Volume: 3, Issue: 1, April 2022
https://dergipark.org.tr/en/pub/ijaa/issue/69569

INTERNATIONAL JOURNAL OF AERONAUTICS AND ASTRONAUTICS

IJAA

E-ISSN : 2757-6574 ijaa@selcuk.edu.tr

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INTERNATIONAL JOURNAL OF AERONAUTICS AND ASTRONAUTICS

IJAA

e-ISSN: 2757-6574

April 2022 Editorial Members of IJAA

INTERNATIONAL JOURNAL OF AERONAUTICS AND ASTRONAUTICS

(IJAA)

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Printed in TURKEY-eISSN 2757-6574

Publishing date: April, 2022

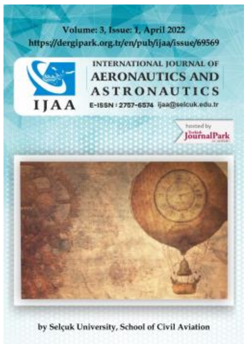
EDITORIAL MEMBERS OF IJAA – APRIL 2022, VOLUME:3, ISSUE:

Publishing date: April, 2022

International Journal of Aeronautics and Astronautics

Volume 3, Issue 1, April 2022

https://dergipark.org.tr/en/pub/ijaa/issue/69569



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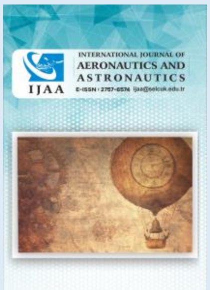

2022, VOL:3, ISS:1, 1-6

e-ISSN: 2757-6574

Research Article

Minimizing deflection on the yaw axis on VTOL type air-vehicles with three rotors

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Received	Revised	Accepted
January 12, 2022	February 6, 2022	**February 18, 2022**

Keywords

Hybrid UAV
Rotor
UAV
VTOL
Yaw axis

ABSTRACT

This study provides an effective solution to the problem of deflection on yaw axes of air-vehicles capable of three-rotor Vertical Take-Off and Landing (VTOL). Most VTOL aircraft are produced with five rotors in national context. Four of these rotors are used for landing and taking off and are positioned to balance each other. The other rotor is positioned to fly with fixed wings. Therefore, no deviation in the yaw axis is experienced during descent-off. Three rotor VTOL configurations are available as an alternative to five rotor VTOL air-vehicles. This study is available through the three rotor VTOL prototypes that we have developed. The biggest drawback of three rotor VTOLs is the instability due to the position of the rotors during takeoff. This instability has been eliminated and three rotor VTOLs have been more advantageous than other configurations.

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Authorship contribution statement for Contributor Roles Taxonomy

Kürşat Çiçin: *Writing - original draft, Investigation, Visualization, Conceptualization, Methodology, Software, Formal analysis.* **Emrehan Yavşan:** *Visualization, Supervision, Writing – review & editing.*

Conflicts of Interest: The authors declare no conflict of interest.

Citation: *Çiçin, K., Yavşan, E. 2022. Minimizing deflection on the yaw axis on VTOL type air vehicles with three rotors. International Journal of Aeronautics and Astronautics, 3(1), 1-6.*

1. Introduction

VTOL type aircrafts are hybrid vehicles that can travel vertically, take off and move off, like fixed wings. VTOL type aircraft can be easily used in civilian and military areas due to reliability and lack of track requirements. NASA's UAM (Urban Air Mobility) [1] project and the KAIA (Korea Aerospace Industries Association) civil aviation works [2] are available to accelerate urban transport research in civil aviation. Most of the work on VTOLs with tilt rotor mechanism is theoretical work [3-5]. There are also different types of VTOL studies conducted nationally [6]. Very few of these studies have been conducted on the tilt rotor. VTOL type air vehicles are divided into tilt rotor (movable rotor) and non-tilt rotor (motionless rotor). Tilt rotors save energy and cost. This operation is based on the VTOL type with three rotors and a tilt mechanism. The moment produced by three rotors during vertical descent and departure causes a deviation in the yaw axis due to the position of the rotors. The tilt motors are given more than 90° angles during vertical descent to remove the deflection. The position of the motors during the vehicle's fixed wing flight is accepted by 0°. The rotors are positioned depending on the condition of the deviation during descent-off. The flight controller determines the degree required for this location. The flight tests have shown that the deviation in the yaw axis has been corrected.

1.1 VTOL (Vertical Take-off and Landing)

Drones (UAV) are divided into three fixed wing, rotary wing and hybrid (VTOL). VTOL type drones fly as rotating blades, as a fixed wing during vertical descent and travel. With this feature, it doesn't need a track to land. It can track as a fixed wing or rotary wing on the speed of the target during target tracking. In hazardous situations when flying, the VTOL can switch to rotary wing mode and safely land. The main drawbacks of the VTOL type are the cost and weight of energy consumption and the number of motors.

1.2 VTOL types

VTOL type air vehicles are categorized according to the condition of the rotors. These categories are shown in Figure 1. SUAVI for tailsitter type of non-tilt multicopter rotor category [7] and Mirac K. Aksugur's [8] operation can be shown as an example.

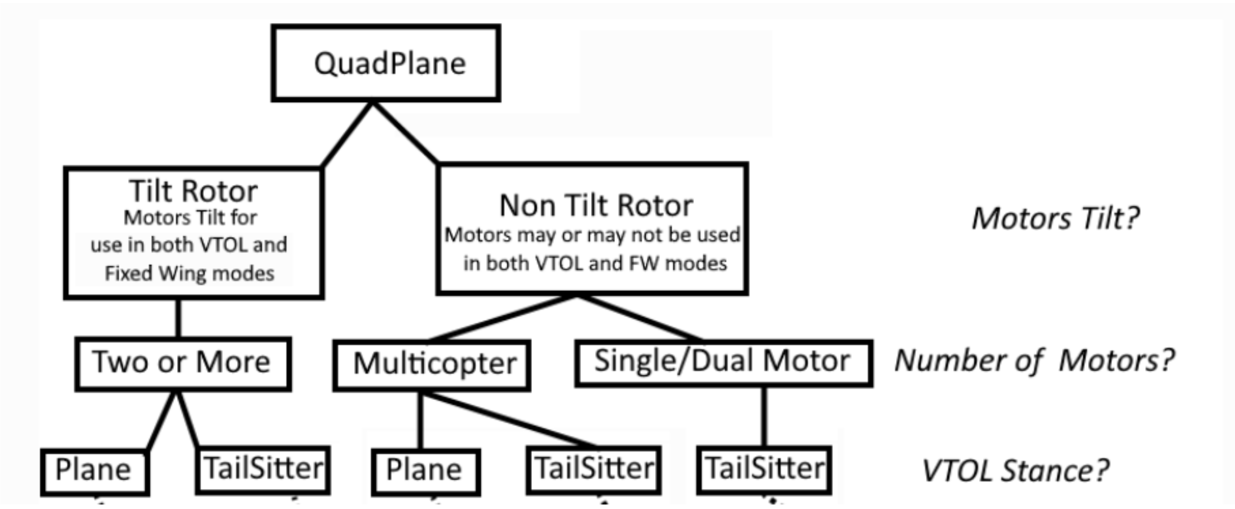

Fig. 1. VTOL types according to rotor conditions [9]

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The rotating part of the electric motors is called the rotor. Figure 2 shows the rotor part of an electric motor.

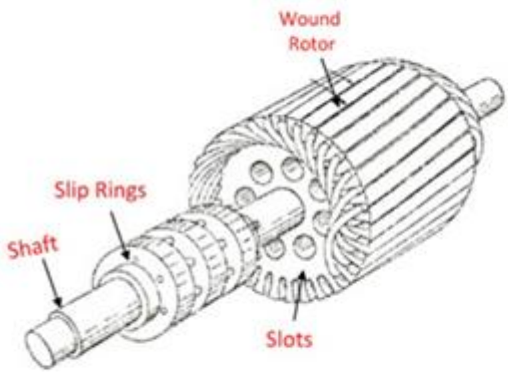

Fig. 2. Engine structure [10]

The rotors can be split into tilt and non-tilt. Non-tilt rotors are also divided by the number of rotors. They are divided into multi-rotor (multicopter) or single/double rotor (single/dual rotor). Most VTOL type vehicles are designed in the multi-rotor category of the non-tilt lever. Using five rotors, one rotor is fixed for the fixed wing flight mode. VTOL named Tuğberk was given as an example in Figure 3. These types of VTOLs are preferred more frequently due to ease of manufacture and compliance with most tasks.

Fig. 3. Tuğberk

2. VTOL with Three-Rotor Tilt Mechanism

The three rotor VTOL vehicle, Tulpar, used in this study, is given in Figure 4. Tulpar has a total weight of 4 kg. The flight time is 30 min and the travel speed is 18 m/s. It can fly both as a rotary wing and a fixed wing. Tulpar is designed with three rotors to minimize weight and power consumption, and the two leading rotors work on both swivel and fixed wing flights. it falls into the plane category with tilt mechanism. The moving rotors are 920 kv and can produce a maximum of 2360g impulse power with 11x5.5-inch propeller at 14.8V.

https://doi.org/10.55212/ijaa.1056802

Fig. 4. Tulpar

2.1 Configuration types

VTOLs with three rotors have two different frame combinations. These combinations are shown in Figure 5. The same orientation of the cruise propeller increases the yaw axis drift problem that we will refer to in the following section (Title 2.2). Installing fixed wing propellers to absorb each other slightly reduces the deflection on the yaw axis. For this reason, Tulpar has been selected as in configuration Type-2.

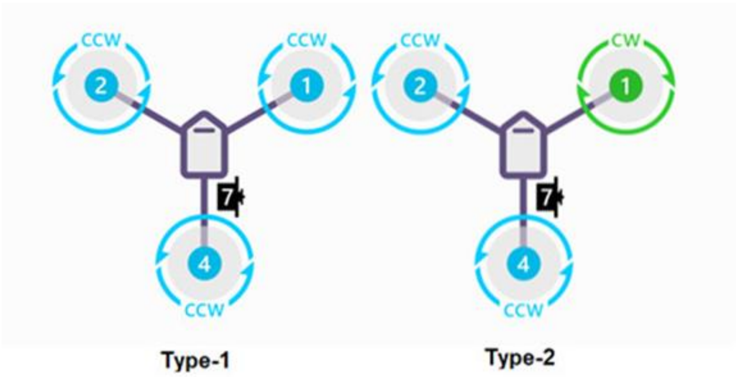

Fig. 5. Propeller direction configurations [11]

2.2 Yaw axis deviation

On flights with Tulpar, it has been observed that the yaw axis deviation occurs during vertical descent approach. The cause of this problem is caused by the momentum produced by the rotors. Fitting the propellers of the two front rotors in the opposite direction absorb the torque of the motors/rotors. Yaw axis deviation occurs because there is no moment in the tail section that dampens the rotor.

2.3 Presentation solution methods for instability

There are two methods for resolving instability on the yaw axis. The first of these methods is to move the tail part. With the moving tail section, instability in the yaw axis will try to dampen by moving the tail pipe. The moving tail section can affect the stability of the vehicle and create a safety issue when flying in a fixed wing mode. Locking of the servo used for travel under load or failing to reach the desired position by noise can cause the vehicle to fall. This method is not preferred due to security issues.

https://doi.org/10.55212/ijaa.1056802

Another method is to give the moving tilt mechanisms an angle greater than 90° when takeoff. This method can save cost and weight. The angle provided also does not create any safety problems during flight as it will only be valid in drone mode.

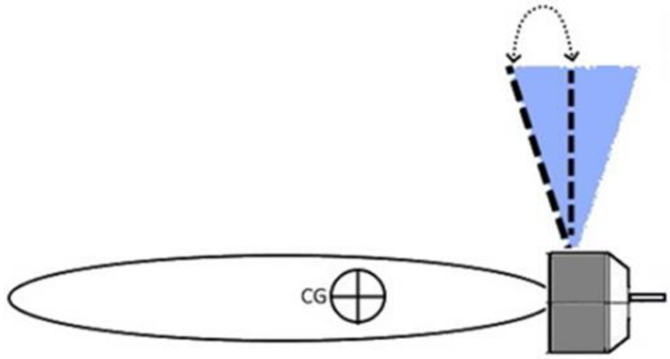

Fig. 6. Positioning the rotor for the vehicle [4]

Figure 6 shows the tilt mechanism on Tulpar. Figure 6 is a symbolic representation. Shows the position of the rotors accepted by 90° and the maximum position of the rotors. CG (Center of Gravity) represents the center of gravity of the vehicle.

2.4 Adjusting the angles of the tilt rotors

The angle of the tilt mechanisms is determined by test flights. After test flights, the logs (flight logs) that the flight computer have been reviewed. The flight logs have analyzed the vehicle's compass data, looking at the amount of deviation of the axes during the vehicle's vertical descent. The maximum tilt angle value of the tilt mechanism is determined according to the amount of deviation. The specified value is defined in the flight controller and the vehicle's rotors are assured that they do not exceed those values during flight. The value given is of the degree. If this value is kept too low, the VTOL will not be able to compensate for the deviation in the yaw axis and will start to rotate around its axis during vertical descent-off. If this value is held too high, the vehicle will react abrupt and overly to deviations in the yaw axis. Following the flight tests, this value for Tulpar was determined by 13° on the graph in Figure 7.

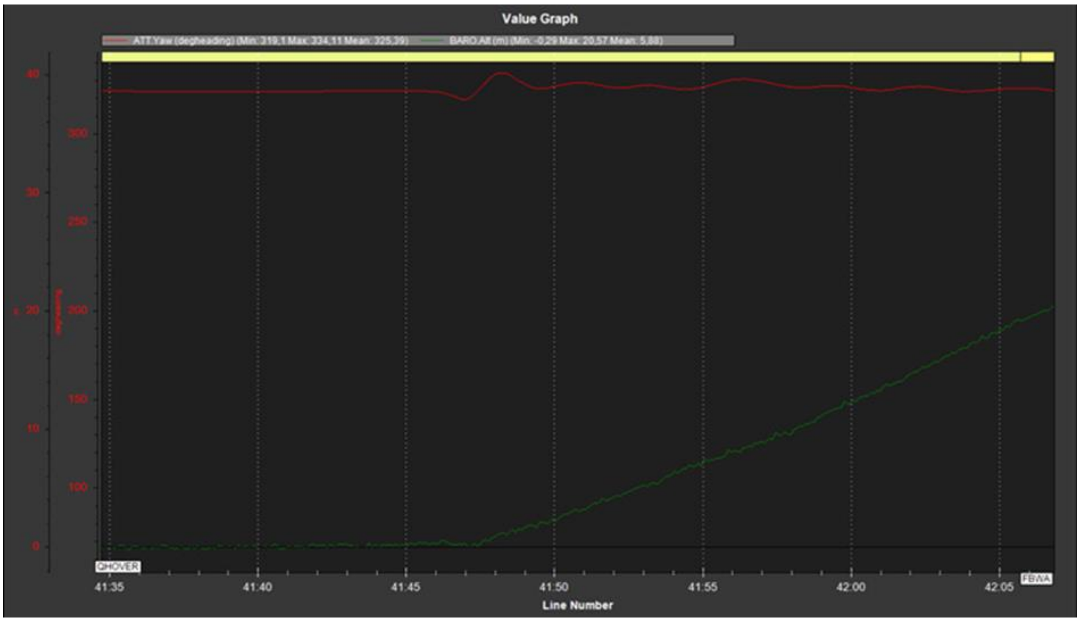

Fig. 7. Altitude and yaw axis graph

https://doi.org/10.55212/ijaa.1056802

In Figure 7, the red line gives the status of the yaw axis in degrees. The green graph gives the value of the height in meters according to the vehicle's starting position. The X-axis shows the time in seconds, the right column on the Y-axis shows the degree on the yaw axis, and the left column shows the height in meters. The lower left-hand side shows the vehicle is in “QHover” mode, which is the takeoff mode. A small amount of deviation is visible as soon as the vehicle is off the ground. The graph continued decisively. The maximum degree of tilt is 13° when flying. The graph shows that this value is the best value for Tulpar.

5. Result

In this study, the yaw axis deviation of VTOLs with three rotor tilt mechanism has been corrected. The solution is an alternative to five common rotor non-tilt VTOLs. Compared to the five rotor VTOLs, the two leading rotors work as both swivel wings and fixed wings saving a lot of cost and weight. The work conducted will contribute significantly to the choice of three rotor VTOLs with tilt mechanism. Another disadvantage is that energy consumption continues.

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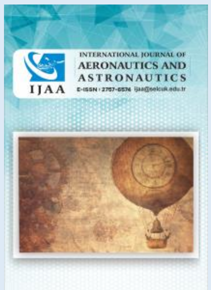

2022, VOL:3, ISS:1, 7-19 e-ISSN: 2757-6574

Research Article

Safe land system architecture design of multi-rotors considering engine failure

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Received	Revised	Accepted
December 5, 2021	February 5, 2022	**February 18, 2022**

Keywords

Emergency Scenarios
Functional Architecture
Multi-Copters
Physical Architecture

ABSTRACT

There is growing interest to use drones for application like delivery services, air taxi, surveillance, and inspection to reduce operational time and cost and increase the performance and functionalities. However, there are some risks related to using this technology one of them is the hazard to the humans and assets in the case of an emergency scenario like motor failure. The current technologies suggest to land as soon as possible in such these scenarios, however finding and selecting a suitable landing area considering the capabilities of the faulty drone and controlling the drone towards the selected point is a problem which requires provisions during the design process of the drone. The situations get more complex considering that the vehicle should be able to adopt itself by its time varying environment. In this paper the system approach is used to break the safety requirements to functional and physical requirements and based on these requirement analyses, the functional and physical architectures of the drone are designed. The proposed design suggests that the drones aggregate their perception about the environment to maximize the safety of people and assets through a special databank called potential landmark databank.

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Authorship contribution statement for Contributor Roles Taxonomy
Seyed-Yaser Nabavi-Chashmi: *Writing, Conceptualization, Methodology, Development, and Formal analysis specifically on using System Concepts, Requirement management and Functional and Physical architecture development.* **Davood Asadi:** *Investigation, Methodology, Supervision, Writing – review & editing.* **Karim Ahmadi:** *Formal analysis on Functional and Physical architecture development*

Conflicts of Interest: The authors declare that they have no conflict of interest.

Citation: *Asadi, D., Ahmadi, K., Nabavi Chashmi, S. 2022. Safe land system architecture design of multi rotors considering engine failure. International Journal of Aeronautics and Astronautics, 3(1), 7-19.*

1. Introduction

Using autonomous drones for operations like good delivery, transportation and remote sensing proposes very operational capabilities to improve the efficiency and reduce cost and time. However, they can lead to new challenges in subjects like safety, security and reliability. So, the development of drone system is not limited just to technical problems and many different perspectives should be included to develop a reliable and secure system. This offers to employ system perspective during the design process to integrate different disciplines to achieve the best operational solution. In spite of plenty of works which has been done on detailed problems like control system design [1-7], path planning, obstacle avoidance, and navigation [8-10], there are few works which look the problem in a system perspective. Forced landing of UAV was evaluated by [11] to propose an architecture to select the best landing site between some pre-known candidate landing sites. However, this architecture cannot handle the challenges raised by the changes in the environment. On the other hand, Ref. [12, 13] focuses on guidance of a remotely piloted vehicle using natural landmarks and its landing on a selected area. The proposed architecture relies on a remote operator which reduces its operability in some applications. Another problem which was not considered in the previous studies was about the presence of humans in the landing area. Ref [14] uses data sources like to incorporate the risks posed to property and people on the ground during the trajectory planning. The main focus of this reference is risk while other factors like UAV capabilities, trajectory planning should be also included it the functional and physical structure of the system. In this paper the problem of emergency landing is studied as a system problem in which the safety requirement is considered as the top-level requirements and is mapped to a concept of operations (CONOPS) and using this CONOPS the functional and physical architecture of the system is developed. In spite of other references which employ a Down-Up strategy to propose solutions for some detailed problems, in this paper the main problem is to convert the general problem of safe landing to some the detailed problems using an Up-Down breakdown strategy and find the inter-relationships between these variety of problems. Clearly presenting final solutions for all of these detailed problems are out of the scope of this paper. However, using other researches presented in the literature and some initial evaluations possible solution approaches will be also discussed in this paper.

