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A REVIEW OF TACTICAL UNMANNED AERIAL VEHICLE DESIGN STUDIES

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Abstract: In this study, a literature search was conducted on tactical unmanned aerial vehicles. First of all, it was classified as an unmanned aerial vehicle. It is mentioned about the characteristics of ZANKA-III, which is highly autonomous, passive and active morphing, aerodynamically perfect, tactical unmanned aerial vehicle (TUAV) ZANKA-III, supported by TUBITAK's 1001 Ardeb program 115M603 by TUBITAK and it is mentioned that they have superior characteristics from other tactical unmanned aerial vehicles. Not only physical properties but also the autopilot system structure, the optimization method used, and the state space model through the executive equations of the body are briefly mentioned. For this purpose longitudinal and lateral dynamics modeling of TUAVs produced in Erciyes University, Faculty of Aeronautics and Astronautics, Model Aircraft Laboratory are considered in order to obtain simulation environments. Our produced TUAV is called as ZANKA-III which has weight of 50 kg, range of around 3000 km, endurance of around 28 hour, and ceiling altitude of around 12500 m. Von-Karman turbulence modeling is used in order to model atmospheric turbulence during flight in both longitudinal and lateral simulation environments. A stochastic optimization method called as simultaneous perturbation stochastic approximation.

Keywords: Tactical unmanned aerial vehicle (TUAV), state space model, optimization

Introduction

Definition of the Unmanned Aerial Vehicle System

They are, in their simplest terms, vehicles that can be manipulated by remote control, autonomously directing themselves or both, loading and unloading their useful cargo into their main body, and landing at the end of the mission. In other words, these tools are also called "drone".

In recent years, "Unmanned Aerial Vehicle Systems" have just started to be used for these new unmanned vehicles, mostly known as "unmanned aerial vehicles" in the development process. The reason is that the unmanned aerial vehicle implies only the aircraft platform and cannot meet the entire system that is flying it. But both countries and institutions seem to use different terminologies for air vehicles. For example, while Israel's official open sources are often referred to simply as "unmanned aerial vehicles", British and European Union official open sources seem to use the concept of "Remotely Piloted Aircraft Systems (RPAS)", a sub-component of unmanned aerial vehicles. Despite this, the notion of "unmanned aerial vehicle system", which is used both by the sector representatives and by the country as the most accepted concept in the literature, stands out because it expresses the whole of the system [European RPAS Steering Group, 2013].

With the revolution in the military technology that lived in the 90s, the unmanned aerial vehicles that can be operated in any weather condition for a longer time, much more remotely controlled, have come to the point where intelligence, exploration and surveillance tasks are indispensable. From the beginning of the 2000's, the use of the armed versions started. The work of the world public to recognize and perceive these systems has also been influenced by the effects of armed versions.

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The unmanned aerial vehicle system has a complex structure and can perform its function by integrating various elements. In other words, it is a system that requires coordinated and coordinated operation of multiple components as shown in Figure 1. Unlike the flying of human systems, it is a system that brings together the sub-elements and works in a synchronized manner.

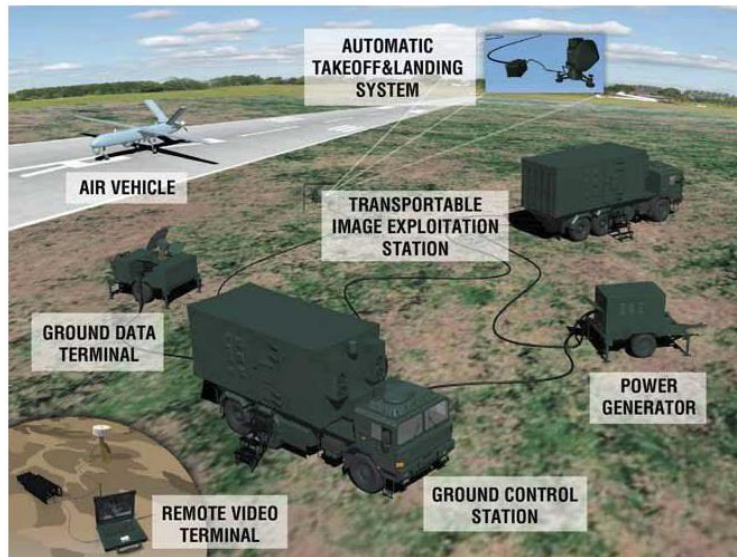


Figure 1. Unmanned aerial vehicle components [European RPAS Steering Group, 2013]

Classification of Unmanned Aircraft System

A uniform classification accepted by the public for unmanned aerial vehicles is not yet available, as a vehicle can carry the characteristics of multiple classes. A worldwide consensus on the classification of unmanned aerial vehicles is yet to be found. Each country has its own classification and the most comprehensive categorization is done by the United States. Moreover, the NATO classification, which is inspired by the US approach, is a candidate to reach an increasingly accepted framework. Classifications based on altitude and airtime periods are evident over time with the useful loads they carry in addition to these criteria.

