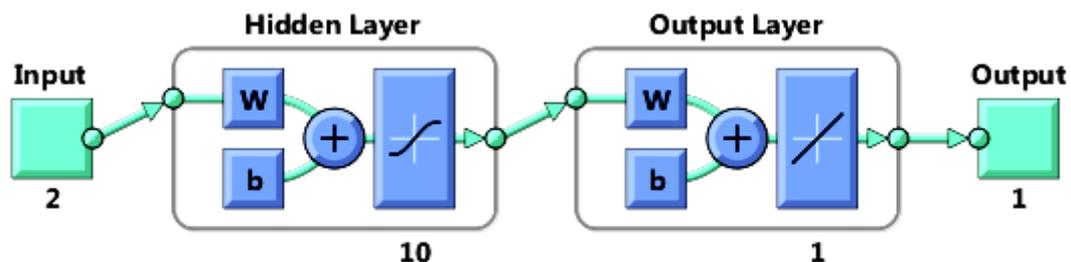


Fig9:Block diagram of neural network architecture

The results shown in Fig10, 11 and12 were obtained after performing manytraining patterns with the data collected from a real flight testsusing a human-piloted drones. the results are due to data concerning “pitch” and speed flight parameters, the output of the trained network are used in the flight simulator by the flight controller so that the UA is able to pitch up and down bychanging the angles to the desired altitude and control speed

under various flight conditions. The mean square error (MSE) of the network is about .807, the actual output tracks the target closely for training, testing, and validation, and the R-value is over 0.99 for the total response.