2. Operational and Functional Architecture

To design an appropriate architecture for the multi-copter a precise definition of system of interest (SOI) and its environment is required first. As depicted in Figure 1, the safe landing system (SLS), as the SOI, is a system which should operate in an environment including the UAV, ground, flying space, peoples and assets and regulations. The SLS is a system which can be used by a multi-rotor to provide maximum possible safety for humans, natural environment and assets while following the mission of UAV. The top-level requirements, guaranteeing the safety of the system, as defined for this system as:

Req. 1 - The SLS must be completely autonomous

Req. 2 - The SLS should minimize the hazards and risks for the people and assets in UAV engine-failure scenarios

Req. 3 - The SLS should try to keep the UAV safe for future uses in engine-failure scenarios

Req. 4 - The SLS should try to enable the UAV to accomplish its operations in fault scenarios

Req. 5 - The SLS must be able to adopt itself with the changes in the environment (e.g., wind, night and day, new constructions, disasters)

Req. 6 - It is recommended that the SLS has minimum supporting systems dependencies and human workload

Req. 7 – The SLS should be able to keep and share flight recordings for future flights

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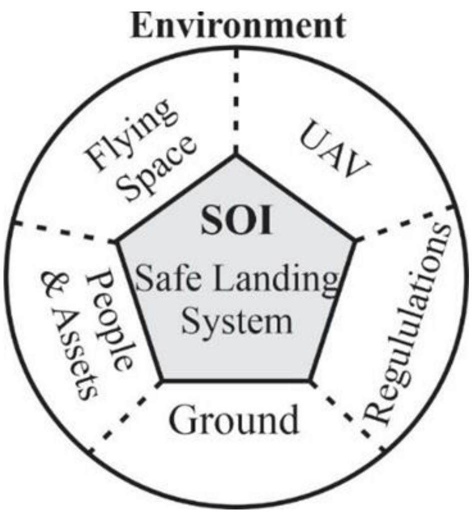

Fig. 1. System of interest and its environment

It is assumed that the UAV has a pre-determined trajectory to accomplish its mission in normal scenario. Here the problem is to how the UAV should flight when at least one of its engines fails. Clearly the trajectory should be re-planned considering the mission, safety issues and UAV capabilities. To solve this problem and based on the definition of SOI, the operational architecture of the system is proposed according to the Figure 2. In this operational architecture of the system, two definitions are used (Figure 3):

- Landing site: This is an area which the UAV can potentially land
- Landing region: Any desired area around the UAV which can fly to find the Landing Site

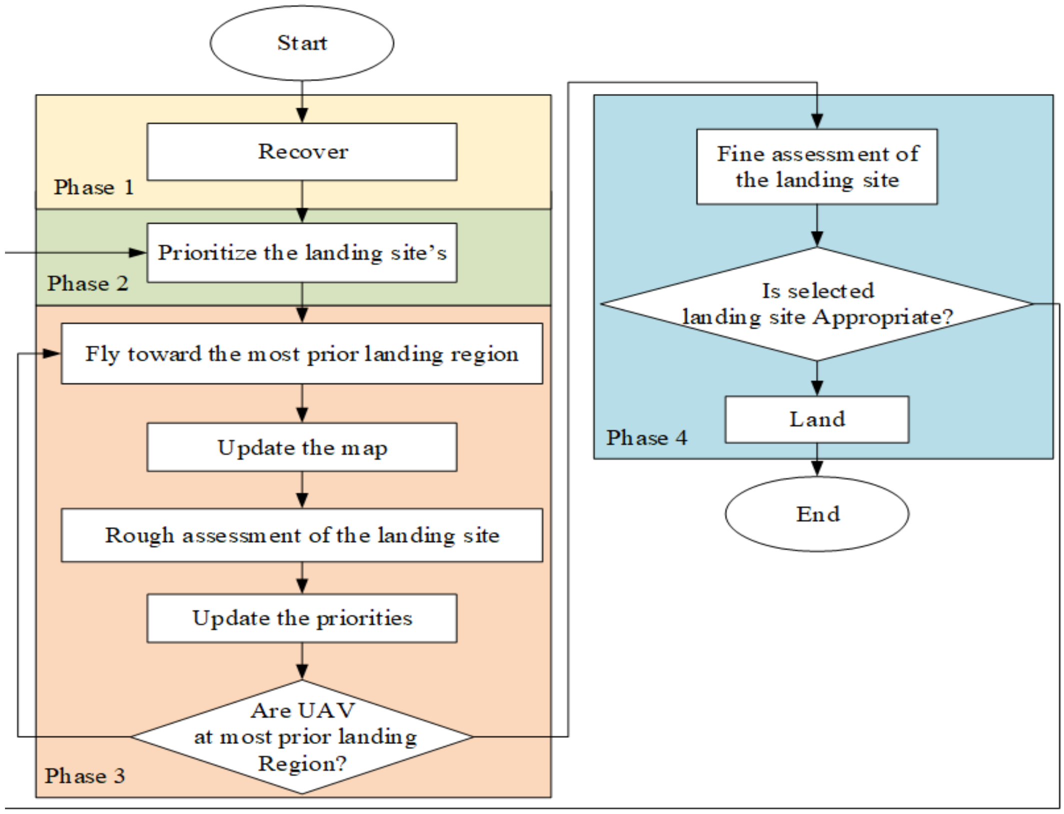

Fig. 2. Operational architecture of SLS

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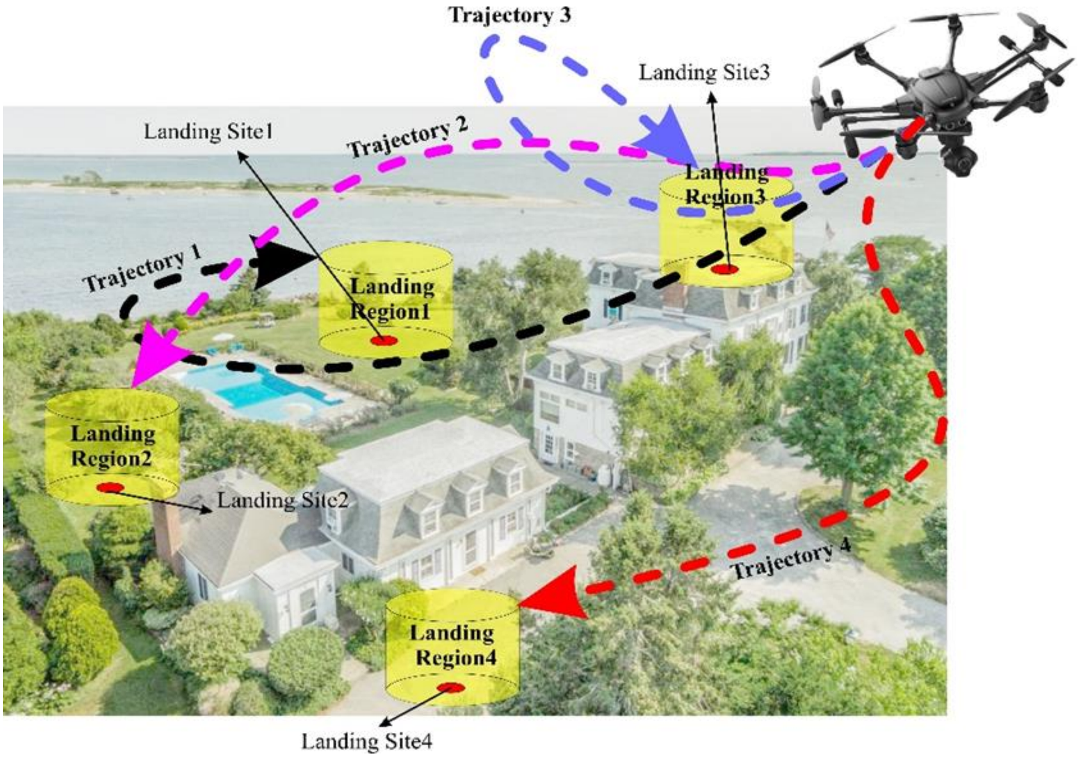

Fig. 3. Operational architecture of SLS

According to this algorithm the UAV priories and monitors the landing site, updates its perception about the environment and plans the trajectory to the selected site repeatedly during its flight. In this architecture the drone first makes a coarse analysis using its available map to identify the possible landing sites and then prioritize them based on criteria's like required trajectory, emergency considerations and capabilities of the UAV to reach the site. During the flight towards the selected site, the UAV uses its vision-based capabilities to update the map. Then the updated map will be used to re-assess the selected site and update it if necessary. This assessment is rough to increase the operational capabilities while using limited computational and sensing resources. When the drone reached to a specific region around the landing site, called here landing region, it should make a fine assessment of landing site considering criteria like suitability for land, collision risk in the case of presence of people or animals. The computational and measurement capabilities are key factors on determining the landing region dimension and the flight characteristics. Based on the fine assessment the UAV may continue to land or may abort and switch to the next saved priority. Based on this architecture the system level functions of the are:

FCN 1 - SLS should be able to detect new Landing sites

FCN 2- SLS should initialize the potential landing sites list

FCN 3- SLS should make rough assessment of potential landing sites

FCN 4- SLS should make fine assessment of selected landing site

FCN 5- SLS should be able to update potential landing sites list

FCN 6- SLS should be able to flight towards the selected landing site

FCN 7- SLS should be able to land on the selected landing site

FCN 8- SLS should be able to propose a suitable trajectory for the flight

FCN 9- SLS should be able to analyze the position of the UAV

https://doi.org/10.55212/ijaa.1032693

The system requires suitable physical architecture to support these functions. The proposed architecture and its relationship to the functions are presented in Table 1. According to this table the SLS system is decomposed into four physical subsystems. The subsystems which are presented here, are themselves systems which was broken to lower levels in the same manner. In the following section Lower-level requirements and operational and functional architecture are presented. The final Product Breakdown Structure extracted from these architectural analyses are presented in Fig. 4. The datils about the relationships between the PBS of subsystems and their functional and physical architectures are also presented in the following section.

Table 1. Functional and Physical architecture relationship for SLS

		Physical Element									
		LSD	CCU	RDSS	**Algorithms**						
					LA	RAA	FAA	SSA	TPA	FCA	LCA
Functions	1	√		√	√						
	2			√							
	3					√					
	4						√				
	5			√	√						
	6			√	√			√		√	
	7				√			√			√
	8								√		
	9	√			√						

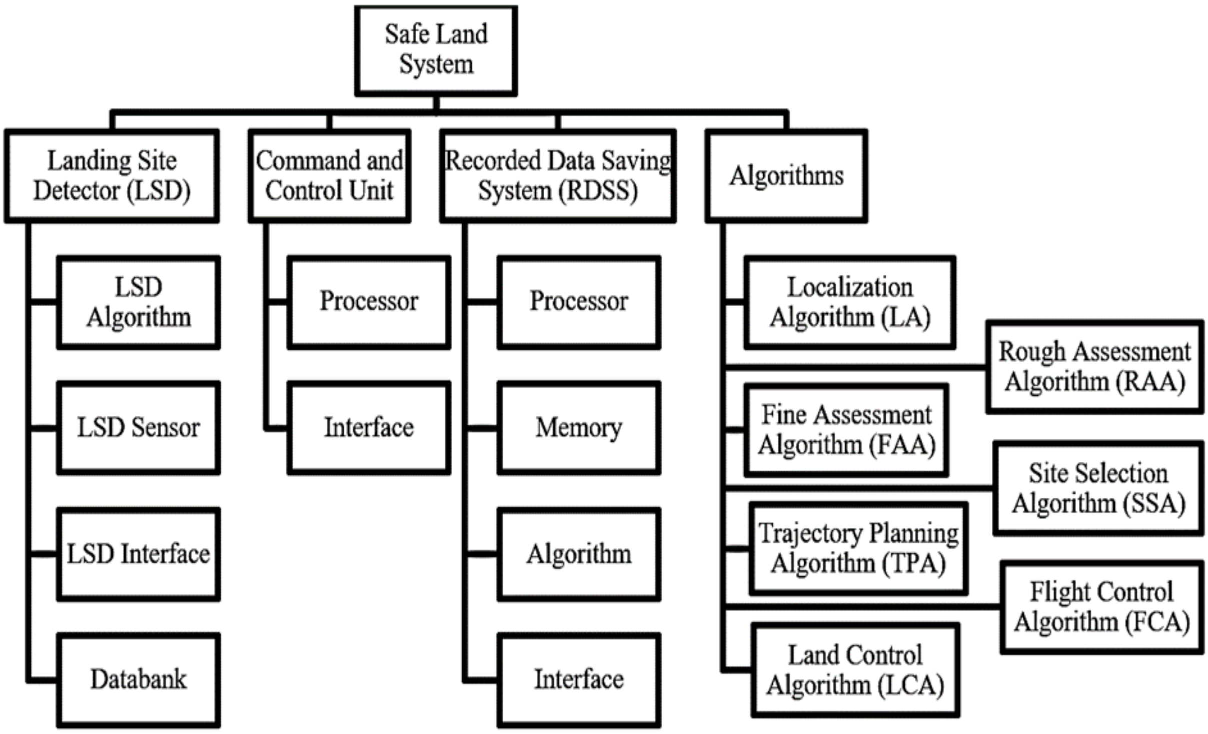

Fig. 4. Proposed Product Breakdown Structure (PBS) for SLS

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3. Subsystem Level Operational Architecture

3.1. Land site detector

In this section the system approach is applied to the LSD subsystem to determine the functional and physical architecture of LSD. Considering the system level analysis, the LSD refers to

- all elements required to provide necessary information for detecting the landing sites
- databank for storing the landing sites during flight
- algorithms for detection the previously stored landing sites
- algorithms for finding the new landing sites

As the first step the requirements of LSD is extracted using the breakdown of the requirements at the system level. These requirements and their relationships with the system-level requirements are presented in Table 2. Based on these requirements the functional architecture of the land site detector is presented in Figure 5. According to this architecture the landing sites are initially set by the RDSS based on the planned trajectory. The SLS functional architectures suggests that during the flight it should be updated based on the new detected landing sites, as well as the changes of the loaded landing sites and also newly detected landing sites. So, it is required to measure the environment during the flight. Analysing the measured paramours and comparing it to the available data (considering the current position of UAV) two main questions can be answered: Is a new site detected? And is an available landing site conditions changed? Answering these questions helps to update the UAV databank of potential landing sites.

Table 2. Requirements of LSD and their relationships with system level requirements

		System Level Requirements						
No.	**Description**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
1-1	The LSD must detect mapped land sites (in LSD) during flight		√	√				
1-2	The LSD must detect new land sites during flight autonomously	√				√		
1-3	It is recommended that the LSD should use natural landmarks for detection						√	
1-4	The LSD calculations should be done CCU					√		
1-5	The LSD should be able to detect the land sites during the flight	√						
1-6	The LSD should contain information about the pre-identified landing sites		√					
1-7	The LSD should be updatable automatically using every new flight	√				√	√	
1-8	The LSD should contain the risk of presence of people/assets in each landing site		√					
1-9	The LSD should contain some measures about the suitability of each landing site			√				

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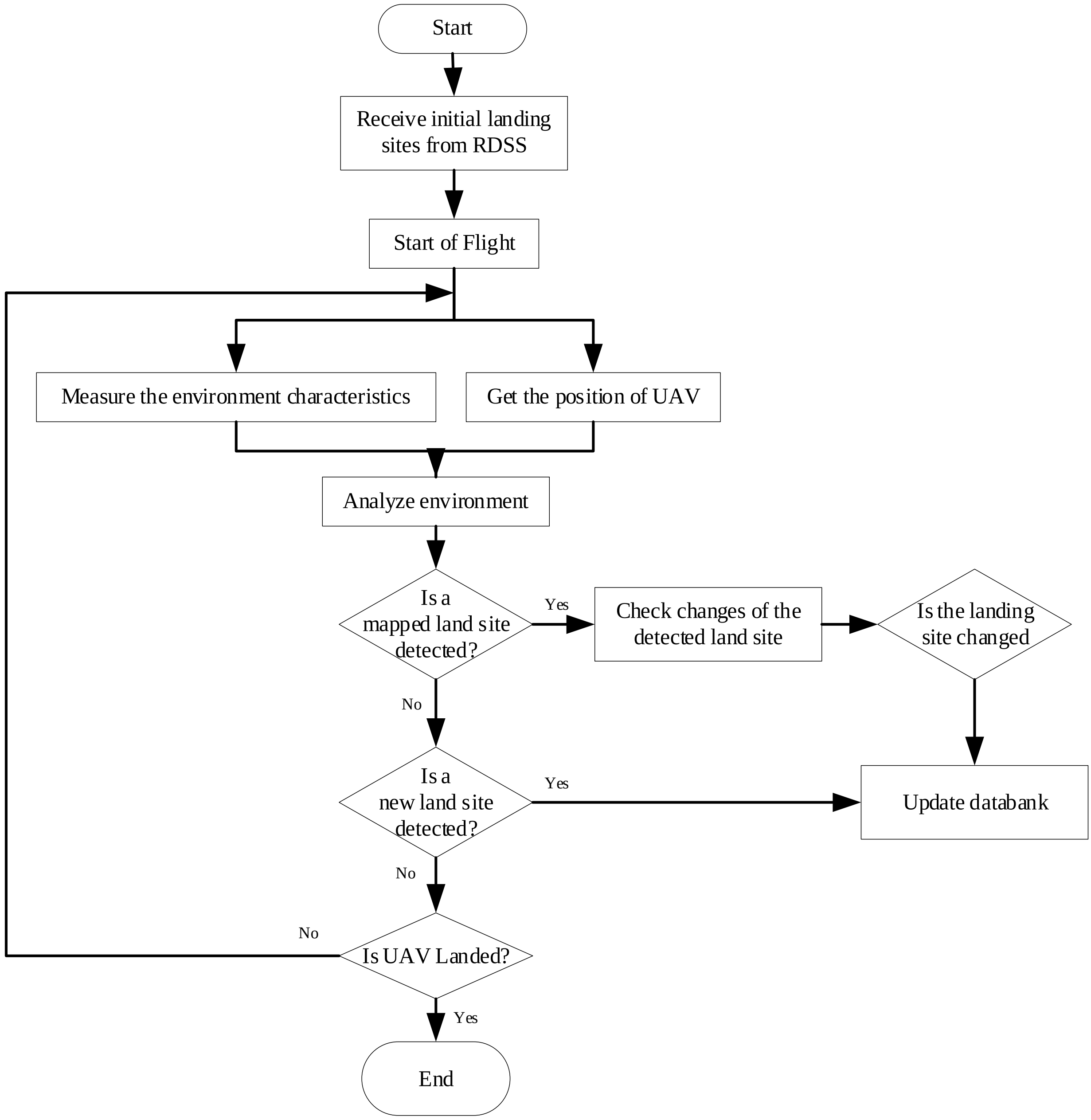

Fig.5. Operational architecture of LSD

This architecture offers the LSD functions as presented in Table 3. The physical elements required to apply this functional architecture is also presented in this table. These elements should be analyzed similarly to determine their requirements and if necessary, they can be considered again as a system to be designed or as a part to be selected, ordered or implemented.

https://doi.org/10.55212/ijaa.1032693

Table 3. Functional and physical architecture relationship for LSD

			Element			
			LSD Algorithm	LSD Sensor	LSD Interface	Databank
Functions	1-1	LSD receives position data			√	
	1-2	LSD measures the environment characteristics		√		
	1-3	LSD analyzes the measured characteristics	√			
	1-4	LSD detects the mapped landing sites	√			
	1-5	LSD detects new landing sites	√			
	1-6	The LSD receives initial landing site from RDSS			√	
	1-7	The LSD receives the start signal from the CCU			√	
	1-8	The LSD checks the changes of current landing sites	√			
	1-9	The LSD update its databank				√
	1-10	The LSD receives the landing signal from the CCU			√	

3.2. Computation and communication unit

Similar to what which done for LSD the functional and physical architecture of CCU are determined in this section. The CCU is the system which is responsible of conducting the calculation required by all subsystems of the SLS. To design the CCU, the system level requirements have been broken down to the requirements related to this this subsystem as presented in Table 4. The functional architecture of CCU is designed based on the derived requirements as presented in Figure 6. According to this functional architecture three algorithms are running in parallel during the flight: Flight Control Algorithm (FCA), Land Site Detector (LSD) and Localization Algorithm (LA). Every time that LSD detects a new landing site or updates an available landing site, Site Selection Algorithm (SAA) and Trajectory Planning Algorithm (TPA) will be run to determine the new trajectory to the best landing site in failure scenarios. On the other hand, if LA shows that the UAV is in the selected landing site, the Fine Assessment Algorithm (FAA) will be ran to accurately analyse the landing site in terms of the changes, presence of the people and height map. If the selected landing site is suitable for land then Landing Control Algorithm (LCA) should be ran else the selected landing site and the trajectory should be updated. In Table 5 the LSD functions designed based on this architecture is presented and according to the analysis on requirements and functions two subsystems are proposed for CCU: Processor and Interface.