Unmanned aerial vehicles have a variety of additional capabilities compared to human aircraft. These are generally according to the literature:

- Flight capability in risky environments,
- Design flexibility,
- The length of the air stay is long,
- Possibility of task flexibility and diversity,
- Cost about 1/20 less than human aircraft,
- Being able to gather intelligence on the ground of operations without introducing risk to the human life and have the ability to shoot without aiming,
- Ability to carry out the task of force protection,
- Having the right discrimination feature,
- To be able to use proportional power,
- The prevention of continuing a widespread war.

The limitations of the unmanned aerial vehicle systems are still in the literature:

- Limited "feel and avoid" ability,
- Adherence to data links
- The inability to be as fast as the human warplanes,
- Electronic Warfare Effect,
- Ineffective against air defense systems,
- Asymmetric [Karaağaç, C., 2012]

A classification with international validity for unmanned aerial vehicles is not available at this time. Each country makes its own classification according to such factors as altitude, endurance and take-off weight. The classification of unmanned aerial vehicles is the same as in Table 1 in my study of performance characteristics such as endurance, weight and altitude.

Table 1. Classification of unmanned aerial vehicles

Category	Maximum Take-Off Weight (Kg)	Maximum Flight Altitude (Meter)	Endurance (Hours)	Sample Platform
Micro (<2kg)	3	250	1	Blackwindow, Microstar, Microbatfancopter, Hornet
Mini (2-20 Kg)	3-30	150-300	1-2	Bayraktar, Malazgirt, Scan Eagle, Mikado, Raven, Robocopter
Small (20-50 Kg)	30-75	300-100	2-3	Hermes 90, YH-300SL
Tactical Uav	50-1500	3000-8000	4-12	Anka, Zanka-III, Caldiran, Karayel, Aerostar, Heron, Predator, Reaper
Medium Altitude Long Endurance (Male)	1500-2500	3000-8000	12-24	Skyforce, Hermes 1500, Heron TP, Predator-IT, Dominator, E-Hunter
High Altitude Long Endurance (Hale)	2500-5000	5000-8000	12-24	Global Hawk, Raptor, Condor, Theseus, Helios Eurohawk, Mercator, Global Observer
Attack/ Battle	-	8000-12000	-	X-47B, Phantom Ray

There are three main UAV technologies: micro and mini UAVs, tactical UAVs, and strategic UAVs.

Micro and Mini UAVs

Micro and mini UAVs are the smallest UAV technology. These platforms fly at low altitudes (below 300 meters). Designs in this category focus on UAVs that can operate in “urban canyons” or inside buildings, flying along hallways, carrying listening and recording devices, transmitters, or miniature TV cameras [Bento M., 2008]. Micro UAVs are smaller than mini UAVs, weighing as little as 100 grams; mini UAVs weigh less than 30 kilograms and fly at altitudes between 150 and 300 meters. Micro and mini UAVs are mostly used in civil/commercial applications.

Strategic UAVs

At higher altitudes, UAVs incline to be heavier platforms with longer flight ranges and endurance. The High Altitude Long Endurance (HALE) UAVs are the heaviest UAVs, having Maximum Take-off Weight of up to 12,000 kilograms and a maximum flight altitude of about 20,000 meters. These sizably voluminous platforms can carry more astronomically immense and heavier payloads and more sophisticated equipment. The military UAV Ecumenical Hawk, with 35 hours of endurance, is perhaps the well-kenned UAV in this class. An example of a non-military HALE is the electric/solar powered Helios, which is operated by NASA. The Helios uses solar panels to power electrically driven propellers and has set an altitude record of 30,000 meters. The utilizations of the Helios UAV include observing Earth, mapping, and atmospheric monitoring.

Tactical UAVs

Tactical UAVs are heavier UAVs (from 150 to 1,500 kilograms) that fly at higher altitudes (from 3,000 to 8,000 meters) and are currently used primarily to support military applications. Tactical UAVs can be divided into six subcategories: Close range, short range, medium range, long range, endurance, and Medium Altitude Long Endurance (MALE) UAVs. Long range UAVs use more advanced technology: typically this means a satellite link (or other platform), which acts as a relay in order to overcome the communication problem between the ground station and UAV [Ibid]. The lack of satellite communications systems in certain tactical UAVs limits the

distances over which close, short, and medium range UAVs can operate. MALE UAVs such as the MQ-1 Predator can operate for more than 40 hours at a maximum range of more than 3,000 kilometers, and can also be equipped to carry and release precision guided missiles.