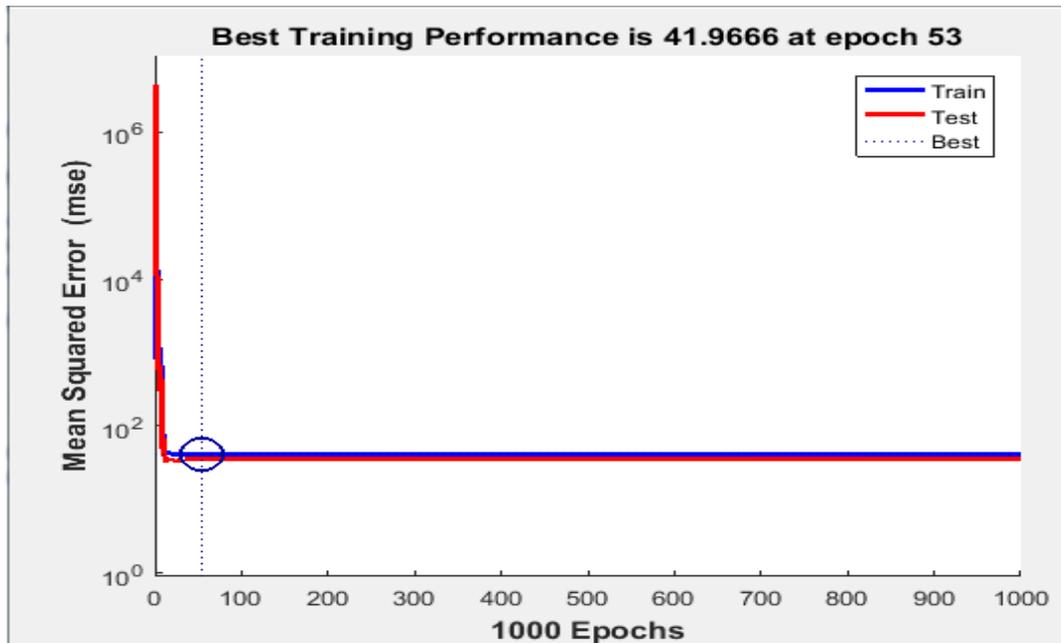


Fig 10: Pitch and speed control data network performance

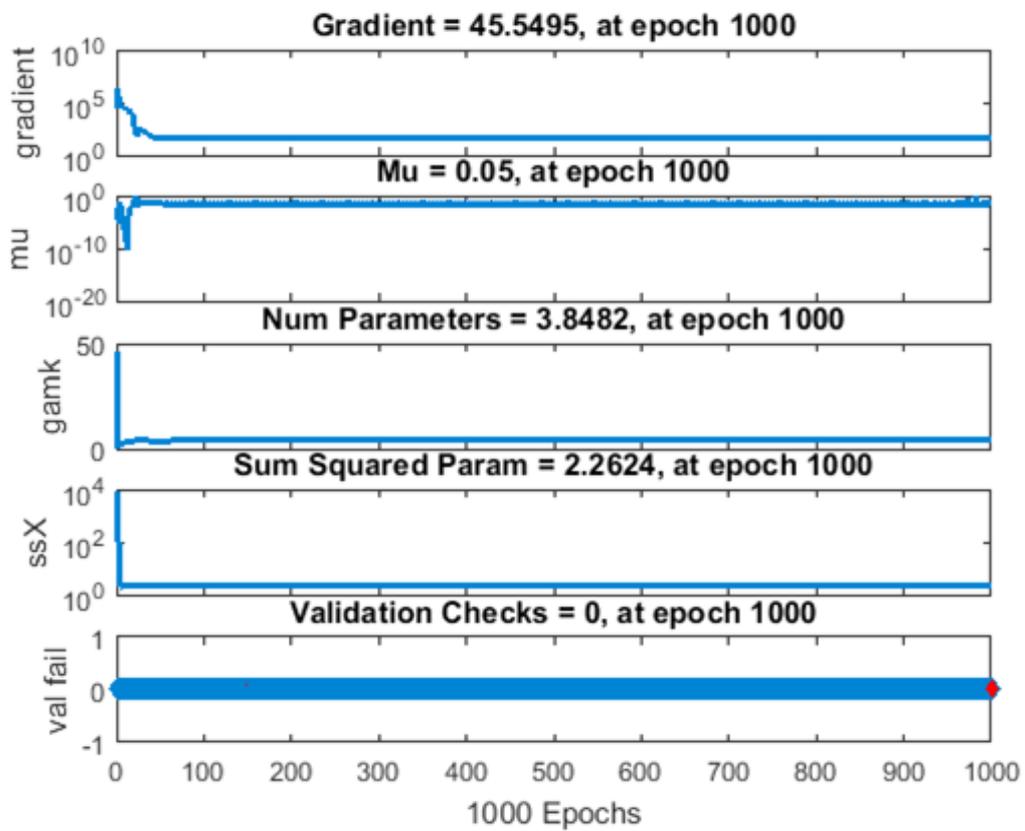


Fig10: Network Training State

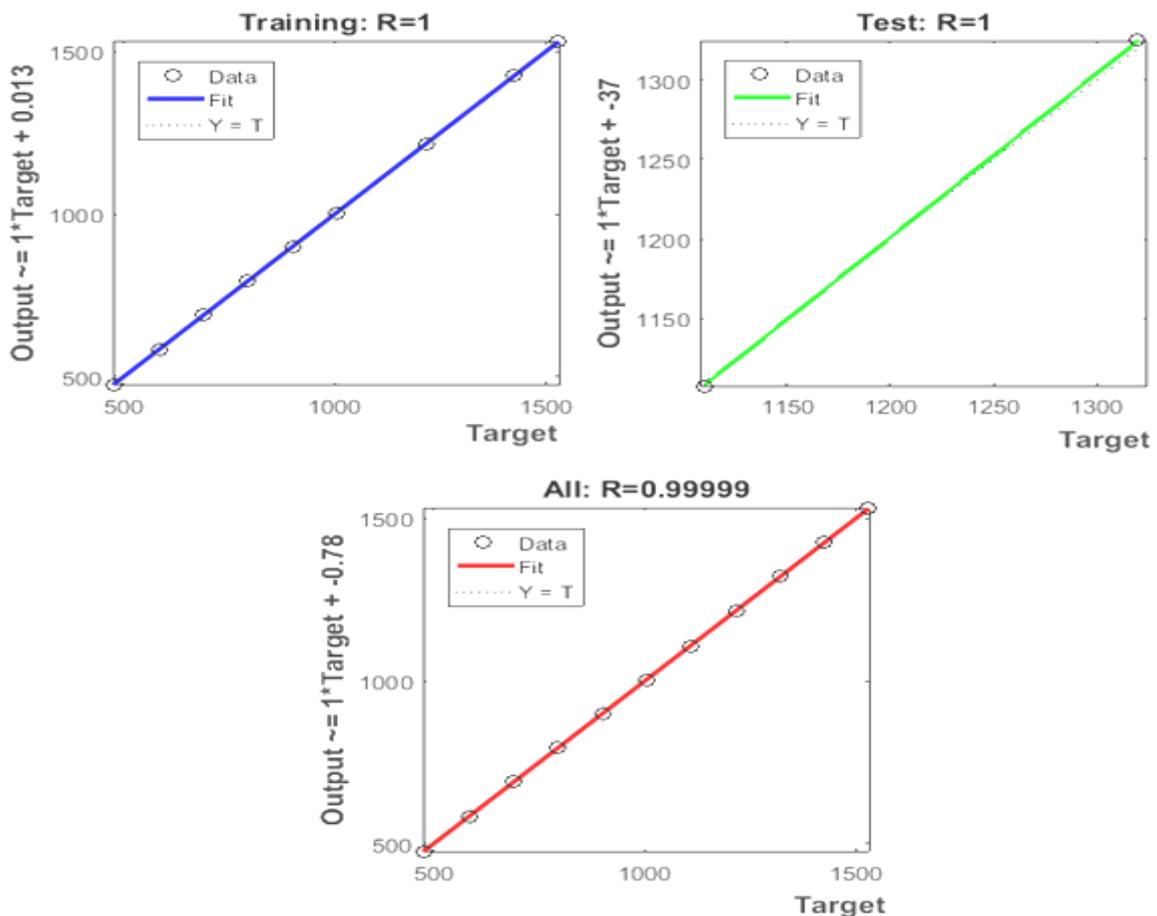


Fig11: Regression graphs for pitch and speed data

V. CONCLUSION

The results confirm the hypothesis that the neural network controller are enough capable to understand flight data required to maintain stabilized guidance of an Unmanned Aerial Vehicle through during landing phase, the proposed algorithms for each phase of landing of the UAV are to be executed autonomously during the landing phase by the flight controller that replaces the human pilot in the manned aircraft, based on the experience and training the controller has to decide what is next action and forward the command to the and the manipulated variable to the longitudinal and lateral autopilot. the truth that work presented in this paper focus mainly on the possibility of developing of a new algorithm that enables autonomous landing of UAV based prior knowledge and training of the machine (UAV) , has been confirmed by results that the neural network training has shown.

REFERENCES

- [1] Nelson, R.C., "Flight Stability and Automatic Control, second edition, McGraw-Hill", 1998.
- [2] John. H. Blakelock, "Automatic Control of Aircraft and Missiles", John Wiley & Sons Iic, 1991.

- [3] Kotha Nagarjuna, Dr.G.R.Suresh, Design of Effective Landing Mechanism for Fully Autonomous Unmanned Aerial Vehicle, IEEE, 978-1-4673-6823-0/15/\$31.00 ©2015 IEEE
- [4] Bruno SiellyJales Costa, A Visual Protocol for Autonomous Landing of Unmanned Aerial Vehicles Based on Fuzzy Matching and Evolving Clustering, IEEE
- [5] Siri Holthe Mathisen, Thor I. Fossen, Non-linear Model Predictive Control for Guidance of a Fixed-Wing UAV in Precision Deep Stall Landing, IEEE 978-1-4799-6009-5/15/\$31.00 ©2015 IEEE
- [6] Naila Qayyum^{1,2}, Aamer Iqbal Bhatti³ Landing Control of Unmanned Aerial Vehicle using continuous Model Predictive Control, IEEE, 978-1-5090-4657-7/17/\$31.00_c 2017 IEEE
- [7] Jian-Ming Bai¹, Hai-Jun Rong², Fault-Tolerant Autolanding Controller Design using Neural Network, proceeding of the 31st Chinese control conference July 25-27, 2012 Hefei, China