Table 4. Requirements of CCU and their relationships with system level requirements

		System Level Requirements						
No.	**Description**	1	2	3	4	5	6	7
2-1	The CCU should be installed on the UAV						√	
2-2	The CCU should have connection on-line or off-line with PLSD						√	
2-3	The CCU should be able to run all algorithms	√						
2-4	The CCU should be able to transfer new found data to the RDSS							√

https://doi.org/10.55212/ijaa.1032693

Table 5. Functional and physical architecture relationship for CCU

			Element	
			Processor	Interface
Functions	2-1	CCU Run LA, FCA, LSD, FAA, TPA and LCA algorithms	√	
	2-2	CCU update RDSS		√
	2-3	CCU should receive data from LSD		√
	2-4	CCU should start its computational algorithm after the start of flight		√

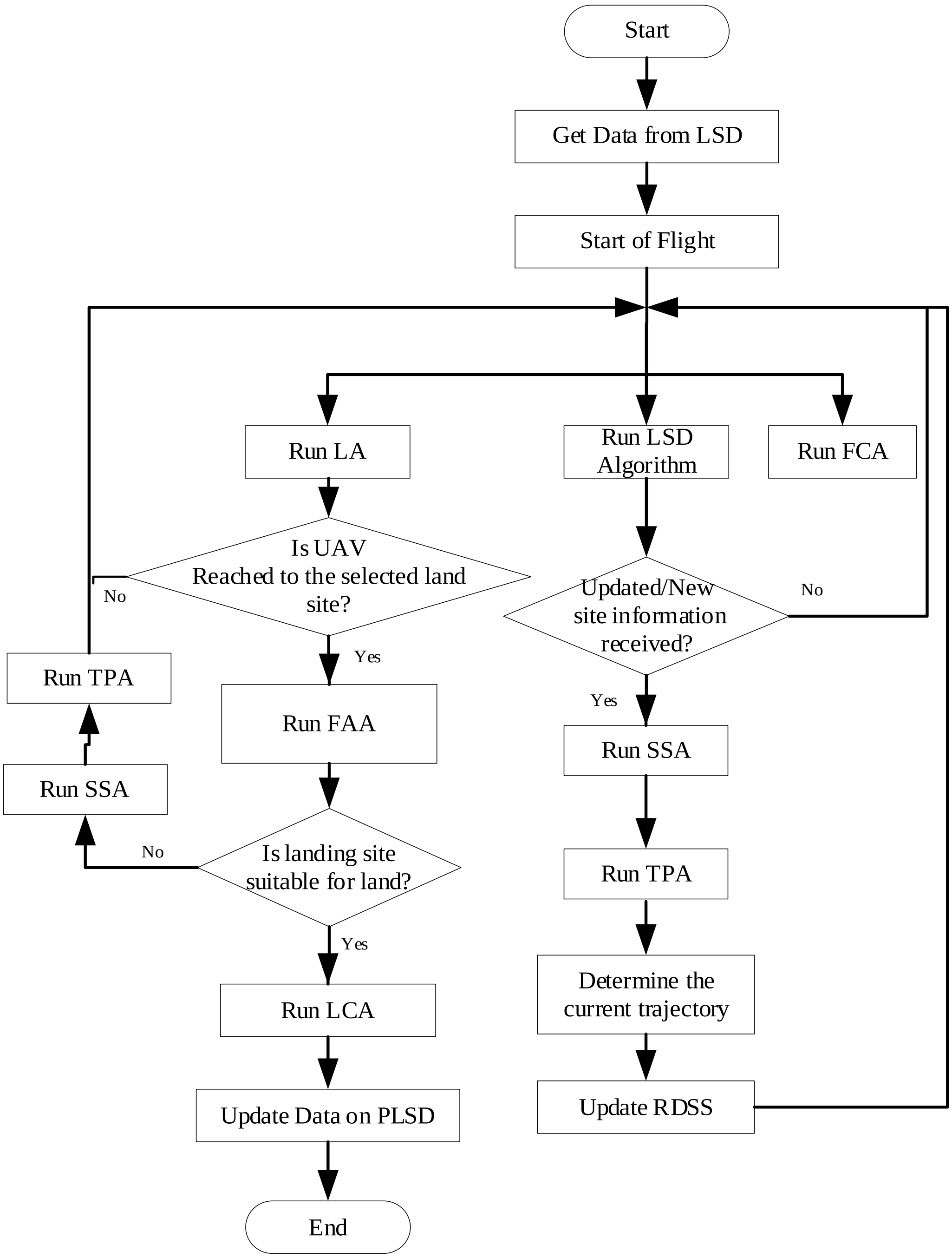

Fig. 6. Operational architecture of CCU

https://doi.org/10.55212/ijaa.1032693

3.3. Algorithms

Algorithms are software elements which runs on CCU to provide necessary commands for the UAV to follow a suitable trajectory. These algorithms are: Localization Algorithm (LA), Rough Assessment Algorithm (RAA), Fine Assessment Algorithm (FAA), Site Selection Algorithm (Site Selection Algorithm (SSA), Trajectory Planning Algorithm (TPA), Flight Control Algorithm (FCA) and Land Control Algorithm (LCA). It should be noted that LSD and RDSS have their own algorithms which are considered directly as a part of these subsystems and are not presented here. At the system level it is sufficient to determine the requirements of algorithms and look them as parts which is not necessary to break more. The software developer uses the requirements to develop them. These algorithms should be delivered based on specific delivery criteria which should be determined during the design process. In Table 6 the requirements of different algorithms presented in this table are summarized.

Table 6. Requirements of algorithms and their relationships with system level requirements

			System Level Requirements						
	No.	**Description**	1	2	3	4	5	6	7
LA	4-1	The LA should be run on CCU to localize the UAV during the flight	√						
	4-2	The LA should be able work without the need of interference of human (tuning, prioritizing, …)						√	
	4-3	The LA should be able to work when the UAV is rotating due to some engine's failures				√			
	4-4	The LA should be able to be adopted to localize the UAV during various environmental conditions					√		
RAA	5-1	The RAA should be run on CCU to assess and score the sites which are already available in the map	√					√	
	5-2	The RAA should consider the hazard probability to people and assets in scoring the sites (using LSD)		√					
	5-3	The RAA should consider the landing suitability in scoring the sites (using LSD)			√				
FAA	6-1	The FAA should be run on CCU and use SLS sensors to find and score new landing sites	√						
	6-2	The FAA should consider the hazard probability to people and assets in its scoring mechanism		√					
	6-3	The FAA should consider the suitability for landing in its scoring mechanism			√	√			
	6-4	The FAA should be able to update LSD							√
SSA	7-1	The SSA should be able to analyze the available sites (in LSD) to propose the best selected site	√						
	7-2	The SSA should minimize the hazards and risks for the people and assets in engine-failure scenarios		√					
	7-3	The SSA should try to keep the UAV safe for future uses in engine-failure scenarios			√				
	7-4	The SSA should try to enable the UAV to accomplish its operations in engine-failure scenarios				√			
	7-5	The SSA should decide the self-destruction mode if necessary		√					
TPA	8-1	The TPA must be run on CCU	√						
	8-2	The TPA must use data of PLSD to plan the trajectory	√						
	8-3	The TPA must propose trajectories which makes minimum risk to people and assets		√					
	8-4	The TPA must propose trajectories considering the failure/abort scenarios				√	√		
FCA	9-1	The FCA must be run on CCU	√						
	9-2	The FCA should be able to detect the failure of the UAV				√			
	9-3	The FCA should be able to control the UAV when some engines are failed		√	√		√		
	9-4	The FCA should be compensate the effects of environmental changes like wind		√	√	√			
	9-5	The FCA should use as minimum energy as possible							
LCA	10-1	The LCA must be run on CCU	√						
	10-2	The LCA should be able to land the UAV in normal scenario and when some engines are failed			√	√			
	10-3	The LCA should be compensate the effects of environmental changes like wind					√		
	10-4	The LCA should be able to land the UAV on unprepared landing sites				√			

https://doi.org/10.55212/ijaa.1032693

3.4. Recorded data saving system

The last subsystem is Recorded Data Saving System which is a ground system and is responsible to aggregate the data collected during different flights to propose initial landing sites to any new flight. These subsystem requirements are all related to the Req. 7 in system level requirements as presented in the Table 7. According to the operational architecture of RDSS (Fig. 7), this system operates in two modes loading mod (Transferring data to the UAV) and update mod (Receiving data from the UAV). In loading mod, the RDSS receives the planned trajectory of UAV and based on this trajectory, determines the part of the map which is necessary to be send to the UAV and then sends these data to the UAV. In update mod, the RDSS connected to a UAV after its operation to receive its updated landing sites. After that RDSS analyses the changes in the maps and decides that how its databank should be updated. This decision-making process is required to avoid updating databank based on any unreliable recordings by the UAVs. According to the decision-making process the map will be updated at the end. The functional architecture of the RDSS and its relationship with proposed physical architecture is presented in Table 8.

Table 7. Requirements of RDSS and their relationships with system level requirements

		System Level Requirements						
No.	**Description**	1	2	3	4	5	6	7
11-1	The RDSS should be able to get and store all flights recording from the UAVs							√
11-2	The RDSS should be able to create and load updated maps into the UAVs							√
11-3	The RDSS should be able to analyze and score the maps according to the requirements of LSD							√

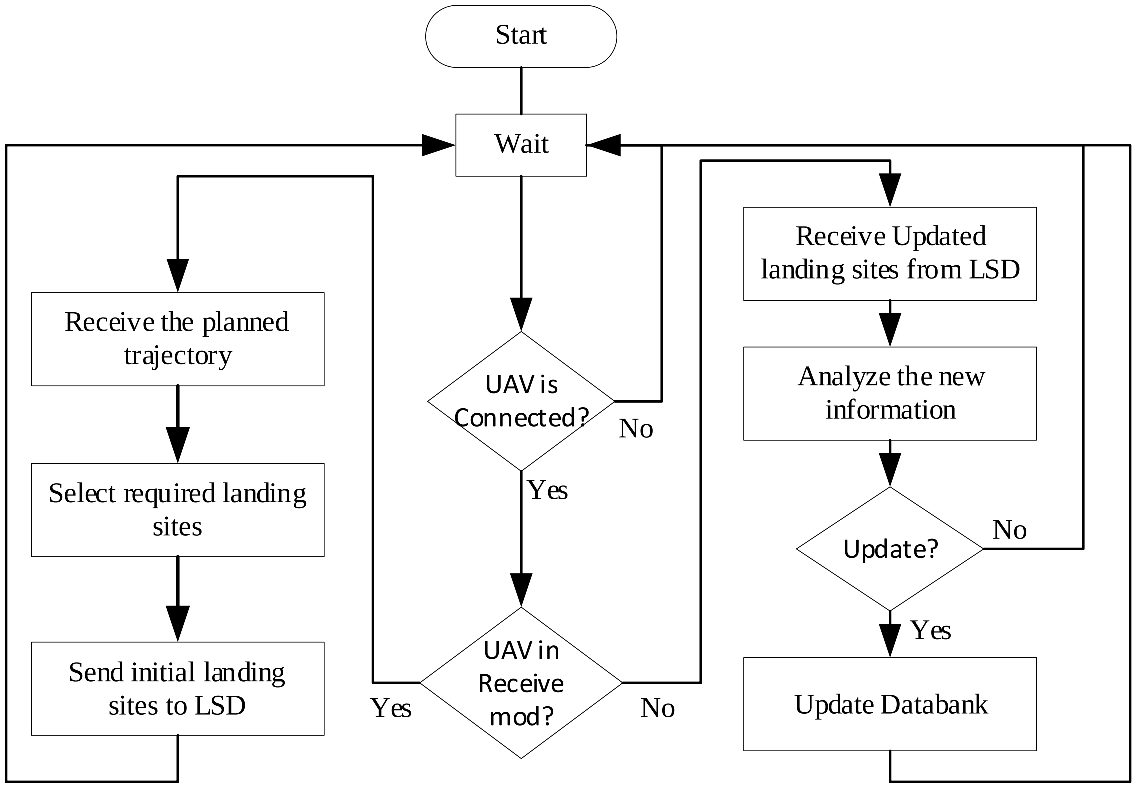

Figure 7. Operational architecture of RDSS

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Table 8. Functional and Physical architecture relationship for RDSS

			Element			
			Processor	Memory	Algorithm	Interface
Functions	1-1	Check that UAV is connection status and mod of connection				√
	1-2	Receive planned trajectory from the UAV		√		
	1-3	Select required landing site for the UAV	√	√	√	
	1-4	Send selected landing sites to the UAV				√
	1-5	Receive Updated landing sites from UAV				√
	1-6	Analyze new information received from the UAV	√	√	√	
	1-7	Update Databank		√	√	

5. Conclusion

In this paper a system approach has been adopted to design the operational, functional and physical architecture of the SLS. To breakdown the architecture between different levels of the system, requirements are used to guarantee that the system level requirements are satisfied. In each level of the system, these requirements are employed to propose an operational architecture for the subsystems. Based on this operational architecture the functional and physical architecture of system/subsystem is extracted. Then the requirements of the system/subsystem are breakdown as the requirements of the its subsystems. The process should be continued until a part is achieved which can be selected or ordered according to a specific set of requirements and delivery criteria. The proposed system, does not limit the SLS only to the UAV itself but it proposes RDSS as a ground system to aggregate the data gathered by different flights to ensure that always an updated perception about the map of area is available. This system also reduces the operational cost of the system and increases the safety of the system.

In this process the derived requirements are mostly used in the design process. To improve the process, other types of the requirements like design requirements can also be considered during the design process. More studies are also required about the relationships between the elements of the system using tools like Design Structure Matrix (DSM) or N*N Matrices.

Acknowledgment

This research is supported by the Scientific and Technological Research Council of Turkey (TÜBİTAK) under 3501 programs, with project number [120M793].

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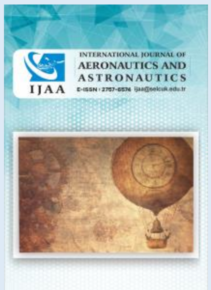

2022, VOL:3, ISS:1, 20-27 e-ISSN: 2757-6574

Research Article

The mental health of ab-initio pilots during the COVID-19 pandemic

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Received	Revised	Accepted
February 11, 2022	March 18, 2022	**March 24, 2022**

Keywords
Ab-initio pilot
COVID-19
Depression
Flight Safety
Pilot Training
Stress

ABSTRACT

The novel coronavirus disease- 2019 (COVID-19) is a major health crisis that has affected several nations and the life of millions to date. The aim of this study is to examine the impact of COVID-19 on student pilots. To the best of the authors' knowledge, no study has been performed on the effect of COVID-19 pandemic on the mental status of ab-initio pilots. As a cross-sectional study, a self-administered 48-item survey was conducted among ab-initio pilots. A total of 108 ab-initio pilots completed the survey. The Depression, Anxiety and Stress Scale - 21 (DASS-21) was used to assess the mental health of the ab-initio pilots. Independent-samples t-test and one-way ANOVA were performed to explore contributing factors associated with the presence of depression, stress and anxiety. Based on the findings, 24% of the ab-initio pilots had anxiety on varying levels. 44.2% of the participants were depressed. Varying levels of stress were detected in 45% of the ab-initio pilots. Vulnerability, working conditions, isolation, social and mass media and the lack of job opportunities were factors associated with stress, anxiety and depression among the ab-initio pilots. This study showed that depression, anxiety and stress were prevalent among the ab-initio pilots who were included in the study, and the participants were adversely affected by the COVID-19 pandemic. The mental health of ab-initio pilots needs the urgent attention of aviation authorities and experts. This study contributes to the current literature on the impacts of the COVID-19 pandemic and may make noteworthy contributions to aviation safety.

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Authorship contribution statement for Contributor Roles Taxonomy
Bilal Kılıç: *Writing - original draft, Investigation, Supervision and Writing – review & editing,* ***Melis Tabak:*** *Writing – review & editing, Investigation.*

Conflicts of Interest: The author(s) declare no conflict of interest.

Citation: *Kılıç, B., Tabak, M. 2022. The mental health of ab-initio pilots during the COVID 19 pandemic. International Journal of Aeronautics and Astronautics, 3(1), 20-27.*

1. Introduction

On 11 March 2020, the novel coronavirus (COVID-19) was officially declared a global pandemic by the World Health Organization (WHO) [1] The pandemic has had a devastating effect on people's livelihoods, their health, and the economy [2]. It had also adversely affected the global economy and public mental health [3]. Furthermore, the COVID-19 outbreak has had a significant impact on the education system in the world [4]. To control the spread of the novel coronavirus - 2019 (SARS-CoV-2), universities, schools and colleges had been closed in 107 countries by March 18, 2020 [5]. Distance learning was implemented as a solution throughout the COVID-19 pandemic lockdown period [3]. The COVID-19 pandemic has had a devastating impact on the aviation industry [6]. The aviation market all around the world has experienced a substantial loss of traffic within a short period. A number of airlines completely ceased their operations and filed for bankruptcy (Table I) [7]. Moreover, airline crews have been on various furlough schemes such as unpaid leave and part-time employment as a result of the diminished demand in air transportation [8].

Table 1. Airlines filed for bankruptcy due to pandemic [9].

Airline	Servicing Date	Bankruptcy Application Date	Fleet Size
Flybe	1979	2020.03.05	63
Miami Air International	1990	2020.03.24	6
Trans States Airlines	1982	2020.04.01	45
Compass Airlines	2007	2020.04.05	56
Ravn Air	1948	2020.04.05	73
Braathens Regional Airlines	1976	2020.04.06	14
Germanwings	1997	2020.04.07	33
South African Airways	1934	2020.04.16	39
Virgin Australia	2000	2020.04.21	98
LGW	1980	2020.04.22	15
German Airways	1980	2020.04.22	20
Air Mauritius	1972	2020.04.23	14
Avianca	1919	2020.05.10	102
LATAM	1919	2020.05.10	315
Thai Airways	1988	2020.05.27	80
Level Europa GmbH	2017	2020.06.18	6
NokScoot	2015	2020.06.26	7
Aero Mexico	1934	2020.06.30	68
Avianca Brasil	1998	2020.07.06	10

The unprecedented burden of the severe outbreak of COVID-19 on the aviation industry has significant implications for pilot training [10]. First, flight training organizations (FTOs) and aviation schools at universities have globally ceased pilot trainings. Ab-initio pilot trainings across 40 countries worldwide have been severely affected [11]. Second, the airline industry has faced the worst crises since the September 11 attacks which gave rise to the mass unemployment of pilots [9]. Furthermore, the mental health of staff in the aviation industry might have severely deteriorated due to the unprecedented impact of the COVID-19 pandemic [12].

In the context of aviation safety, the physical state and mental state of aircrew are of great importance. The mental health status of pilots might severely affect the flight safety. It has been found that adverse mental state of pilots

https://doi.org/10.55212/ijaa.1071166

jeopardized the flight safety and gave rise to unwanted situations (e.g., near-miss, incidents and accidents) [13]. It has been reported that degraded physical condition of pilots resulted in failures, errors, near-misses, incidents, and accidents [14-16]. Factors affecting ab-initio pilots' physical and mental state have been extensively studied [17-19].

The impact of the COVID-19 outbreak has been extensively investigated in various industries including healthcare [3] education [4], economy [20] and aviation [6]. Moreover, a considerable amount of literature has been published on the impact of the COVID-19 pandemic on students [21,22]. Although extensive research has been carried out on the impact of COVID-19, no single study which investigated the psychological impact of COVID-19 on ab-initio pilots exists. With this consideration in mind, we set out to analyze the psychological impact of the COVID-19 pandemic on ab-initio pilots.

2. Material and Methods

2.1. Participants

A 48-item survey was delivered online to 400 ab-initio pilots from four flight schools and two university-level aviation schools. The response rate was 108/400. Of the participants, 54 (50.0%) had private pilot licenses (PPL), 47 (43.5%) had ab-initio pilot licenses (SPL), and 7 (6.5%) had commercial pilot licenses (CPL). The majority (56.3%, N= 61) of the ab-initio pilots were between the ages of 17 and 23. Among the participants, 97 (89.8%) were unmarried, and 11 (10.2%) were married. Ethical approval for this study was received from the Ozyegin University Human Research Ethics Board (2021/01/05).

2.2. Survey

The survey which was used in the study was developed based on two previously reported surveys [20,23]. This survey was organized into three parts. The first part was composed of 10 items questioning demographic information. In the second part, there were 17 items regarding situations related to the COVID-19 pandemic. The last part included the Depression, Anxiety and Stress Scale - 21 (DASS-21). DASS-21 contains 21 items to assess 3 emotional states (i.e., depression (items: 30,32,37,40,43,44, and 48), stress (items: 28,33,35,38,39,41, and 45), and anxiety (items:29,31,34,36,42,46, and 47) [24]. The questions in the second part had 5-point Likert-type response options (1 – strongly disagree to 5 – strongly agree). The questions in the third part (DASS-21 Scale) had 4-point Likert-type response options (1. Never – 4. Always). (Appendix)

2.3. Statistical analysis

We used Kolmogorov-Smirnov test to analyze the compliance of the parameters with normal distribution. In addition to descriptive statistical methods, independent-samples t-test and one-way analysis of variance (ANOVA) were used to analyze the results of the survey on a significance level of 5%. The reliability of 17 expressions was determined by applying Cronbach's alpha analysis. The Cronbach's alpha coefficient was found to be 0.89. The reliability of 21 expressions of the DASS-21 scale was also determined. It was found to be 0.93. Factor analysis was performed to investigate the consistency.

3. Results and Discussion

It was revealed that the COVID-19 pandemic had a negative impact on the psychological states of the ab-initio pilots who participated in the study. Of the participants, 24% (N=18) had anxiety on varying levels. Almost half of the participants (44.2%, N=41) stated that they were depressed. Varying levels of stress were detected in 45% of the participants.

https://doi.org/10.55212/ijaa.1071166

The participants were asked, “Have you ever received psychological support during the pandemic period?” To this question, 9.3% of the participants (N=10) reported that they received psychological support during the pandemic period. Among all participants, 0.9% (N=1) requested it. Approximately one-third of the participants (9.3%, N=10) suggested that they had contact with a person who had a suspected or confirmed diagnosis of COVID-19. About one-third of the 108 participants pilots who completed the survey (37%, N=40) said they had elderly or high-risk individuals in their family.

The participants were asked whether their flight training was ceased or postponed. Almost two-thirds of the participants (63%, N=68) stated that their flight training was ceased or postponed during the pandemic period. Close to one-third of the participants (26.9%, N=29) said they had signed a cadet pilot agreement whereby the ab-initio pilot commits to serve an airline for a specified term.

Based on the results, there were no significant differences in stress and depression levels based on the participants’ age, gender, marital status, type of pilot license or status of receiving psychological support.

A significant difference was found between the male and female participants. The female participants had a higher level of anxiety than the male participants. One of the most striking results that emerged from the study was that there was no significant difference between the levels of anxiety, depression and stress of the participants who had cadet agreements and those who covered their training with their own budget ($p > 0.05$).

There was a significant difference in anxiety levels based on the age groups of the participants ($p < 0.05$). The number of the participants at the ages of 17-23 was higher in comparison to the number of those who were 24 or older. Flight training organizations should pay particular attention to younger pilots and plan supportive seminars, courses and organizations. Flight training departments of universities may develop a career plan for their students and graduates. Students may participate in career-related volunteer opportunities.