Tactical UAV is basically responsible for surveillance as well as reconnaissance missions. Although all of the tools involved in exploration and surveillance tasks and acting for tactical purposes within a certain range and over time are now referred to as "tactical uav", there are actually some differences in the concepts of these two self-directed designs. A vehicle with an altitude of 40,000 feet maximum take-off weight, ranging from 50 to 1500 kg, which can stay in the air between 4 and 12 hours, is currently the most accepted tactical UAV definition.

Our Tactical Unmanned Aerial Vehicle (i.e. ZANKA III)

Zanka-III Tactical UAV capability and general features is given in table 2.

Table 2: Tactical Unmanned Aerial Vehicle ZANKA-III Physical Properties

TACTICAL UNMANNED AERIAL VEHICLE ZANKA-III PHYSICAL PROPERTIES	
Property	Size
Total Weight	50 kg
Payload	15 kg
Maximum Fuel Weight	5 kg
Wing Span	4 m
Wing Cord Length	40 cm
Engine Power	18 Hp
Theoretical Maximum Range	2500 Km
Theoretical Maximum Endurance	28 h
Speed For Maximum Endurance	89 km/h
Ceiling Altitude	12800 m

In figure 2 morphing wing and airframe of our TUAV ZANKA-III, fully active + passive morphed wing and horizontal tail case, no active + no passive morphed wing and horizontal tail case, photo of manufactured TUAV and upper technical view of TUAV are illustrated, respectively.

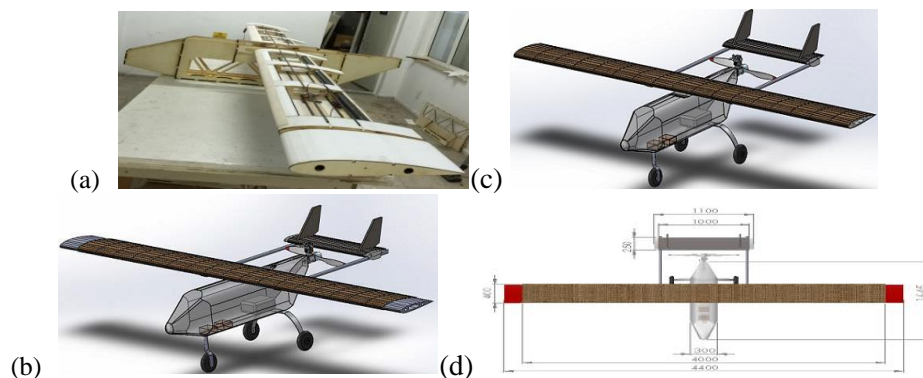


Figure 2: (a) Morphing wing and airframe of TUAV (b) Fully-active+passive morphed wing and HT TUAV (c) No active + no passive morphed wing + and HT TUAV (d) Upper technical view of TUAV (mm s are used)

Dynamic Models of Our TUAVs

Equivalent simulation is performed in computer environment before real-time application using state space model. In order to perform dynamic modeling of any aviation vehicle or any unmanned aerial vehicle, it is first necessary to obtain the executive equations of the aircraft body. Flight motion equations are obtained using the Newton's 2nd Law and the law of conservation of angular momentum. In order to examine the lateral and longitudinal movement, it is necessary to first remove the lateral state space model. This is given parametrically in detail in the space model Prof. Nelson's flight stability and automatic control book [Nelson, R. C, 1998]. In order to obtain the space model, stability derivatives and stability coefficients are needed.

Autopilot System Construction

Identification of the dynamic model of the aircraft is important in developing control systems. Models with high accuracy have a great influence on the quality of the designed control algorithms. An adjustable autopilot was used using flight observations and our autopilot system has the classic autopilot structure. There are three layers for the hierarchical control structure and are divided into outer loop, middle loop and inner loop. Correct the altitude and deviation errors in the outer loop. In the middle loop, out of these faults, the pitch of the pitching and rolling is determined. In the inner loop, the position to be taken by the control elements is determined by rolling and pitching.

Optimization and Simultaneous Design

The aerodynamic forces acting on an unmanned aerial vehicle that is experimentally placed in the wind tunnel can be obtained by a force measurement system. However, it is costly to calculate these forces by examining each body shape individually in the wind tunnel. It is also not possible to calculate analytically due to the nonlinear complex components of aerodynamic forces. For this reason, methods based on random estimation are used. In our study, an optimization method called simultaneous perturbation stochastic approximation was applied to improve the autopilot and to improve the design performance of the unmanned aerial vehicle.