- [8] Padraic Moriarty, Dr. Robert Sheehy, Neural Networks to Aid the Autonomous Landing of a UAV on a Ship, IEEE, 978-1-5386-1046-6/17/\$31.00 ©2017 IEEE
- [9] *Howard Demuth, Mark Beale, Martin Hagan*, Neural Network Toolbox™ 6, c COPYRIGHT 1992–2009 by The MathWorks, Inc.
- [10] U.S. Department of Transportation, FEDERAL AVIATION ADMINISTRATION, Flight Standards Service; Advanced Avionics Handbook, United States Government Printing Office Washington, DC 20402-9325

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Ahmed Yagoub In 2012 Ahmed Yagoub graduated from control engineering department, faculty of engineering, Al Neelain University, Khartoum, Sudan. Since then he works as teaching assistant in the collage, he was fully involved in the electronic, control and industrial automation laboratories. In 2015 Mr. Ahmed received his master degree in electric and electronic engineering department of control, since then he worked as a lecturer at different and as industrial automation trainer at A.BARY technical. Currently he is doing his final research dissertation in PhD program in control engineering. His research interest includes control engineering, UAV, embedded control system and industrial automation.



Mohammed Elmaleeh received his BSc degree from University of Gezira (Sudan), Faculty of Engineering and Technology (Communication and Control Engineering). In 1998 Elmaleeh received his MSc in Electrical and Electronic Engineering, University of Khartoum, Sudan. From 1994-1998 Elmaleeh worked as a researcher in Sudan Atomic Energy Commission. In 1999 he worked as automation engineer, QAPCO, Qatar. In 2009 Elmaleeh received his PhD degree in EEE, UTP Malaysia. Currently Elmaleeh works as Associate Professor at the Department of Computer Engineering, FCIT, and Tabuk University, Saudi Arabia. Dr Elmaleeh published many papers in the field of electronic engineering. He supervised many post graduate and undergraduate students in their research projects. Dr Elmaleeh is assigned as a reviewer for several IEEE conferences and

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