Female gender, being aged between 17 and 23, status of receiving psychological support during the pandemic period, items related to vulnerability (16-19), working conditions (20-22), isolation (23,24), knowledge (26) and the media (27) were factors associated with the presence of anxiety on varying levels.

School closures (e.g., FTOs and university-level aviation schools), items related to vulnerability (16-19), working conditions (20-22), isolation (23,24), lack of job opportunities (25), knowledge (26) and the media (27) were related to stress among the participants (Table 2).

The status of receiving psychological support during the pandemic period, items related to vulnerability (16-19), working conditions (20-22), isolation (23,24), lack of job opportunities (25) and the media (27) were associated with depression (Table 2).

It is well-known that the airline industry and air transport rely on keyworkers such as flight deck crew and cabin crew. Previous studies have reported that the psychological status of pilots was severely affected during mass disruptions in the past such as the September 11 attacks, the SARS epidemic, the Gulf War, and the recession in the 1990s. Therefore, the investigation of the impact of the COVID-19 pandemic on pilots, especially ab-initio pilots that are more vulnerable to stressors, is of great importance.

The findings of this study provided evidence that the COVID-19 outbreak had a significant impact on the psychological status of the ab-initio pilots who were included in the study. It was found that more than 20% of the participants had anxiety on varying levels, and more than 40% of them had different levels of stress and depression. Aviation authorities may initiate preventive actions against the negative affect of the COVID-19 pandemic on ab-initio pilots and publish recommendations for flight training organizations.

Contrary to expectations, there was no significant relationship between the participants’ statuses of having signed a cadet agreement and their levels of depression, anxiety and stress.

It is interesting to note that the most significant factor related to stress among the participants was vulnerability. This finding was directly in line with previous findings [23].

https://doi.org/10.55212/ijaa.1071166

Table 2. The comparison of 18 items related to the COVID-19 outbreak between the groups with and without anxiety, stress, and depression

	Anxiety							Stress							Depression						
	Anxiety absent			Anxiety at any level			P.	Stress absent			Stress at any level			P.	Depression absent			Depression at any level			P.
	Med.	Min	Max	Med.	Min	Max		Med.	Min	Max	Med.	Min	Max		Med.	Min	Max	Med.	Min	Max	
	Health of myself/ others																				
11	3	1	5	4	1	5	0.283	3	1	5	3	1	5	0.060	3	1	5	3	1	5	0.115
12	2	1	5	3	1	5	0.627	2	1	5	3	1	5	0.337	2	1	5	3	1	5	0.705
13	3	1	5	5	1	5	0.031	3	1	5	4	1	5	0.078	3	1	5	4	1	5	0.011
14	4	1	5	5	1	5	0.548	5	1	5	4	1	5	0.856	4	1	5	5	1	5	0.261
15	4	1	5	5	1	5	0.452	4	1	5	5	1	5	0.382	4	1	5	5	1	5	0.096
	Vulnerability																				
16	3	1	5	4	1	5	0.001	2	1	5	3	1	5	<0.001	2	1	5	4	1	5	<0.001
17	2	1	4	3	1	5	0.003	2	1	4	3	1	5	<0.001	2	1	4	3	1	5	<0.001
18	2	1	4	3	1	5	0.002	1	1	4	3	1	5	<0.001	1	1	4	3	1	5	0.001
19	2	1	5	3	1	5	0.002	1	1	4	3	1	5	<0.001	1	1	4	3	1	5	<0.001
	Work																				
20	2	1	5	4	1	5	0.002	2	1	4	3	1	5	<0.001	2	1	4	3	1	5	0,001
21	1	1	5	3	1	5	0.001	1	1	4	3	1	5	<0.001	1	1	4	3	1	5	<0.001
22	2	1	5	4	1	5	0.003	1	1	5	2	1	5	0,.005	1	1	5	2	1	5	0.013
	Isolation																				
23	1	1	3	1	1	5	0.014	1	1	2	1	1	5	0.001	1	1	2	1	1	5	0.003
24	3	1	5	4	1	5	0.042	3	1	5	3	1	5	0.031	2	1	5	3	1	5	<0.001
	The lack of job opportunities																				
25	4	1	5	5	1	5	0.125	3	1	5	5	1	5	0.011	3	1	5	5	1	5	<0.001
	Knowledge																				
26	2	1	4	2	1	5	0.016	1	1	4	2	1	5	0.003	1	1	4	2	1	5	0.063
	Media																				
27	2	1	5	4	1	5	0.001	2	1	5	4	1	5	<0.001	2	1	5	4	1	5	<0.001

The results of this study also showed that female gender and request for psychological support were associated with varying levels of depression, anxiety and stress. This was in agreement with previous findings [3]. Furthermore, consistent with earlier findings reported by Aslaner et al., we identified the following factors that had a significant negative impact on the participants' mental health [3]:

- excessive exposure to pandemic news on social and mass media
- inadequate amount of valid information about COVID-19
- vulnerability
- lack of knowledge
- isolation
- lack of job opportunities
- hygiene in the workplace

4. Conclusion

In summary, we were able to demonstrate the negative impacts of the COVID-19 pandemic on the mental state of ab-initio pilots. The findings of this study suggested that almost half of the ab-initio pilots had varying levels of depression and stress, and a quarter of them showed different levels of anxiety. The impaired mental health of ab-initio pilots may jeopardize the flight safety. Therefore, the findings of this study may contribute the flight safety by implementing preventive actions against the contributing factors to mental health disorders (e.g., stress, anxiety, and depression) [13].

https://doi.org/10.55212/ijaa.1071166

Finally, a number of important limitations need to be considered. First, the response rate was low. Second, the sample was representative of ab-initio pilots on a national scale, but it would tend to miss students who were hesitant to participate in the study.

It would be interesting to assess the effects of the COVID-19 pandemic on airline pilots, cabin crews and technicians. Work towards examining the impact of the COVID-19 outbreak on the mental states of airline pilots is in progress in our research team.

This study extends our knowledge on the impact of the COVID-19 pandemic on employees in the aviation industry. This information can be used to develop targeted interventions aimed at planning ahead of time to provide support for ab-initio pilots in the future.

Acknowledgment

The authors would like to express their sincere gratitude to the ab-initio pilots

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Appendix

SURVEY
Part 1. Demographics
1.Gender
Female
Male
Prefer not to say
2. Age
17-23
24-30
31 and older
3. Holding type of license
SPL
PPL
CPL
4. Marital status
Married
Unmarried
5. Did an airline company provide financial assistance for you with a certain time (5 years, 10 years, etc.) of service for tuition related expenses?
Yes
No
6. Has your flight training been ceased or postponed?
Yes
No
7. Do you have any comorbidities (additional disease)?
Yes
No

https://doi.org/10.55212/ijaa.1071166

8. Do you have elderly or high-risk individuals among the family or do you live with those?
Yes
No
9. Have you ever got in contact with a COVID-19 suspected person?
Yes
No
10. Have you ever received psychological support during the pandemic period?
Received
Requesting
Not requesting
Part 2. Situations related to the COVID-19 pandemic
Health of myself/others
11. I am worried about being infected.
12. I think I already got the infection.
13. I am worried about my/my family's other health problems.
14. I am afraid of spreading the infection to my family or others.
15. I am afraid of my parents getting infected.
Vulnerability
16. I think the virus spread can not be controlled.
17. I don't feel safe myself.
18. I feel my life is under threat.
19. I feel I lost control of my life.
Work
20. I feel stressed because of the increase in my workload.
21. I am afraid of doing my job (performing flight training).
22. I think there is not enough equipment (e.g., disinfection kit and protection mask) in training aircraft to prevent contamination and to be protected.
Isolation
23. I think I have been excluded by my relatives and other people because of my job.
24. I am afraid of being isolated or restricting my activities.
Lack of job opportunities
25. I am afraid of the lack of open position in aviation or lack of recruitment in aviation.
Knowledge
26. I think I have a lack of information about preventing the epidemic and protecting myself.
Media
27. News/ TV/ Social Media increases my stress level.
Part.3 DASS-21 Scale
28. I found it hard to wind down during the past week
29. I was aware of dryness of my mouth during the past week
30. I couldn't seem to experience any positive feeling at all during the past week
31. I experienced breathing difficulty (e.g., excessively rapid breathing, breathlessness in the absence of physical exertion) during the past week
32. I found it difficult to work up the initiative to do things during the past week
33. I tended to over-react to situations during the past week
34. I experienced trembling (e.g., in the hands) during the past week
35. I felt that I was using a lot of nervous energy during the past week
36. I was worried about situations in which I might panic and make a fool of myself during the past week
37. I felt that I had nothing to look forward to during the past week
38. I found myself getting agitated during the past week
39. I found it difficult to relax during the past week
40. I felt down-hearted and blue during the past week
41. I was intolerant of anything that kept me from getting on with what I was doing during the past week
42. I felt I was close to panic during the past week
43. I was unable to become enthusiastic about anything during the past week
44. I felt I wasn't worth much as a person during the past week
45. I felt that I was rather touchy during the past week
46. I was aware of the action of my heart in the absence of physical exertion (e.g., sense of heart rate increase, heart missing a beat) during the past week
47. I felt scared without any good reason during the past week
48. I felt that life was meaningless during the past week

https://doi.org/10.55212/ijaa.1071166

International Journal of Aeronautics and Astronautics
https://dergipark.org.tr/en/pub/ijaa

2022, VOL:3, ISS:1, 28-47 e-ISSN: 2757-6574

Research Article

Fault tolerant control of a quadrotor based on incremental nonlinear dynamic inversion

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Received	Revised	Accepted
December 6, 2021	February 7, 2022	**February 18, 2022**

Keywords
Fault Tolerant Control
Multirotor
Nonlinear Dynamic Inversion
Incremental

ABSTRACT

The multirotor unmanned aerial vehicles (UAVs) have rapidly attracted interest of the researchers since they play a unique role in a variety of areas including the military, agriculture, rescue, and mining. Actuator fault or failure is inevitable during multi-rotor's operations, which can endanger humans on the ground in addition to costly damage to the system itself. Therefore, this paper introduces a nonlinear controller algorithm for fault-tolerant control of a quadcopter with partial loss of actuator effectiveness. The introduced controller includes a cascade structure of the fast inner-loop dynamics and slow outer-loop dynamics. In the inner-loop part of the controller, an incremental nonlinear dynamic inversion controller is applied and a modified PID control algorithm is used in the outer-loop of the controller. Simulation results for different fault scenarios demonstrate that the proposed fault-tolerant controller approach can quickly adapt itself to the abrupt change due to the motor faults and tracks the desired inputs satisfactorily.

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Authorship contribution statement for Contributor Roles Taxonomy
Karim Ahmadi, *has developed the theoretical analysis and the numerical simulations regarding the control algorithm and experiments as well as manuscript preparation.* **Davood Asadi,** *has supervised the theoretical development of control approaches, and experiments as well as helped in preparing the manuscript.* **Yaser Nabavi,** *has helped in manuscript writing.*

Conflicts of Interest: The authors declare no conflict of interest.

Citation: *Ahmadi, K., Asadi, D., Nabavi Chashmi, S. 2022. Fault tolerant control of a quadrotor based on incremental nonlinear dynamic inversion. International Journal of Aeronautics and Astronautics, 3(1), 28-47.*

1. Introduction

Multi-rotor Unmanned Aerial Vehicles (UAVs) have rapidly attracted the interest of researchers since they are being implemented in a variety of different applications including surveillance, reconnaissance, agriculture, rescue, and mining. One of the outstanding research challenges in multirotor design is the requirement of a sophisticated control system that can cope with unexpected casualties like actuator failures [1**,** 2].

Faults and failures are inevitable in complex systems like aircraft. Hence, scientists are working on fault-tolerant control strategies to safely land the aircraft in presence of faults or failures [3–5]. The controllability of the multirotor in presence of motor fault is investigated in [6]. Fault-tolerant control (FTC) techniques have been proposed in [7–12] to recover the control of faulty vehicles. Nonlinear L1 adaptive control [7], robust adaptive control [8], adaptive sliding mode control [9], Linear Parametric Variable (LPV) sliding mode control [10], optimal adaptive control [11], and Model Reference Adaptive Control (MRAC) [12] are some instances of direct fault-tolerant control algorithms.

In addition to the direct methods, fault-detection and identification algorithms are also used in fault-tolerant control strategies [13]. Timely detection of the actuator failures and estimation of their severity plays an important role in avoiding crashes and leading to fast recovery for a safe landing. Fault-detection approaches can be categorized into model-based, signal-based, knowledge-based, and active diagnosis techniques [14]. Since multi-rotors have a nonlinear, highly–coupled, and underactuated dynamic system, controlling them is a challenging problem. On the other hand, actuator fault is also a common problem in multi-rotors, which raises discussions about their reliability and safety.

In the event of a motor fault and/or failure, numerous studies are being conducted to recover multi-rotor vehicles. FTC researches corresponding to the multi-rotor's motor faults and failures can be classified into two groups of partial actuator fault and complete loss of actuator effectiveness or actuator failure. Some researches investigate the effect of partial fault on the rotor and propose fault-tolerant strategies while other researches have examined the effect of motor failure and appropriate fault-tolerant control strategies. Among the researches, some have applied fault detection algorithms as a part of the FTC strategy, while others apply direct fault-tolerant control algorithms to control the multirotor. Ref [15] introduced a fault-tolerant control strategy to control a quadcopter in case of a time-varying motor fault. The proposed fault-tolerant strategy includes fault detection and identification algorithm based on the controller outputs and the angular rates calculated by a discrete extended Kalman filter and a discrete nonlinear adaptive tracking controller.

There are also several other researches [2, 16, 17], which have tried to control the quadrotor in presence of partial fault [2]. The sliding mode control technique has been applied in Ref. [16] as a passive fault-tolerant control method to control the quadrotor's attitude considering partial rotor fault. An adaptive fuzzy system is used as a compensator to compensate for the estimation error of nonlinear functions and faulty parts. Ref. [17] applies a sliding mode disturbance observer inside the fault-tolerant sliding mode controller to control and improve the performance of the quadrotor with partial actuator fault. There are several researches regarding the controllability of multi-rotors in presence of rotor fault or failure, in which different configurations including quadrotor, hexarotor, and octarotors have been investigated to determine the status of controllability [18,19].

Among the aforementioned multi-rotors, quadrotors suffer more from rotor fault due to lack of actuator redundancy. Respecting the controllability of quadrotors, it is well known that failure of one rotor results in an uncontrollable system. Therefore, full attitude control of the quadrotor can be achieved for a maximum specific magnitude of the partial fault and is not achievable in presence of complete one rotor failure. In case of one rotor failure in quadrotors, controllability of the yaw state is scarified and the controller tries to control the roll and pitch

https://doi.org/10.55212/ijaa.1033224

angles [20]. Various control methodologies have been addressed in literature the problem of complete loss of one or two rotors of the quadrotor [20–22].

A robust feedback linearization controller along with an H∞ loop shaping technique is adopted in Ref. [20] to achieve regulation of roll and pitch angles around the chosen working point. A nonlinear sensor-based fault-tolerant controller is developed in Refs. [22,23] to stabilize a quadrotor with failure of two opposing rotors in the high-speed flight condition.

Ref [24] proposes a complete FTC design approach with fault detection and diagnosis (FDD) of a quadrotor in presence of a partial fault. Hexarotor seems to be more robust respecting motor failure because of having more actuators. Despite the higher numbers of motors concerning quadrotors, researchers demonstrated that standard hexarotors are not fully controllable in case of one motor failure, in which yaw control is lost if one engine is failed [25]. It is difficult to reach a controller that can cope with motor failures in the standard configurations, and most proposed controller algorithms in the literature are confined to reduced attitude control [26]. In the standard configuration of hexarotor (PNPNPN: P stands for rotation in the positive direction and N stands for rotation in the negative direction), all neighboring motors rotate in opposite directions. Non-standard configurations (PPNNPN) can maintain full controllability in presence of one rotor failure.

Accordingly, Ref. [27] applies the composition of a Tau-observer and a disturbance based sliding mode controller on a non-standard configuration of hexarotor and investigated the fault detection and control of a hexarotor in presence of one and two motor failure with controlling the attitudes including the heading and keep the hovering flight to landing. It can be demonstrated that the non-standard configurations of hexarotor are fully controllable in 33% of up to two random motor failures [18]. According to the literature and above discussion, full controllability of quadrotor (roll, pitch, and yaw) is not possible for complete loss of effectiveness of one motor (motor failure).

In a novel approach proposed here, the Incremental Nonlinear Dynamic Inversion (INDI) control algorithm is applied and augmented with a nonlinear robust adaptive controller to control the quadrotor in presence of a motor fault. The simulation results verify the perfect performance of the introduced architecture. Additionally, for trajectory tracking, a modified PID algorithm is applied in the third loop of the three-loop control strategy.

The remainder of this paper is organized as follows. The quadrotor's nonlinear dynamic equation of motion is derived in section (II). The controller architecture including the INDI algorithm, robust adaptive controller approach, and the PID controller is presented in section (III). Numerical results, controller performance, and the comparison are examined in section (IV), and finally, the conclusion section briefly discusses the key results.

2. Mathematical Model

In this section, the quadrotor model and equations of motion, disturbance due to unknown dynamics, the motor model, as well as the motor mixer equations are presented.

a) Quadrotor frame

The S500 frame with the EMAX2212/ 820KV motors is selected as the plant model in this research. The quadrotor parameters, which are used in this paper are given in Table 1.

https://doi.org/10.55212/ijaa.1033224

Table 1. Quadrotor frame specifications

Quadrotor Parameters	Values
Mass, *m*	1.59 *kg*
Thrust Parameter, *b*	2.02×10^{-7} *N/rpm*^{2}
Drag Parameter, *d*	4.18×10^{-9} *Nm/rpm*^{2}
Moment arm (C.G to motor distance), *l*	0.243 *m*
Moment of Inertia about the *x*-axis, I_{xx}	0.0213 *kg.m*^{2}
Moment of Inertia about the *y*-axis, I_{yy}	0.0221 *kg.m*^{2}
Moment of Inertia about the *z*-axis, I_{zz}	0.028 *kg.m*^{2}
Translational drag coefficients, k_x, k_y	$5.5e-4\,N/m/s$
Translational drag coefficients, k_z	$6.3e-4\,N/m/s$
Rotational drag coefficients, k_φ, k_θ	$5.5e-4\,N/rad/s$
Rotational drag coefficients, k_ψ	$6.35e-4\,N/rad/s$
Total rotational moment of inertia, J_T	6.8×10^{-5} *kg.m*^{2}
Max motor speed, Ω_{max}	6250 rpm

b) Dynamic equations

The translational and rotational equations of the quadrotor in the body frame are presented in Eqs. (1) and (2), respectively. As depicted in Fig. 1, the quadrotor consists of four motors. Number one and two motors rotate counterclockwise with velocities Ω_1, Ω_2, respectively, whereas the other two motors (number 3 and 4) rotate in the opposite (clockwise) direction with velocities Ω_3, Ω_4.