Closed Loop Responses

Simultaneous longitudinal and lateral flight control system design for passive and active morphing TUAVs are considered. In our application longitudinal autopilot is tracking 5 degrees of pitch angle and lateral autopilot is tracking 5 degrees of roll angle. The cost index consists of longitudinal flight terms and lateral flight terms. Combined design of flight control system design and morphing parameters is followed. At the end due to the using combined approach rather than conventional sequential approach, more cost index minimization is obtained. Moreover, since longitudinal and lateral flight control systems are designed simultaneously while determining optimum magnitudes of morphing parameters, the resulted parameters improved both longitudinal and lateral flight. Total cost improvement and relative total cost improvement, and also longitudinal and lateral cost improvements are given. The relative total energy save is around %46 after applying simultaneous longitudinal and lateral flight control system design. During this design longitudinal cost is also minimized considerably. During also this design, lateral cost is not affected considerably. This result demonstrates that our simultaneous design idea do not break lateral performance while improving longitudinal performance. Closed loop responses for both longitudinal and lateral flight while there exist atmospheric turbulence is also investigated. It should be noted that there is 30 and 10 degrees saturations on active surfaces, i.e. elevator for longitudinal flight and aileron for lateral flight, respectively. The longitudinal and lateral autopilots track desired reference trajectories successfully. The active control surfaces also obey the constraints on them. The other outputs such as linear and angular velocities do not experience catastrophic behavior.

Conclusions

Simultaneous longitudinal and lateral flight control systems design for both passive and active morphing tactical unmanned aerial vehicles (TUAVs) was benefited for total autonomous flight performance maximization in this article. For this intention longitudinal and lateral dynamics modeling of TUAVs produced in Erciyes University, Faculty of Aeronautics and Astronautics, Model Aircraft Laboratory were used in order to get simulation environments. Our produced TUAV was called as ZANKA-III having weight of 50 kg, range of around 3000 km, endurance of around 28 hour, and ceiling altitude of around 12500 m. Von-Karman turbulence modeling was applied in order to model atmospheric turbulence during flight in both longitudinal and lateral simulation environments. A stochastic optimization method named as simultaneous perturbation stochastic approximation

(i.e. SPSA) was used in order to obtain optimum dimensions of morphing parameters (i.e. extension ratios of wingspan and tailspan, assembly positions of wing and tailplane to fuselage) and optimum magnitudes of longitudinal and lateral controllers' gains (i.e. P, I and D gains) while minimizing cost index capturing terms related both longitudinal and lateral autonomous flight performances and while there were lower and upper constraints on all optimization variables.

Using SPSA, % 46 of the total cost index was saved. Since the total cost index captures terms both related with longitudinal and lateral flights, considerable improvement in longitudinal autonomous flight performance was obtained and the lateral autonomous flight performance were not broken. The desired trajectories (i.e. 5 degrees pitch angle for longitudinal autopilot and 5 degrees roll angle for lateral autopilot) were successfully tracked. The saturations on active control surface were also satisfied. The other outputs such as linear and angular velocities were not experienced with catastrophic behavior [Oktay T., Coban S., 2017].

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References

- European RPAS Steering Group. (2013a). Roadmap for the integration of civil remotely piloted aircraft systems into the European aviation
<http://www.qsl.net/w2tap>.
- Karaağaç, C. (2012) İnsansız hava aracı sistemleri: Gökyüzünün yeni yırtıcı kuşları.
- Karaağaç, C. (2014) İHA sistemlerine genel bakış. Academia.edu. 07 Şubat 2015'de
<https://metu.academia.edu/CengizKaraa%C4%9Fa%C3%A7/Papers> adresinden alınmıştır.
- Mcneal, G. S. (2013). Amazon testing drones for 30 minute delivery using service called Amazon prime air video.
- Taşlı, İ.T. (2011). Terörle mücadelede insansız hava araçlarının kullanılması.
- Pakkan, B. ve Ermiş, M. (2010). İnsansız hava araçlarının genetik algoritma yöntemiyle çoklu hedeflere planlanması. Havaçılık ve uzay teknolojileri dergisi, 4.(3), 77-84.
- Akyürek, S., Yılmaz, M.A., ve Taşkiran, M. (2012). İnsansız hava araçları Muharebe alanında ve terörle mücadelede devrimsel dönüşüm, Bilgesam Yayınları, Rapor No:53. Ankara.
- Bento, M. (2008). Unmanned aerial vehicles: An overview. Inside GNSS 54. Online:
<http://tinyurl.com/d8wo2kn>.
- Nelson, R. C. (1998). Flight stability and automatic control (Vol. 2). WCB/ McGraw Hill.
- Oktay T., Coban S. , "Lateral Autonomous Performance Maximization of Tactical Unmanned Aerial Vehicles By Integrated Passive and Active Morphing", 6th International Research Conference on Science, Management and Engineering (IRCSME 2017), Dubai, UNITED ARAB EMIRATES, 4-6 January 2017.