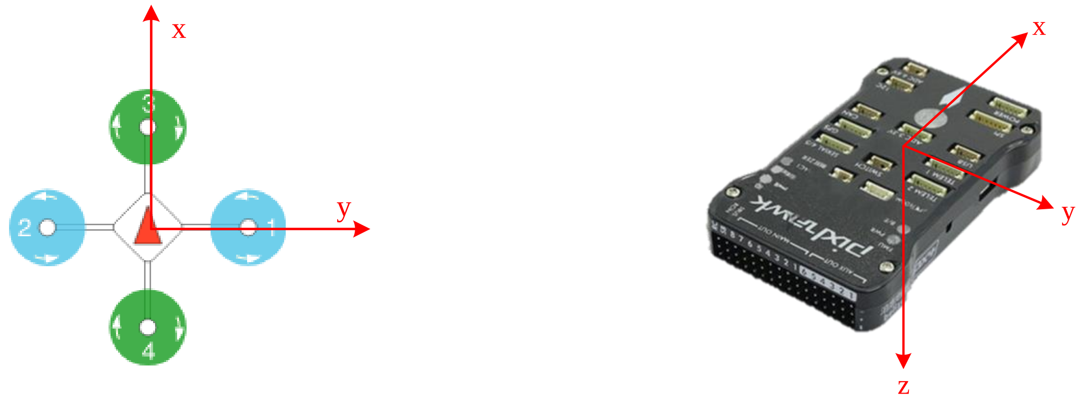

Fig. 1. Schematic representation of quadrotor

- **Translational dynamics**

$$\ddot{x} = -\frac{T}{m}(\sin\psi\sin\phi + \cos\psi\sin\theta\cos\phi)fx^{drag} + f_x^{\omega}$$
$$\ddot{y} = -\frac{T}{m}(-\cos\psi\sin\phi + \sin\psi\sin\theta\cos\phi) + f_y^{drag} + f_y^{\omega} \qquad \textbf{(1)}$$
$$\ddot{z} = g - (\cos\theta\cos\emptyset)\frac{T}{m} + f_z^{drag} + f_z^{\omega}$$

https://doi.org/10.55212/ijaa.1033224

- **Rotational dynamics**

$$\dot{p} = \frac{I_{yy} - I_{zz}}{I} qr + \frac{M_x}{I_{xx}} + \mathcal{T}_p^{drag} + \mathcal{T}_p^{gyro} + \mathcal{T}_p^{\text{wind}}$$
$$\dot{q} = \frac{I_{zz} - I_{xx}}{I_{yy}} pr + \frac{M_y}{I_{yy}} + \mathcal{T}_q^{drag} + \mathcal{T}_q^{gyro} + \mathcal{T}_q^{wind} \quad \textbf{(2)}$$
$$\dot{r} = \frac{I_{xx} - I_{yy}}{I_{zz}} pq + \frac{M_z}{I_{zz}} + \mathcal{T}_r^{drag} + \mathcal{T}_r^{gyro} + \mathcal{T}_r^{wind}$$

- **Euler equations**

$$\dot{\varphi} = p + q \sin\varphi \tan\theta + r \cos\varphi \tan\theta$$
$$\dot{\theta} = q \cos\varphi - r \sin\varphi \quad \textbf{(3)}$$
$$\dot{\psi} = \frac{1}{\cos\theta}[q \sin\varphi + r \cos\varphi]$$

where *x*, *y*, and *z* are the position of quadrotor center of mass in the inertial frame and ψ,θ,φ are the Euler angles, which represent the body frame rotation concerning the inertial frame. I_{xx}, I_{yy}, and I_{zz} are the moments of inertia in *x*, *y*, and *z-direction*, respectively, *m* is the system mass, *l* is the distance between the center of the mass and the motors, and *g* is the gravitational acceleration. The quadrotor inputs are represented by $\mathcal{T}$,M_x,M_y,cM_z, which are the total thrust force ($\mathcal{T}$) generated by propellers in *z*-direction and moments about *x*, *y*, *z* axes, respectively. The terms f_x^{drag}, f_y^{drag},f_z^{drag}, $\mathcal{T}_p^{drag}$,$\mathcal{T}_q^{drag}$, and $\mathcal{T}_r^{drag}$ are the drag forces and moments produced by the quadrotor's frame, which are expressed as $f_x^{drag} = -\frac{k_x}{m}\dot{x}$, $f_y^{drag} = -\frac{k_y}{m}\dot{y}$, $f_z^{drag} = -\frac{k_z}{m}\dot{z}$, $\mathcal{T}_p^{drag} = -\frac{k_\varphi}{I_{xx}}p^2$, $\mathcal{T}_q^{drag} = -\frac{k_\theta}{I_{yy}}q^2$,$\mathcal{T}_r^{drag} = -\frac{k_\psi}{I_{zz}}r^2$. The constant parameters k_x, k_y, k_z are translational drag coefficients, and $k_\varphi, k_\theta, k_\psi$ are rotational drag coefficients, which are considered with values according to Table 1. Moments produced by the gyroscopic effect of the rotors around *x* and *y* axes are presented by $\mathcal{T}_p^{gyro}$, $\mathcal{T}_q^{gyro}$, which are expressed as $\mathcal{T}_p^{gyro} = \frac{J_T}{I_{xx}}q\Omega$ and $\mathcal{T}_q^{gyro}, = -\frac{J_T}{I_{yy}}p\Omega$, in which J_T is the moment of inertia of each motor and Ω represents the propellers total speed as below:

$$\Omega = \Omega_1 - \Omega_2 + \Omega_3 - \Omega_4 \quad \textbf{(4)}$$

The terms f_x^w, f_y^w, f_z^w and $\mathcal{T}_p^{\text{wind}}$, $\mathcal{T}_q^{wind}$, $\mathcal{T}_r^{wind}$ are the forces and moments, which are produced by the effect of wind. The wind model can be composed of different elements of the wind including the mean wind, wind gust, and turbulence. For the purpose of simulation, this paper considers the Dryden turbulence model, which is a stochastic model of the wind and is inherently dependent on the quadrotor's states (attitude, altitude, and velocity). Accordingly, in Dryden model the scale length and the probability of exceedance of high-altitude intensity are considered as 533.4*m* and 0.01, respectively and the low-altitude intensity is defined as 15 m/s.

c) Rotor dynamics

The thrust generated by the motors is modeled as a first-order system to account for the motors dynamic for variation of rotational speed:

$$u_{i_c} = K\frac{\omega_0}{S + \omega_0}u_i \quad \textbf{(5)}$$

https://doi.org/10.55212/ijaa.1033224

where S is the Laplace variable, u_{i_c} is the i-th motor input which is the PWM reference signal to the motors, K is the motor gain, and ω_0 is the bandwidth of the motors. The motors' thrust force and torque depend on the rotational velocity, propeller diameter, as well as the aerodynamics characteristics of blades as below:

$$T_i = C_t \rho {\Omega_i}^2 D^4 = b{\Omega_i}^2$$
$$Q_i = C_d \rho {\Omega_i}^2 D^5 = kT_i = d{\Omega_i}^2, k = 2.07e - 2m \quad \textbf{(6)}$$

Where C_t, C_d are thrust and drag coefficients, ρ is the air density, Ω_i is the rotational speed of each motor in *rpm*, and D is the propeller diameter. The numerical values of b and d are introduced in Table 1. Accordingly, the actuation inputs in the body frame are expressed based on the rotational speeds as follows:

$$\boldsymbol{U} = \boldsymbol{K}_{\Omega 2U}\boldsymbol{\Omega} \quad \textbf{(7)}$$

where $\boldsymbol{U} = [T, M_x, M_y, M_z]^T$, $\boldsymbol{K}_{\Omega 2U} = \begin{bmatrix} b & b & b & b \\ -bl & bl & 0 & 0 \\ 0 & 0 & bl & -bl \\ d & d & -d & -d \end{bmatrix}$, and $\boldsymbol{\Omega} = [\Omega_1^2, \Omega_2^2, \Omega_3^2, \Omega_4^2]^T$.

The autopilot outputs (**U**) must be translated into each motor inputs to send the signal to the quadrotor speed controls, then apply the related PWM signal to each quadrotor's motor.

d) Motor mixer

The motor mixer determines the rotational speeds of each rotor corresponding to the intermediate autopilot outputs (**U**). accordingly, motor mixer expression can be reached by inversing Eq.(7) as below:

$$\boldsymbol{\Omega} = \boldsymbol{K}_{U2\Omega}\boldsymbol{U}, \boldsymbol{K}_{U2\Omega} = inv(\boldsymbol{K}_{\Omega 2U}) \quad \textbf{(8)}$$

e) Motor thrust and speed limitations

When converting the controller outputs to the motor inputs, the maximum constraint of the motors is applied to the motor mixer formulation. Based on the motor type, propeller size, battery specifications, the maximum speed of each motor (Ω_{max}) is found to be 6250 rpm. Accordingly, the maximum thrust of each motor is 7.89*N.*

$$\boldsymbol{T = 4b\Omega^2} \quad \Rightarrow \quad 0 \le T \le 31.56 \quad \textbf{(9)}$$

The maximum bounds of the control moments output before converting to the input of each motor is:

$$M_{x_{\max}} = bl(\Omega_{max}^2) \quad \Rightarrow \quad -1.917 \le M_x \le 1.917$$
$$M_{y_{\max}} = bl(\Omega_{max}^2) \quad \Rightarrow \quad -1.917 \le M_y \le 1.917 \quad \textbf{(10)}$$
$$M_{z_{\max}} = d(\Omega_{max}^2 + \Omega_{max}^2) \quad \Rightarrow \quad -0.33 \le M_z \le 0.33$$

f) Motor fault modeling

Degradation of motor performance or damage to the rotor can be considered as the partial fault on the actuator regarding the normal operative condition of the motor. Partial fault on the i-th actuator can lead to loss of thrust, which generates unwanted roll, pitch, and yawing moments. Accordingly, the effect of partial fault on the thrust force and moment of the faulty motor is considered as parametric uncertainty as follow:

$$T_{i_f} = T_i + \Delta T_i = b{\Omega_i}^2 + \Delta b{\Omega_i}^2, \Delta b = -f_i b$$
$$Q_{i_f} = Q_i + \Delta Q_i = d{\Omega_i}^2 + \Delta d{\Omega_i}^2, \Delta d = -f_i d \quad \textbf{(11)}$$

where $\Delta b, \Delta d$ are bounded variation of motor effectiveness respecting its nominal values and can be represented as c$-b \le \Delta b \le 0, -d \le \Delta d \le 0$ and f_i is the i-th motor fault. Therefore, the actual signal ($\boldsymbol{u}$) generated by the faulty actuator ($\boldsymbol{u}_f$) is as follows:

https://doi.org/10.55212/ijaa.1033224

$$\boldsymbol{u}_f(t) = (1-\boldsymbol{\Gamma})\boldsymbol{u}(t), \boldsymbol{u}(t)^T = [T_1, T_2, T_3, T_4]$$
$$\boldsymbol{\Gamma} = \begin{cases} 0 & t < t_f \\ diag(f_1, f_2, f_3, f_4) & t > t_f \end{cases} \quad (12)$$

In the above equation, t_f is the time that fault occurs and $0 \leq f_i < 1$, in which $f_i = 0, f_i = 1$ represent the healthy and the fully failed actuator, respectively. Based on the maximum rotational speed of the motors (6250 rpm), each motor can generate the required thrust to keep the quadrotor to hover for about 50% partial fault. Therefore, the maximum partial fault is considered to be 50%.

3. Subsystem Level Operational Architecture

In this section, by applying the multiple-timescales approach, the rotational and translational dynamics are separated by assuming that the rotational dynamics are much faster than the translational dynamics. The block diagram of the controller system is shown in Fig. 2.

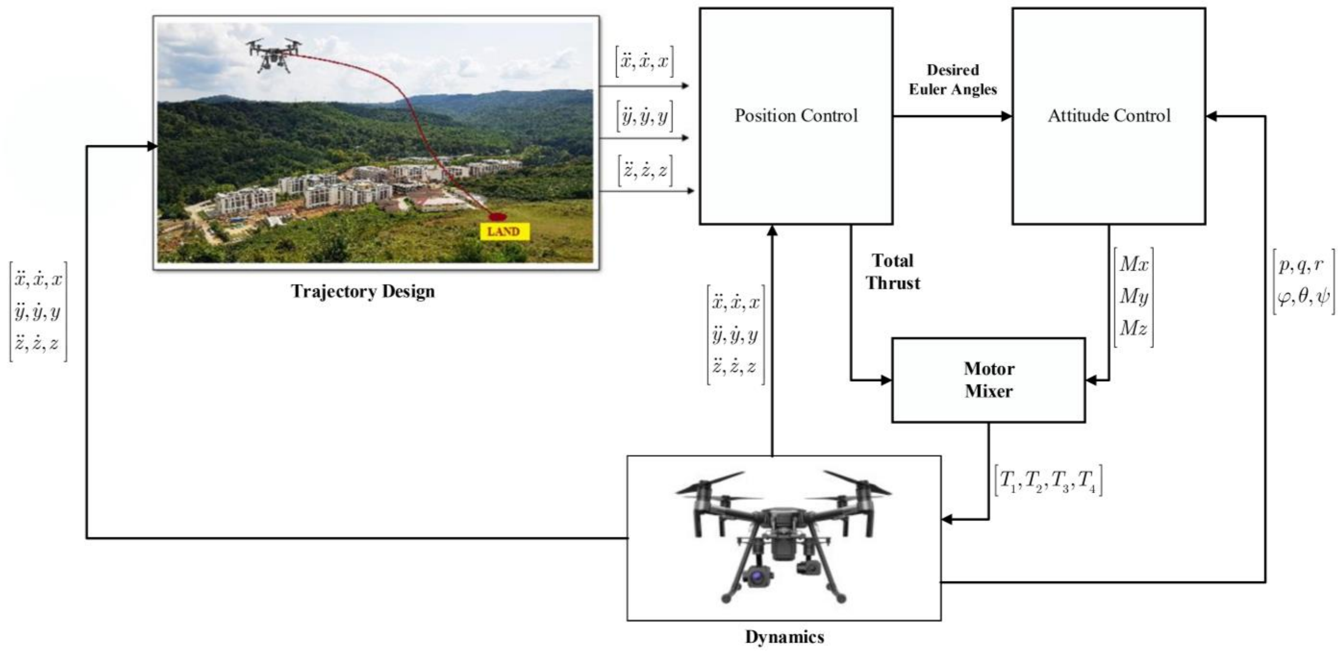

Fig. 2. Total controller architecture

It is clear that classical controller algorithms do not have appropriate performance in presence of motor failure. To deal with fail conditions a cascade control algorithm is applied to the quadrotor. The attitude control loop is a robust adaptive controller based on INDI and the position control loop is the PID algorithm.
Based on the rotational dynamics according to Eq. (2), the nonlinear model of quadrotor can be transformed into an affine control model as below:

$$\dot{\boldsymbol{x}} = \boldsymbol{f}(\boldsymbol{x}) + \boldsymbol{g}(\boldsymbol{x})\boldsymbol{U}_c \quad (13)$$

where $\boldsymbol{x} \in \Re^3$ is the vector of rotational velocities ($\boldsymbol{x} = [p, q, r]$);$\boldsymbol{U}_c \in \Re^3$ is the controller output moments vector ($\boldsymbol{U}_c = [M_x, M_y, M_z]$);$\boldsymbol{f}(\boldsymbol{x}) \in \Re^3$ and $\boldsymbol{g}(\boldsymbol{x}) \in \Re^{3\times3}$ are differentiable matrices of state and input functions, respectively.

a) INDI controller design

Considering the rotational dynamics of the quadrotor based on Eq.(13), the Taylor series approach is applied to expand Eq. (2) while neglecting higher-order terms. Accordingly, Eq. (14) is obtained as below:

https://doi.org/10.55212/ijaa.1033224

$$\begin{aligned}\dot{\boldsymbol{x}}(t) &= \boldsymbol{f}(\boldsymbol{x}(t-Ts)) + \boldsymbol{g}(\boldsymbol{x}(t-Ts))\boldsymbol{U}_c(t-Ts) \\ &+ \frac{\partial}{\partial \boldsymbol{x}}\boldsymbol{f}(\boldsymbol{x})\Big|_{\substack{\boldsymbol{x}=\boldsymbol{x}(t-Ts)\\ \boldsymbol{U}_c=\boldsymbol{U}_c(t-Ts)}} \big(\boldsymbol{x}(t)-\boldsymbol{x}(t-Ts)\big) + \frac{\partial}{\partial \boldsymbol{x}}(g(\boldsymbol{x})\boldsymbol{U}_c)\Big|_{\substack{\boldsymbol{x}=\boldsymbol{x}(t-Ts)\\ \boldsymbol{U}_c=\boldsymbol{U}_c(t-Ts)}} \big(\boldsymbol{x}-\boldsymbol{x}(t-Ts)\big) \\ &+ \frac{\partial}{\partial \boldsymbol{U}_c}\boldsymbol{f}(\boldsymbol{x})\Big|_{\substack{\boldsymbol{x}=\boldsymbol{x}(t-Ts)\\ \boldsymbol{U}_c=\boldsymbol{U}_c(t-Ts)}} (\boldsymbol{U}_c(t)-\boldsymbol{U}_c(t-Ts)) + \boldsymbol{g}(\boldsymbol{x}(t-Ts))(\boldsymbol{U}_c(t)-\boldsymbol{U}_c(t-Ts))\end{aligned} \quad \textbf{(14)}$$

where T_s is the sampling time. The first part of Eq.(14), $\boldsymbol{f}(\boldsymbol{x}(t-Ts)) + \boldsymbol{g}(\boldsymbol{x}(t-Ts))\boldsymbol{U}_c(t-Ts)$ is equal to $\dot{\boldsymbol{x}}(t-Ts)$. This part includes some terms, which can be calculated based on the onboard sensors at any instance of the flight time. The term $\dot{\boldsymbol{x}}(t-Ts)$ can be computed by taking derivative from rate gyros' outputs, which are the rotational speeds. In other words, the dynamic related terms $\boldsymbol{f}(\boldsymbol{x}(t-Ts)) + \boldsymbol{g}(\boldsymbol{x}(t-Ts))\boldsymbol{U}_c(t-Ts)$ are replaced by the derivative of the sensor outputs. That's why this approach. i.e. INDI, is referred to as a sensor-based control strategy.

The other part of Eq. (14)$\left[\frac{\partial}{\partial x}\boldsymbol{f}(\boldsymbol{x})\Big|_{\substack{\boldsymbol{x}=\boldsymbol{x}(t-Ts)\\ \boldsymbol{U}_c=\boldsymbol{U}_c(t-Ts)}} (\boldsymbol{x}(t)-\boldsymbol{x}(t-Ts)) + \frac{\partial}{\partial x}(g(\boldsymbol{x})\boldsymbol{U}_c)\Big|_{\substack{\boldsymbol{x}=\boldsymbol{x}(t-Ts)\\ \boldsymbol{U}_c=\boldsymbol{U}_c(t-Ts)}} (\boldsymbol{x}-\boldsymbol{x}(t-Ts)) + \frac{\partial}{\partial \boldsymbol{U}_c}\boldsymbol{f}(\boldsymbol{x})\Big|_{\substack{\boldsymbol{x}=\boldsymbol{x}(t-Ts)\\ \boldsymbol{U}_c=\boldsymbol{U}_c(t-Ts)}} (\boldsymbol{U}_c(t)-\boldsymbol{U}_c(t-Ts))\right]$ can be neglected if the sampling time T_s is small. Thus, Eq.(14) can be rewritten as Eq.(15).

$$\dot{\boldsymbol{x}}(t) = \dot{\boldsymbol{x}}(t-Ts) + \boldsymbol{g}(\boldsymbol{x}(t-Ts))(\boldsymbol{U}_c(t)-\boldsymbol{U}_c(t-Ts)) \quad \textbf{(15)}$$

According to Eq.(15), the parameters in Eq.(2) can be rewritten as below:

$$\begin{aligned}\dot{p}(t) &= \dot{p}(t-Ts) + \frac{1}{I_{xx}}M_x(t) - M_x(t-Ts) \\ \dot{q}(t) &= \dot{q}(t-Ts) + \frac{1}{I_{yy}}M_y(t) - M_y(t-Ts) \\ \dot{r}(t) &= \dot{r}(t-Ts) + \frac{1}{I_{zz}}M_z(t) - M_z(t-Ts)\end{aligned} \quad \textbf{(16)}$$

As explained before, the angular acceleration terms are derived by taking derivatives from the angular rates. Since the sensor measurements from the gyroscope are naturally noisy due to disturbances induced by the vibrations of the motor or propeller on the vehicle's frame. Since differentiating the noisy signal amplifies the effect of noise on the output, the application of an appropriate filter is required. Accordingly, a second-order filter is adopted to be applied before differentiating the outputs of rate gyros. The implemented filter in the form of a transfer function in the Laplace domain is given in Eq.(17). Satisfactory results are obtained from the filter with $\omega_n = 50 rad/s$and $\zeta = 0.55$. For the same application, other low-pass filters like the Butterworth filter can also be implemented [28].

$$C(s) = \frac{2500}{s^2 + 55s + 2500} \quad \textbf{(17)}$$

In the next step, the controller command should be computed corresponding to the INDI approach. Hence, by inversing Eq.(15) the control signal is obtained as below:

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$$\boldsymbol{U}_c(t) = g^{-1}(\boldsymbol{x}(t - Ts))(-\dot{\boldsymbol{x}}_f + v) + \boldsymbol{U}_c(t - Ts) \quad \textbf{(18)}$$

where:

$$\dot{\boldsymbol{x}}_f = L^{-1}(\dot{\boldsymbol{x}}(t - Ts)C(s)) \quad \textbf{(19)}$$

Where L^{-1} is the Laplace inverse operator, $\dot{\boldsymbol{x}}_f$ is the filtered derivatives of the angular rates, and v is the pseudo-control input, which is determined by the robust adaptive controller in the next section. The INDI controller architecture is illustrated in Fig. 3.

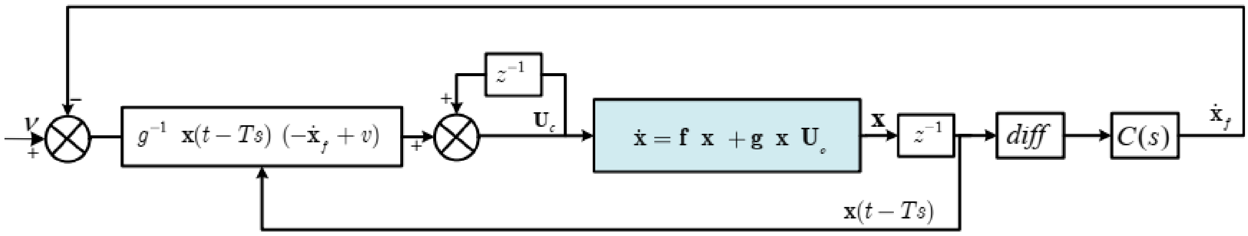

Fig. 3 INDI controller architecture

b) Motor fault modeling

To enhance the INDI robustness, especially in presence of motor fault effect, a robust adaptive control algorithm is augmented to the INDI algorithm to generate the pseudo-control input (v). Integration of the INDI algorithm as the baseline controller and the model reference robust-adaptive controller as the outer-loop controller can improve the performance of the total controller. In the following, the design procedure and application of the robust adaptive algorithm, as an augmentation algorithm to the INDI controller is described.
In our proposed robust MRAC strategy, the dynamics of the reference model is considered as follows:

$$\dot{\boldsymbol{x}}_m = \boldsymbol{A}_m\boldsymbol{x}_m + \boldsymbol{B}_m\boldsymbol{R} \quad \textbf{(20)}$$

where $A_m \in R^{n\times n}$ is known desired Hurwitz closed-loop system dynamics and $B_m \in R^{n\times m}$ is an identity matrix (I) in our case. Applying simple feedback, the poles of the closed-loop system are set to the eigenvalues of the matrix A_m. Therefore, the differential equations of the plant's dynamics can be propagated as follows:

$$\begin{gathered}\dot{\boldsymbol{x}} = \boldsymbol{A}_m\boldsymbol{x}_m + \boldsymbol{B}_m(\omega\boldsymbol{u_{ad}} + \theta\|\boldsymbol{x}\|_\infty + \sigma) + \Delta_1(\boldsymbol{x},\boldsymbol{u}), \boldsymbol{x}(0) = \boldsymbol{x}_0 \\ \boldsymbol{y}(t) = \boldsymbol{c}^T\boldsymbol{x}(t)\end{gathered} \quad \textbf{(21)}$$

where c$\|.\|_\infty$ is the infinity norm; c$x(t) \in R^n$is the measured system state; $c \in R^{n\times n}$is a known constant vector; $\boldsymbol{u_{ad}}(t) \in R^m$is the control input; ω, **θ, σ** are unknown constant parameters with known signs and lower and upper bounds; $\boldsymbol{\Delta_1}(\boldsymbol{x},\boldsymbol{u})$:$R \times R^n \to R^n$ is a continuous bounded unknown nonlinear argument due to INDI error and the effect of rotor fault.
The above system architecture is replicated by the use of state predictor which is given by Eq.(22):

$$\begin{gathered}\dot{\hat{\boldsymbol{x}}} = \boldsymbol{A}_m\hat{\boldsymbol{x}}_m + \boldsymbol{B}_m(\hat{\omega}\boldsymbol{u_{ad}} + \hat{\theta}\|\boldsymbol{x}\|_\infty + \hat{\sigma}), \boldsymbol{x}(0) = \boldsymbol{x}_0 \\ \hat{\boldsymbol{y}}(t) = \boldsymbol{c}^T\hat{\boldsymbol{x}}(t)\end{gathered} \quad \textbf{(22)}$$

where $\hat{\omega}(t) \in R$ is the estimate of $\omega \in [\omega_L, \omega_u]$, $\hat{\theta}(t)\hat{I}R^n$, and $\hat{\sigma} \in R^n$ are adaptive estimates of the dynamic model parameters $\boldsymbol{\theta}(t)$ and $\boldsymbol{\sigma}(t)$, which are continuously differentiable and bounded as; c$\|\dot{\boldsymbol{\theta}}\| \le \delta_1, \|\dot{\omega}\| \le \delta_2, \|\dot{\boldsymbol{\sigma}}\| \le \delta_3$.
Adaptive law: The adaption laws governing the adaptive estimates are as follows [7]:

$$\begin{aligned}\dot{\hat{\theta}}(t) &= \Gamma Proj\dot{\theta}(t), -\tilde{x}^T(t)Pb\|x(t)\|_\infty, & \hat{\theta}(0) &= \hat{\theta}_0,\\ \dot{\hat{\sigma}}(t) &= \Gamma Proj\dot{\sigma}(t), -\tilde{x}^T(t)Pb, & \hat{\sigma}(0) &= \hat{\sigma}_0,\\ \dot{\hat{\omega}}(t) &= \Gamma Proj\dot{\omega}(t), -\tilde{x}^T(t)Pb, & \hat{\omega}(0) &= \hat{\omega}_0,\end{aligned} \quad \textbf{(23)}$$

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In Eq.(23), the term Γ is the adaptation gain and $\hat{\theta}_0$, $\hat{\omega}_0$, c$\hat{\sigma}_0$ are the initial values of pertinent variables, which are guessed for initialization of the algorithm. Large values of G, increases the rate of adaptation for desirable performance without reducing the robustness properties. $P = P^T > 0$ and $Q = Q^T > 0$ are used in the Lyapunov function$A_m^T P + PA_m = -Q$, and $\tilde{x}(t) = \hat{x}(t) - x(t)$ is the error function.
The projection operator, which is denoted by Proj.,. guarantees estimated parameters boundedness according to Ref [7]. The projection operator is defined as below:

$$Proj(\varphi, z) = \begin{cases} z & if \quad h(\varphi) < 0, \\ z & if \quad h(\varphi) \geq 0 \ and \ \nabla h^T z \leq 0, \\ z - \frac{\nabla h}{\|\nabla h\|}\left(\frac{\nabla h}{\|\nabla h\|}.z\right)h(\varphi) & if \quad h(\varphi) \geq 0 and \nabla h^T z > 0. \end{cases} \quad \textbf{(24)}$$

where "." and ∇ represent the inner product and gradient, respectively and h is a convex function defined as $h(\varphi) = \frac{(\varepsilon_\varphi + 1)\varphi^T\varphi - \varphi_{max}^2}{\varepsilon_\varphi \varphi_{max}^2}$, and $\varepsilon_\varphi > 0$ is the projection tolerance bound, and φ_{max} is the norm bound forced on the vector φ, which is defined in a bounded convex as $\Omega_c = \{\varphi \in R^n | h(\varphi) \leq c\}, 0 \leq c \leq 1$.
Control algorithm: The robust model reference adaptive control algorithm signal is obtained as below:

$$u_{ad} = \frac{1}{\hat{\omega}}(-\hat{\theta}\|x\|_\infty + \hat{\sigma} + k_g R) \quad \textbf{(25)}$$

In the above control algorithm equation, k_g is selected to ensure a unity DC gain of the desired system corresponding to Eq.(20). The complete block diagram of the proposed controller including the INDI algorithm, the state estimator, adaptation law, and the adaptive control algorithm is illustrated in Fig. 4.

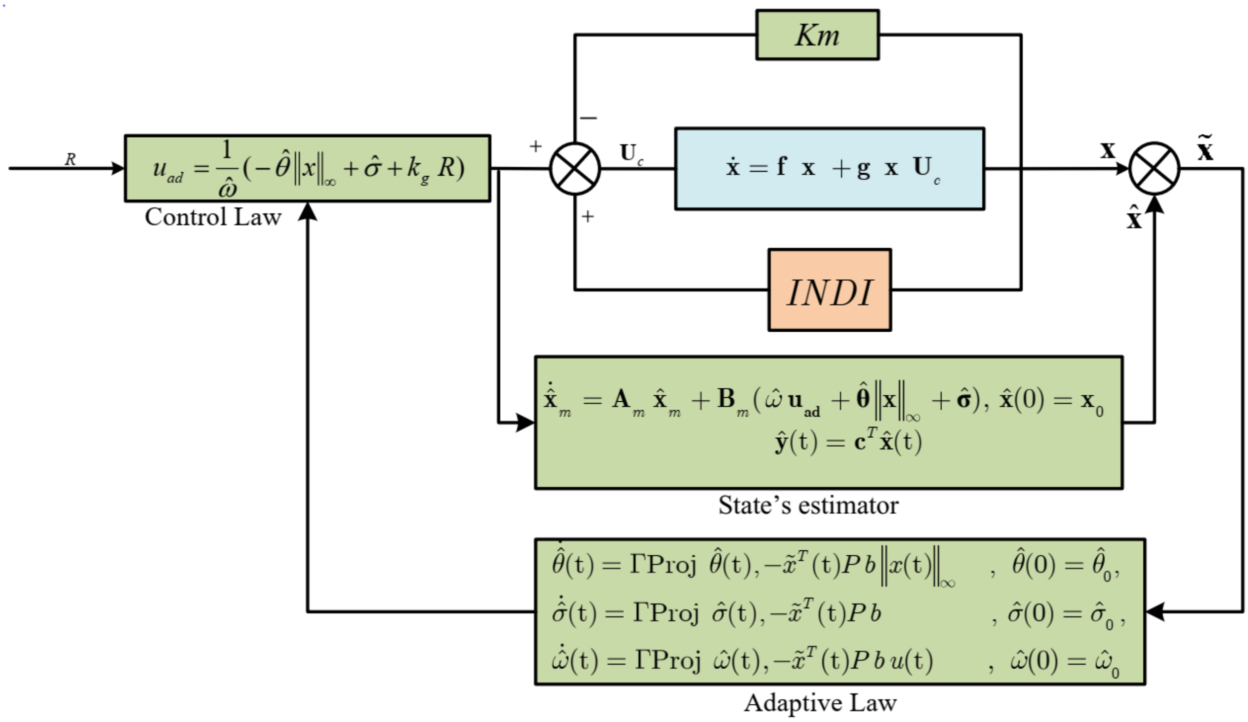

Fig. 4. Model reference robust adaptive controller with INDI Algorithm

c) Outer loop controller design

For the outer-loop position control, a PID control algorithm is applied. Based on the desired trajectory and their first and second derivatives, the dynamics of the position error can be derived as:

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$$\ddot{\boldsymbol{P}}_e + K_d\dot{\boldsymbol{P}}_e + K_p\boldsymbol{P}_e + K_I\int \boldsymbol{P}_e\, dt = 0$$
$$\boldsymbol{P}_d = [x_d, y_d, z_d], \boldsymbol{P}_e = \boldsymbol{P}_d - \boldsymbol{P} \quad \textbf{(26)}$$

where $\boldsymbol{P}_d$ is the desired position with bounded first and second derivatives,$\boldsymbol{P}_e$ is the positions error, and the PID gains (K_p,K_d, K_i) are derived corresponding to the conditions of Routh-Hurwitz to exponentially converge the error to zero. According to the error dynamics, the following equation can be computed:

$$\ddot{\boldsymbol{P}} = \ddot{\boldsymbol{P}}_d + K_d\dot{\boldsymbol{P}}_e + K_p\boldsymbol{P}_e + K_I\int \boldsymbol{P}_e\, dt = 0 \quad \textbf{(27)}$$

Based on the desired positions and translational dynamics of Eq. (1), the desired Euler angles are derived as the command pitch and roll angles as follows:

$$\begin{cases} \theta c = \arcsin\left(\dfrac{m\ddot{x}}{\cos\psi_d}T\right) \\ \varphi_c = -\arcsin\left(\dfrac{m\ddot{y}}{\cos\psi_d T}\right) \end{cases} \quad \textbf{(28)}$$

Where in the above equation $T = m\sqrt{\ddot{x} + \ddot{y} + (\ddot{z} + g)}$ and the desired heading angle (ψ_d) is imposed by the trajectory generation unit corresponding to the desired trajectory. The conventional PID control algorithm has two disadvantages; 1) sudden jump of the output of the derivative part of PID, which can saturate the actuator if the desired input is like a step function and 2) the problem of integral wind up when the integral value is high and the error switches its sign. To remove these problems, as shown in Fig. 5., the system output is used in the derivative part without accounting for the desired input, and an anti-windup filter [29] is applied in an integral part of the PID algorithm.

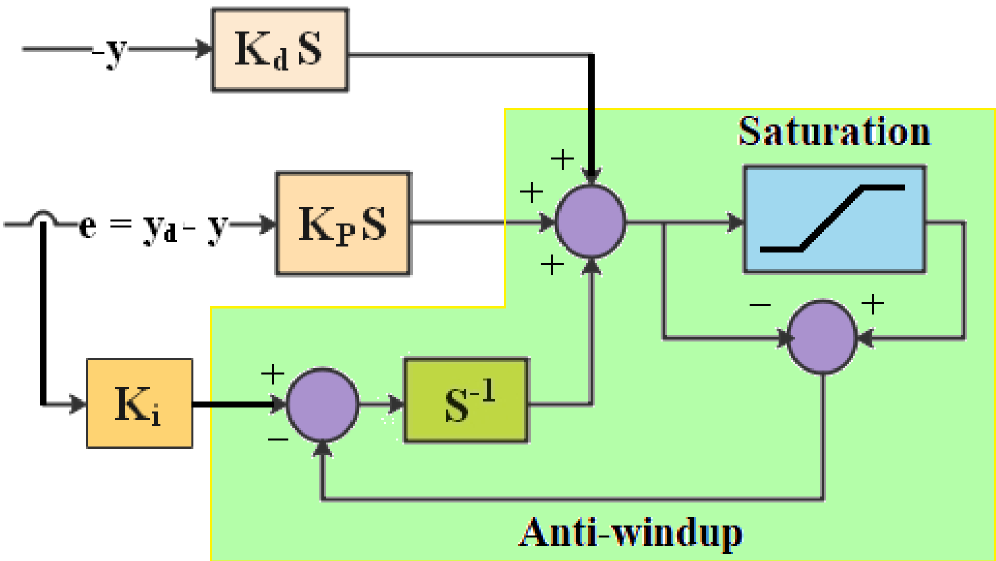

Fig. 5. Anti wind up PID controller architecture

4. Simulation Results

Several numerical simulations are considered in the presence of partial loss of motor effectiveness to verify the performance of the proposed three-loop robust adaptive fault-tolerant controller. In the first simulation scenario, the performance of the introduced controller is investigated for the case of the healthy (no-fault) quadrotor. Accordingly, Figs. 6-10 represent the parameters of the quadrotor, when tracking a helical trajectory. Figs. 6, 7

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represent the quadrotor's attitude rates and Euler angles, respectively. The rotational speeds of the rotors along with the corresponding control moments are depicted in Figs. 8, 9, respectively. Accordingly, the required rotation speed of the rotors to track the desired path are around 4400 RPM. Finally, the quadrotor position in 3D space and the trajectory tracking performance of the proposed controller has been illustrated in Fig. 10. As shown, the controller has a satisfactory tracking performance. Several fault scenarios are considered to investigate the performance and robustness of the controller algorithm. For this purpose, the performance of the controller is examined for different percentages of fault on the motor number one (number1) as illustrated in Figs. 11-25.

Figures 11-15 illustrate the quadrotor's parameters corresponding to 20% of rotor fault. Body rotational speed, Euler angles, motors' rotational speeds, moments generated by the motors, and the quadrotor position are all illustrated in all fault scenarios. All figures contain the curves of the desired values and the INDI outputs. Similar simulations are run for the case of 40% of fault on the number one rotor according to Fig. 16-Fig. 20. As previously discussed, the controller can maintain full controllability (roll, pitch, and yaw) of the quadrotor to maximum of 50% of rotor fault. Figs. 21-25 illustrate the controller performance in presence of 50% of the motor fault. As illustrated in Fig 23, the rotational speed of rotor number one approaches the saturation magnitude in presence of 50% of partial fault. The maximum rotation speed of the rotors is 6250 RPM, that's why for faults bigger than 50% the rotational speed of the faulty motor saturates and the controller performance degrades drastically.

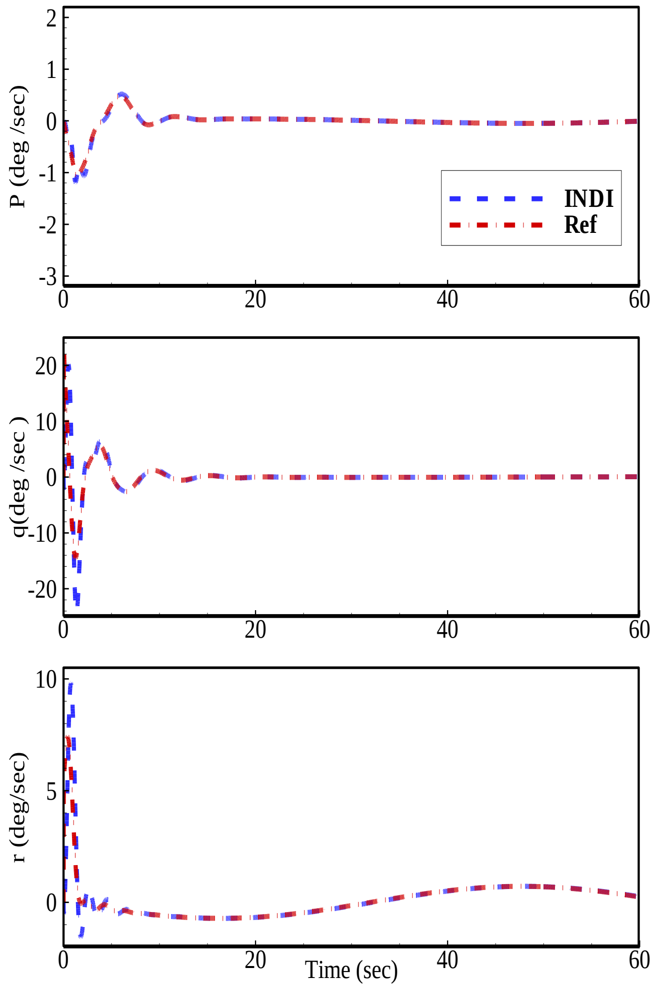

Fig. 6. Quadrotor body angular rates (deg/s)

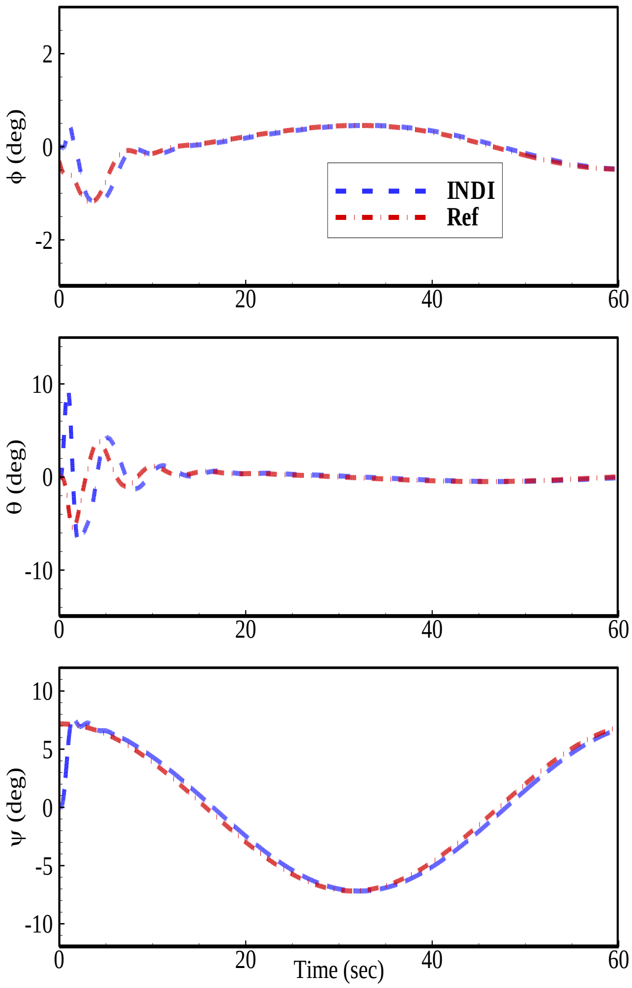

Fig. 7. Quadrotor Euler Angles (deg)

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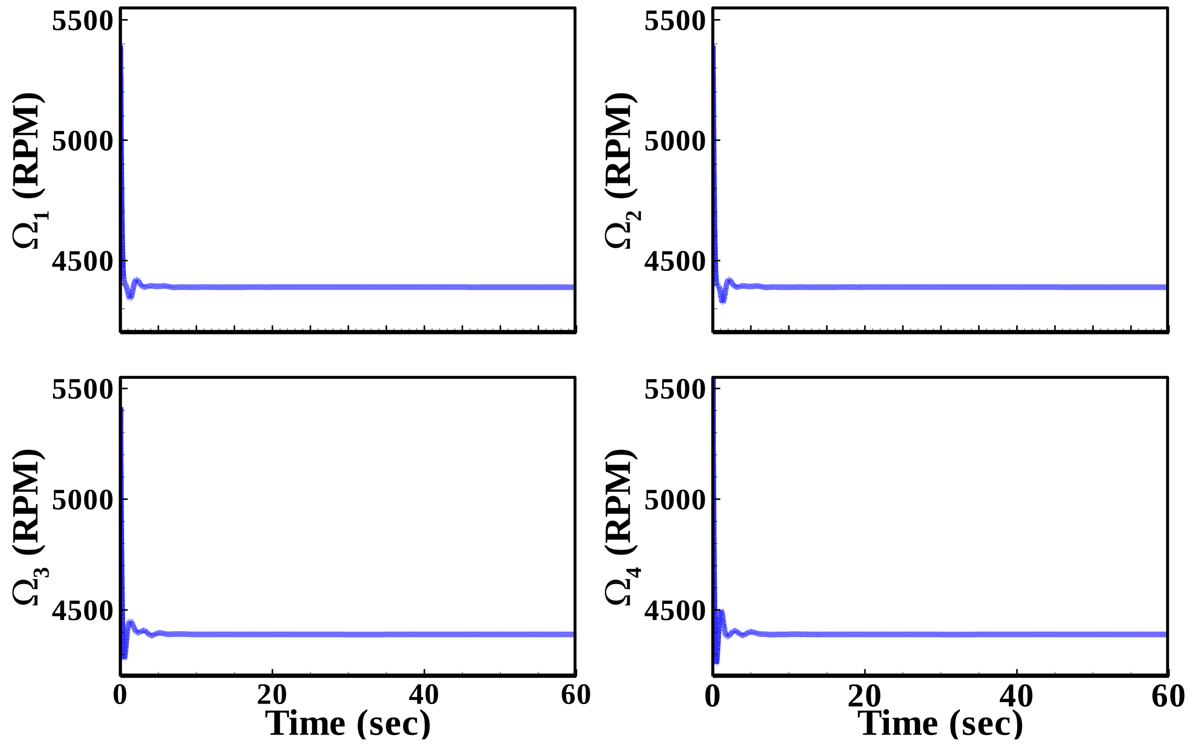

Fig. 8. Quadrotor rotational speeds of motors (RPM)

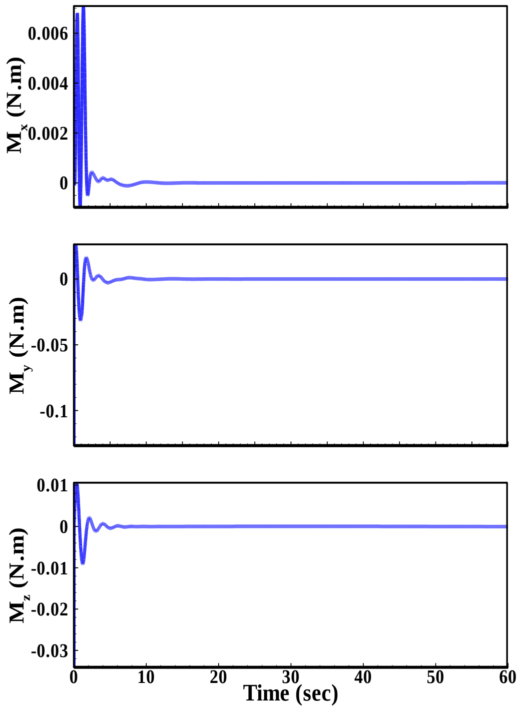

Fig. 9. Quadrotor Controller moments

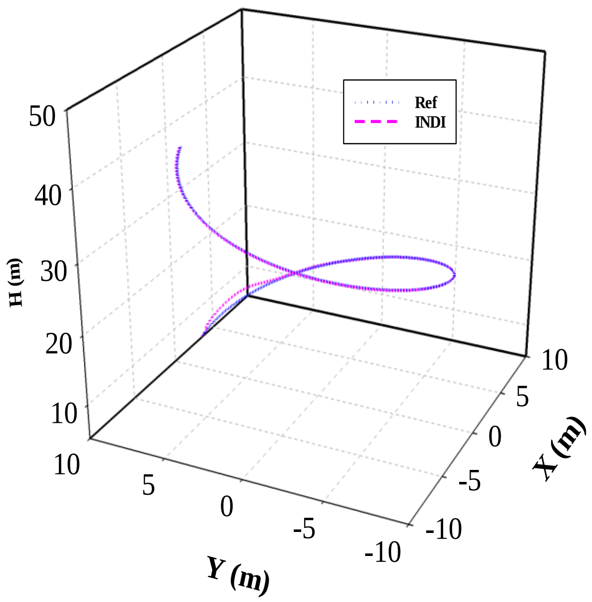

Fig. 10. Quadrotor position in 3D space

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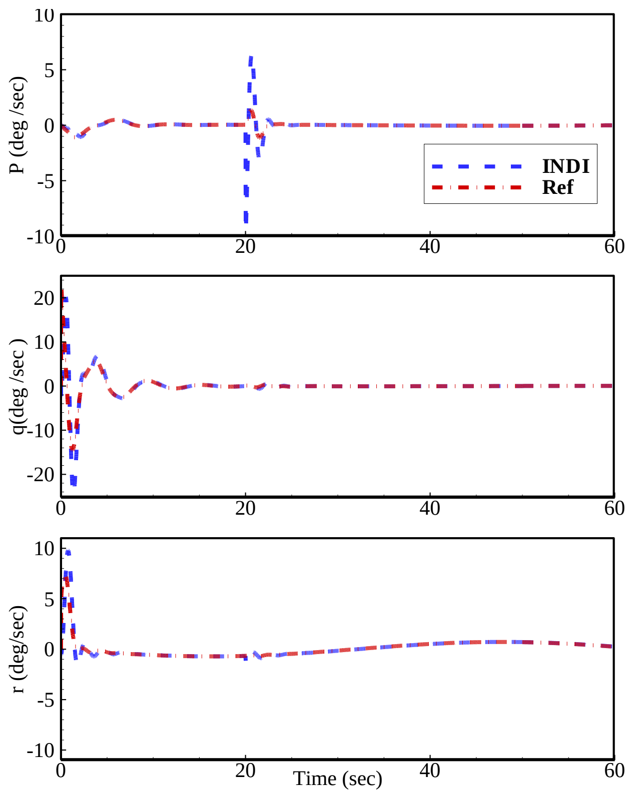

Fig. 11. Angular rates with 20% fault on motor1

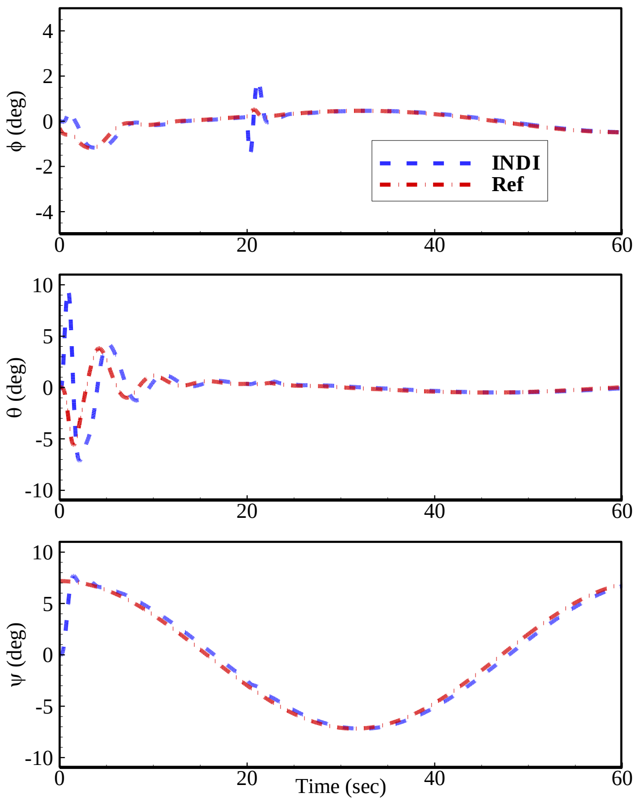

Fig. 12. Euler Angles with 20% fault on motor1

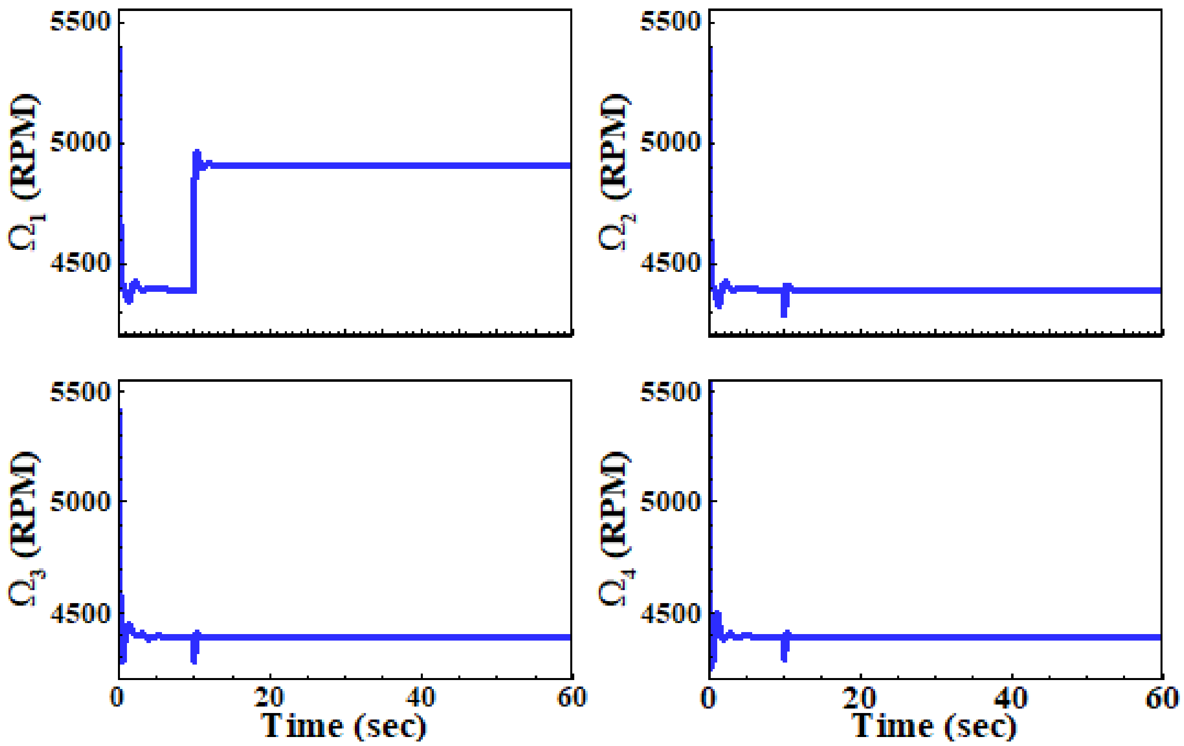

Fig. 13. Motors speeds with 20% fault on motor1

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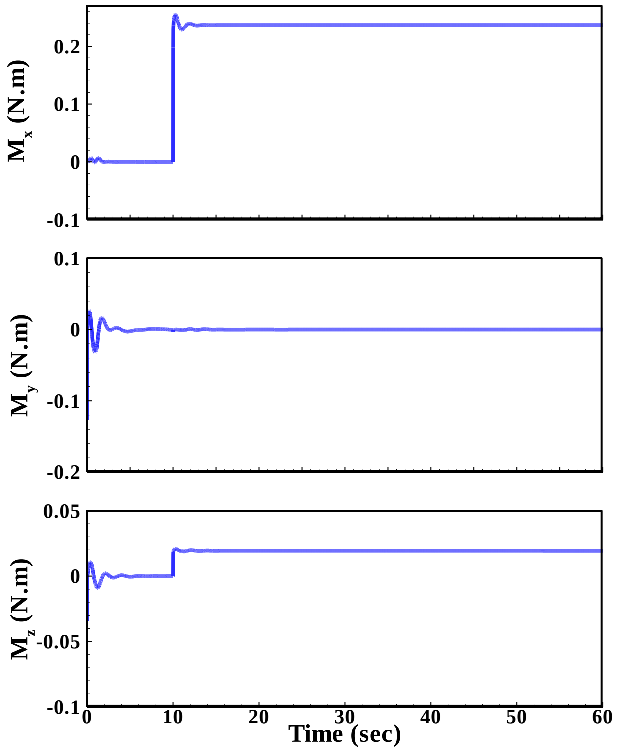

Fig. 14. Controller moments with 20% fault on motor1

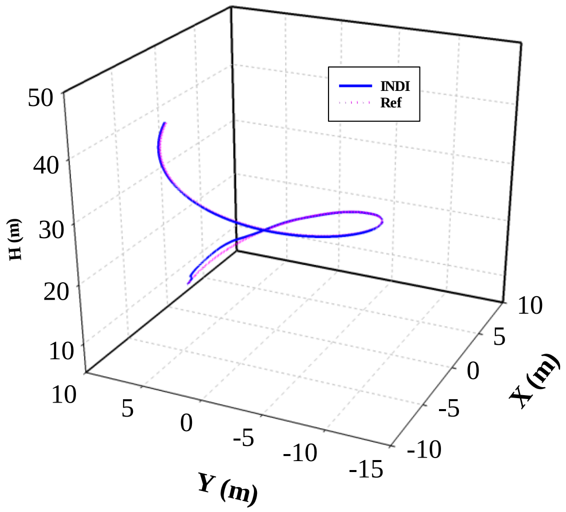

Fig. 15. Trajectory tracking with 20% fault on motor1

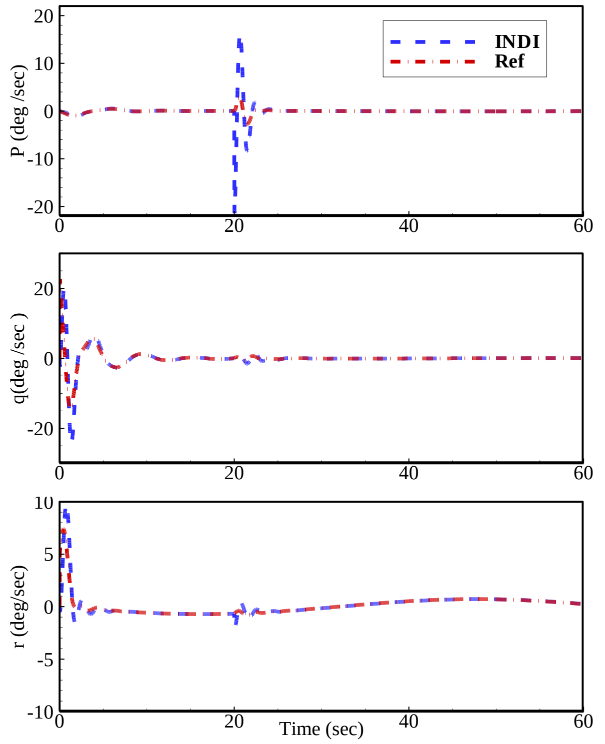

Fig. 16. Angular rates with 40% fault on motor1

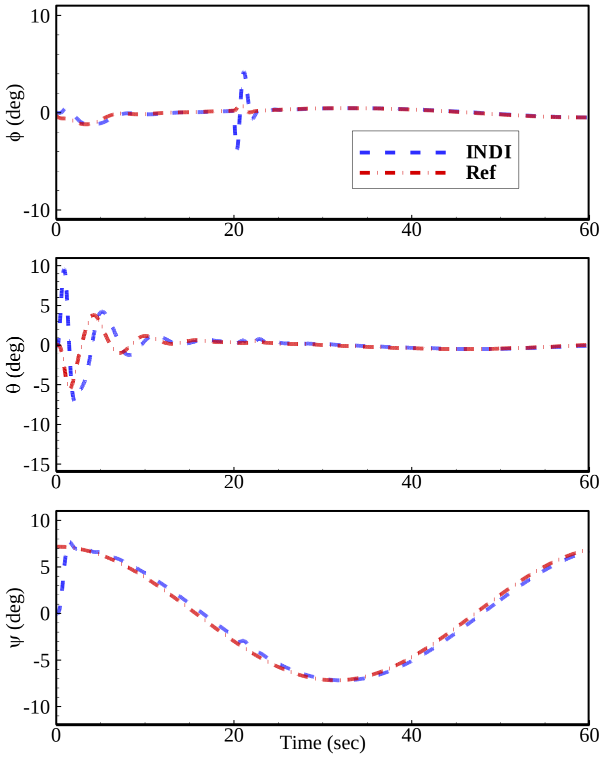

Fig. 17. Euler Angles with 40% fault on motor1

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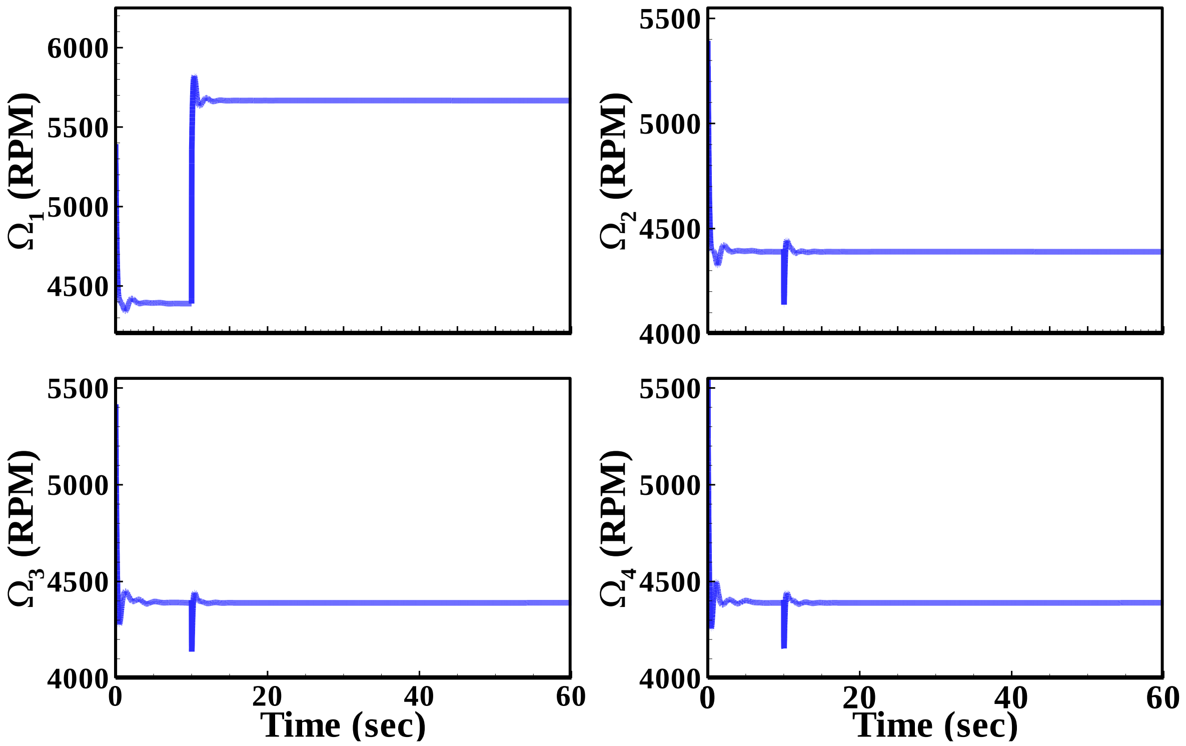

Fig. 18. Motors speeds with 40% fault on motor1

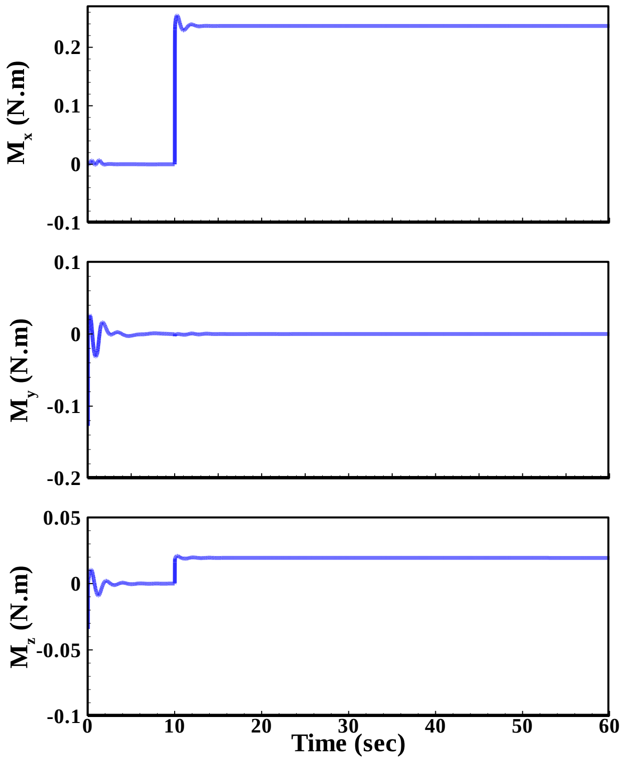

Fig. 19. Controller moments with 40% fault on motor1

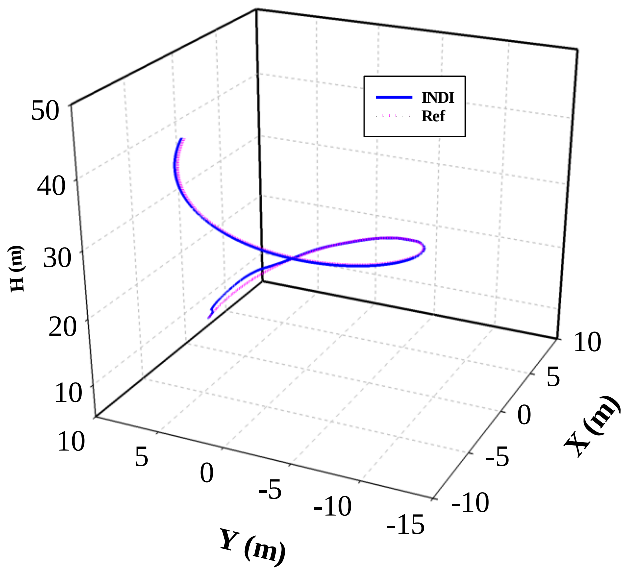

Fig. 20. Trajectory tracking with 40% fault on motor1

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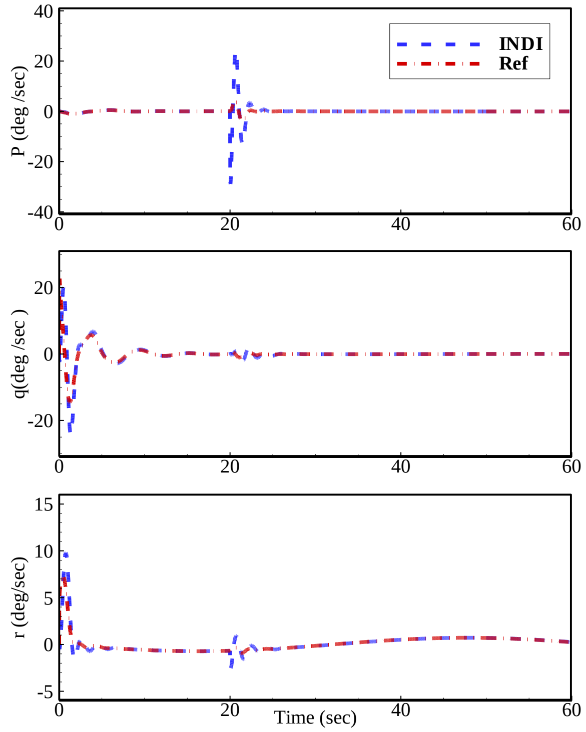

Fig. 21. Angular rates with 50% fault on motor1

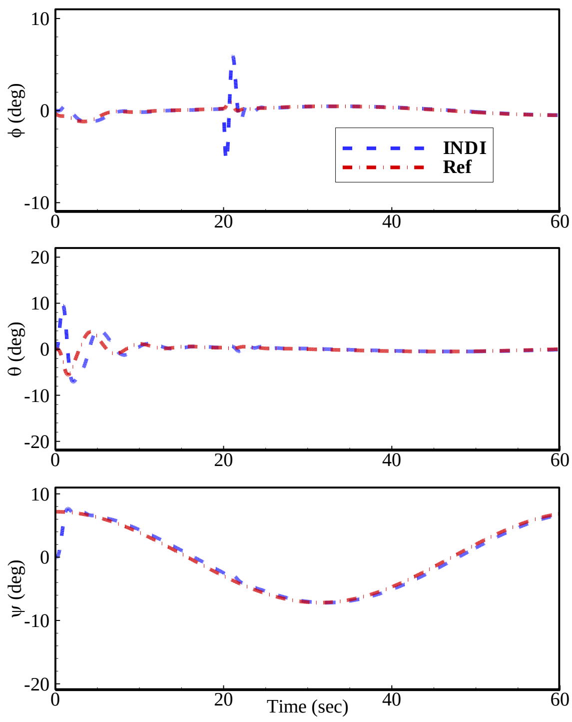

Fig. 22. Euler Angles with 50% fault on motor1

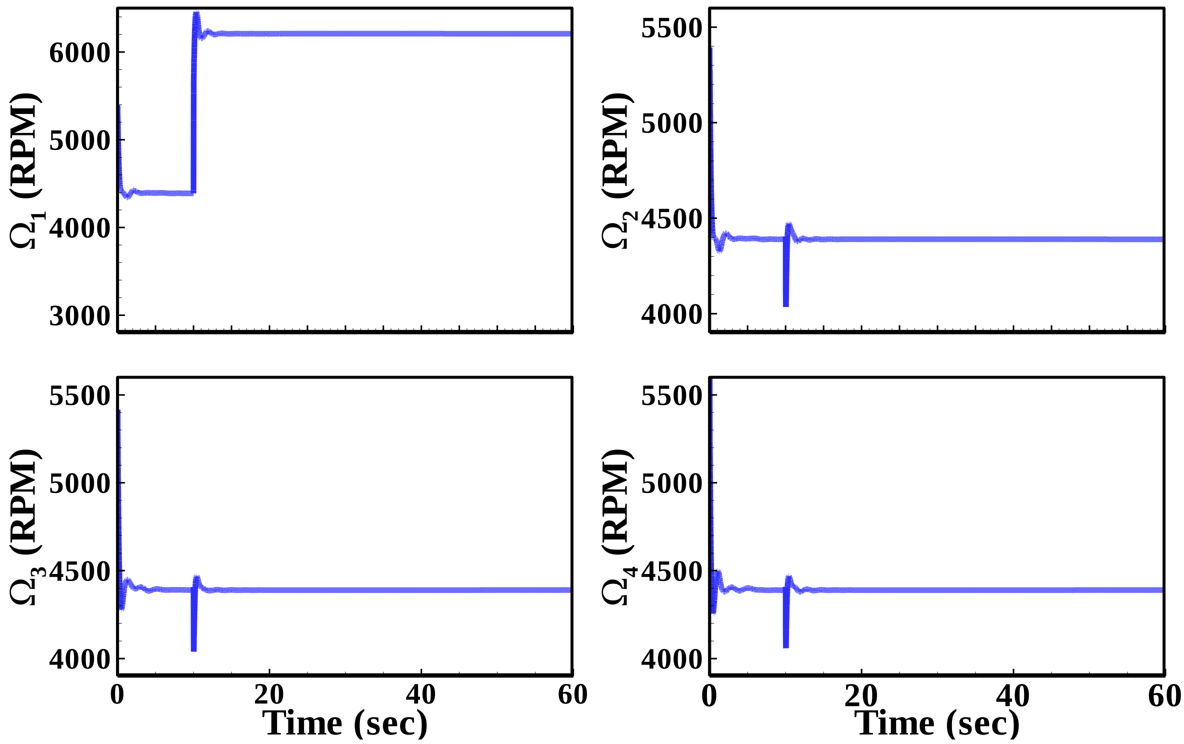

Fig. 23. Motors speeds with 50% fault on motor1

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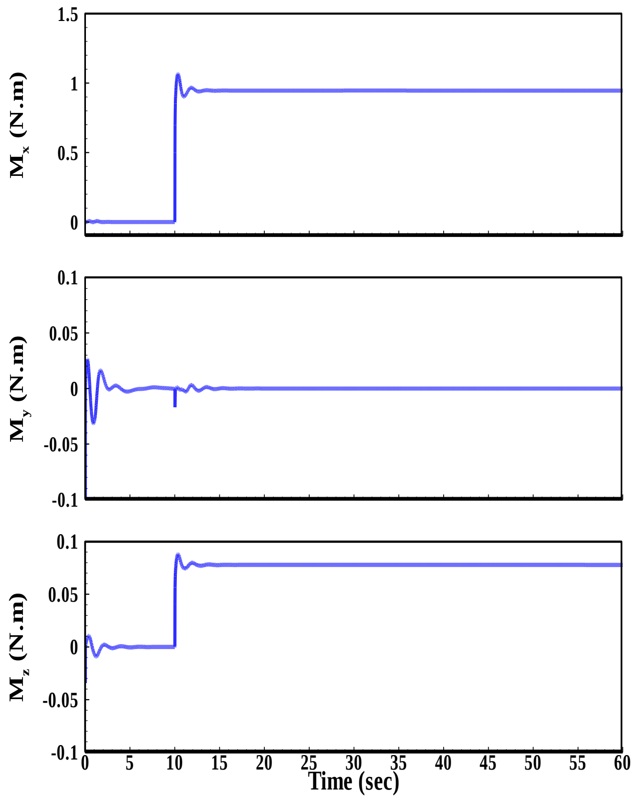

Fig. 24. Controller moments with 50% fault on motor1

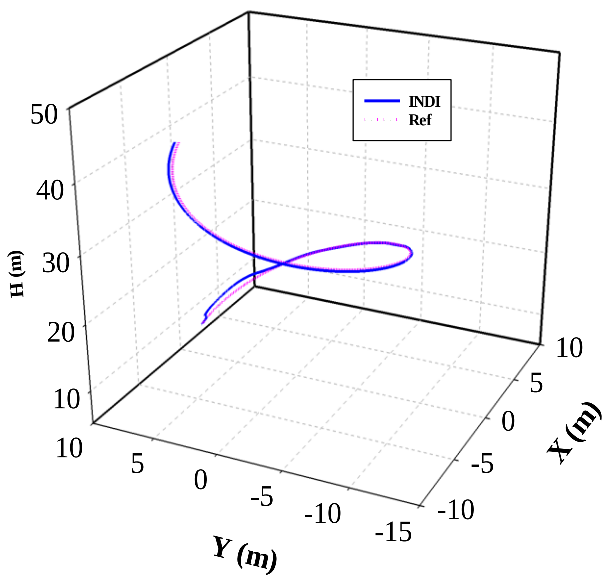

Fig. 25. Trajectory tracking with 50% fault on motor1

5. Conclusion

This paper presents a novel augmentation of Incremental Nonlinear Dynamic Inversion (INDI) as a baseline controller and a model reference robust adaptive algorithm to control and recover the quadrotor in presence of partial actuator fault. The robust adaptive algorithm is augmented to deal with the effect of the un-modeled fault due to the rotors. Different simulation scenarios are run to investigate the performance of the proposed control strategy. According to the simulation results, the proposed control strategy can maintain full controllability of the quadrotor in roll, pitch, and yaw channels in presence of partial faults of the actuator up to 50%. By providing full controllability in all channels, the quadrotor can track the desired trajectories in presence of a partial actuator fault. The results demonstrate that the performance of the INDI controller is desirable, while actuator fault affects the dynamics.

Acknowledgment

This research is supported by the Scientific and Technological Research Council of Turkey (TÜBİTAK) under 3501 programs, with project number [120M793].

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IJAA

International Journal of Aeronautics and Astronautics

https://dergipark.org.tr/en/pub/ijaa

2022, VOL:3, NO:1, 48-59 e-ISSN: 2757-6574

Review Article

Havacılık işletmelerinde sponsorluk uygulamalarının kurum imajına ve tanıtımına etkisi: Türk Hava Yolları örneği

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Received	Revised	Accepted
December 17, 2021	April 15, 2022	**April 18, 2022**

Anahtar Kelimeler

Havacılık
İmaj
Sponsorluk
Tanıtım
THY

ÖZET

Sponsorluk alanında yaşanan değişim ve gelişimle beraber kurumlar kendi kimliğini, imajını oluşturmak ve tanıtmak için çeşitli alanlarda uzun zamanlı ve yüksek fiyatlı yatırımlarda bulunmaktadır. Kurumsal imajı, destekleyen sponsorluk faaliyetleri sayesinde, işletmeler hedef kitlenin gözünde dürüst, güvenilir, toplumsal duyarlılığa sahip ve katılımcı bir profile ulaşmaktadır. Çeşitli alanlarda faaliyet süren işletmeler, kuruma her anlamda katkı sağlayacak dallarda sponsorluk etkinlikleri gerçekleştirmektedir. Havacılık alanında da uygulanan sponsorluk faaliyetleri hem işletme açısından hem sponsor edilen karşı taraf açısından fayda sağlamakta ve iki tarafın da beklentisini karşılamaktadır. Havacılık alanında yapılan sponsorluk faaliyetleriyle kurumsal imajını güçlendiren markalar arasında Türk Hava Yolları sayılmaktadır. THY, yapmış olduğu sponsorluk faaliyetlerinde hem yerel hem küresel ölçekte önemli bir bütçeyi gözden çıkartmakta ve zihinlerde kalıcılığını arttırmak adına aktif bir sponsorluk politikası sürdürmektedir. Bu çalışmanın amacı, havacılık işletmelerinde sponsorluk uygulamalarının kurum imajına ve tanıtımına etkisini araştırmak ve Türk Hava Yolları kurumunun bu çerçevede yapmış olduğu örnekleri incelemektir. Bu araştırma gerçekleştirilirken, literatür taraması yöntemi kullanılmıştır. Yapılan araştırmanın sonucunda, THY'nin yapmış olduğu sponsorluk etkinlikleri sayesinde, hedef kitlenin gözünde kurum imajına ve tanıtım çalışmalarına katkı sağladığı ölçümlenmiştir.

Keywords

Aviation
Image
Sponsorship
Promotion
Turkish Airlines

ABSTRACT

With the change and development in the field of sponsorship, institutions make long-term and high-priced investments in various fields to create and promote their own identity and image. Thanks to its corporate image and sponsorship activities, businesses reach an honest, reliable, socially sensitive and participatory profile in the eyes of the target audience. Businesses operating in various fields carry out sponsorship activities in branches that will contribute to the institution in every sense. Sponsorship activities applied in aviation also provide benefits for both the business and the sponsored counterparty and meet the expectations of both parties. Turkish Airlines is considered among the brands that strengthen its corporate image with sponsorship activities in the field of aviation. THY sacrifices an important budget both locally and globally in its sponsorship activities and maintains an active sponsorship policy in order to increase its permanence in the minds. The aim of this study is to investigate the effect of sponsorship practices in aviation businesses on the corporate image and promotion and to examine the examples of Turkish Airlines in this context. While conducting this research, literature review method was used. As a result of the research, it has been measured that THY contributes to the corporate image and promotional activities in the eyes of the target audience, thanks to its sponsorship activities.

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Citation: *Arpacı, E., Tosun, M.N., Küçükcivil, G. 2022. The effect of sponsorship practices on corporate image and promotion in aviation businesses: The example of Turkish Airlines. International Journal of Aeronautics and Astronautics, 3(1), 48-59.*

1. Giriş

Bilgi ve iletişim çağının yaşandığı günümüzde rakipler arasından ön plâna çıkmak, farklılık yaratmak, hedef kitleyle duygusal bir bağ kurmak önemli hale gelmiştir. Kurumların toplumun problemlerine duyarlılık göstermesi, kitle iletişim araçlarında tanınma imkânı elde etmesi onların iyi bir imaj yaratmasını sağlayacaktır. Bu amaçları gerçekleştirecek etkin pazarlama aracı sponsorluktur. Sponsorluk, etkin bir pazarlama tekniğidir; amacı kurumu ya da ürünü tanıtarak imaj oluşturmak, güçlendirmek, dolaylı olarak da satın alma tercihlerini etkilemektedir [1].
Günümüzde piyasaya sürülen ürünlerin ve hizmetlerin çoğalması ve benzerlik taşıması, işletmelerin kurumsal imaja daha çok önem vermesine ve rakiplerinden sıyrılması için imajını güçlendirecek çalışmalara yönlenmesine sebep olmaktadır. Yalnızca tüketiciye sunulan ürün veya hizmetin üst performansı ile değil kurum olarak topluma 'üst performans' sergilediğini gösteren çalışmalar gerçekleştirilmeye başlanmaktadır. Bunun için sponsorluk faaliyetleri gerçekleştiren işletmeler, hedef kitlenin gözünde güvenilir, dürüst, yardımsever, topluma karşı duyarlı olduğunu vurgulayarak, kurumun imajının olumlu algılanmasına ve güçlenmesine kaynaklık etmektedir.
Havacılık işletmelerinin faaliyetlerini yürütürken birçok işletmeye göre daha tutarlı, kusursuz ve kaliteli bir hizmet sunmaları beklenmektedir. Nitekim alanı itibariyle havacılık, insanlarla doğrudan iletişimi gerektirmektedir. Hava taşımacılığının her geçen gün öneminin daha da artması havacılık şirketlerine büyük sorumluluklar yüklemektedir. Yoğun rekabet ortamında, iyi bir marka imajı oluşturarak, hedef kitleye hitap eden bir havayolu şirketi olmak ancak iyi bir halkla ilişkiler çalışması ile mümkündür [2]. Türk Hava Yolları kurumu, kurum imajını güçlendirmek, hedef kitleye hitap etmek, tanıtım çalışmalarına katkı sağlık için sponsorluk çalışmalarından yararlanmaktadır. THY'nin gerçekleştirmiş ve gerçekleştirmekte olduğu sponsorluk faaliyetleri sayesinde, marka bilinirliğini arttırmış ve rakiplerinden farkını ortaya koyarak tüketici nezdindeki imajını güçlendirmiştir.
Bu çalışmada, havacılık işletmelerinin sponsorluk uygulamalarının kurum imajına ve tanıtımına etkisi araştırılmış ve Türk Hava Yolları kurumunun bu çerçevede yapmış olduğu örnekler incelenmiştir. Çalışmamız üç kısımdan oluşmaktadır. İlk olarak, kavramsal açıdan sponsorluk olgusu ele alınmış, sponsorluğun önemi, hedefleri ve çeşitleri incelenmiştir. İkinci kısımda, kurumsal imaj inşası olan sponsorluk irdelenmiştir. Son olarak çalışmanın amacı olan, havacılık işletmelerindeki sponsorluk faaliyetleri ve THY'nin sponsorluk faaliyetlerini tanıtım ve imaj çalışmalarına katkısı incelerek çalışma sonlandırılmıştır.

2. Sponsorluk Kavramı

Bütün dünyada çağdaş uygulaması ile çok önemli bir yer tutmaya başlamış olan sponsorluk ülkemizde de giderek yaygınlaşmaya başlayan ve geniş bir uygulama alanı bulan bir halkla ilişkiler yöntemidir [3].
Bir işletme faaliyeti olarak yorumlandığında sponsorluk destekleyicilik ya da desteklemek tarzında ifade edilmektedir. Diğer destekleme şekillerinden ayrımını ortaya koyabilmek amacı ile literatürde ticari sponsorluk ya da örgütsel sponsorluk olarak anılan bu faaliyet, bir gösteri, sportif, kültürel vb. bir organizasyonun giderlerinin tümünü ya da bir bölümünü adının o faaliyette anılması karşılığında ödemeyi kabul ederek özel ya da kamu tüzel kişi veya kuruluşun yaptığı desteklemeleri ifade etmektedir. Ayrıca sponsorluğun pozitif değerlerini ölçebilen, topluma değer katarken, destek olana da ticari menfaat sağlayan etkinlikler dizisi olarak da tanımlamak mümkündür [4].
Sponsorluk yardım ya da bağış değil, karşılıklı yarara dayanan bir uygulama olmaktadır [5]. Sponsorluk uygulamalarında her zaman sponsor olan kurum adıyla medyada ya da ilgili alanlarda yer almaktadır. Sponsorluk çalışmasıyla beraber kurumun imajı güçlenmekte, tanıtımı sağlanmakta ve kamuoyu tarafından değer görmektedir. Kamuoyu yapılan sponsorluk faaliyeti sonucunda iyi, yararlı diye takdirde bulunmakta ve gerektiğinde kurumu tercih etmektedir.
Sponsorluk; bir faaliyete, kişiye ya da işletmeye bunların ticari potansiyelinden faydalanabilmek için sponsor tarafından yapılan nakdi ya da ayni yardımdır. Sponsorluk, bir işletmenin çeşitli organizasyonlara veya olaylara

https://doi.org/10.55212/ijaa.1037738

yatırım yaparak markasını dolaylı bir biçimde tanıtmasıdır [6]. Özetle sponsorluk; hedef kitlelere ulaşmak, daha iyi bir izlenim oluşturmak ve tercih edilme noktasında davranışları etkilemek için kurumun karşılıklı faydaya dayanarak gerçekleştirdiği uygulamaları kapsamaktadır.

Sponsorluk faaliyetlerinin bazı temel amaçları şu şekildedir: kurum kimliğinin tanınırlığını sağlamak, kurum imajının oluşmasını ve gelişmesini desteklemek, kurum satışlarını arttırmak, kurum ile hedef kitle arasında sadakat oluşumunu sağlamak ve medyada bulunmaktır. Kurumlar belirledikleri hedefler doğrultusunda hedef kitlelere ulaşabilmek için farklı sponsorluk çeşitlerini kullanmaktadır.

2.1. Sponsorluğun amaçları ve hedefleri

Sponsorluğun yapılma amaçlarını genel olarak; halkla ilişkiler, reklam ve pazarlama amaçları olarak üç grupta toplamak mümkündür [7].

Sponsorluğun halkla ilişkiler amaçları: Sponsorluk ve halkla ilişkiler birbirine benzer kavramlardır. Halkla ilişkilere bakıldığı zaman; imaj yönetimi, hedef kitleyi ikna, bilgilendirme ve kurumun iletişim faaliyetlerini destekleme gibi fonksiyonlardan söz edilebilir. Sponsorluk çalışmalarının ise destekleme faaliyetleri ile kurumun imajını istenilen yere getirmek, kurumsal kimliği pekiştirmek, hedef kitle üzerinde kurumun aşinalığını arttırmak, hedef kitleyi bilgilendirmek vb. işlevleri vardır [8]. Kurumların sanatsal ve toplumsal konulardaki duyarlılığının topluma kabul ettirilmesi sponsorluğun halkla ilişkiler amaçları açısından önem taşımaktadır.

Sponsorluğun reklam amaçları: Reklamda bir hizmetin, bir şeyin ya da bir malın özelliklerini, yararını ve ilgi çekici yanlarını halka duyurmak ve anlatmak için bazı araçların kullanılması sağlandığı bilinmektedir. Toplumda işletmelere karşı sempatinin oluşması sponsorluğun ticari yanını oluşturmaktadır. Sponsorlukta reklam ön planda olursa, destek verilecek faaliyete popülarite aranmaktadır. Fakat sponsorlukla ve reklamı tamamen birbirinden ayırmak da mümkün değildir. Sponsorluk faaliyeti esnasında reklam yapılmasıyla işletmenin amacına ulaşmasını sağladığı bilinmektedir. Bunun yanında reklam esnasında sponsorluk uygulanması kuruluşun belirlediği kitleyle ulaştırmak istediği mesajın güçlenmesini sağlamaktadır [8].

Sponsorluğun pazarlama amaçları: Hedef kitlenin ilgisini çekmek, boş zamanları değerlendirme faaliyetleri içinde ürün ile marka arasında bir bağ kurarak satışları artırmak, pazarlama politikasına yardım etmek amacıyla sponsorluktan yararlanılmaktadır [9]. Sponsorlukta pazarlama kurumun sunacağı ürünün tanıtımının yapılması, yeni ürünün piyasaya çıkarılması, ürünün kullanımı için teşvik edilmesi, müşteri ve marka sadakatinin sağlanması ve satıcıların desteklenmesi açısından önem taşımaktadır.

2.1.1. Rekabet avantajı

Sponsorluğun işletmelere rekabet avantajı kazandırabileceğine dair çalışmalarda vurgulanmakta olan temel düşünce, aynı sektörden tek sponsor kabul edilmekte olan etkinlik ve alanlarda sponsorluk aktivitesi gerçekleştiren firmaların tüketici algısında seçkinlik kazanma yoluyla rekabet avantajını artırabileceğine yöneliktir. Özellikle sponsor talebinin yoğun olduğu alanlarda kazanılmış sponsorluk hakları, markalar için tüketici algısına dönük ayırt edici bir avantaj kaynağı oluşturabilmektedir [10].

2.1.2. Farkındalık oluşturma

Sponsorluk yoluyla uygulanan marka konumlandırma taktikleri ile hedef pazarlardaki bir ürünün görünürlüğünün ve dolayısıyla ürün veya marka farkındalığının arttırılması mümkün olabilmektedir [11]. Bunun yanı sıra bir işletmenin, hedef tüketici kitlesi arasındaki kurumsal görünürlük ve farkındalığını arttırma amacıyla sponsorluk faaliyetlerini kullanması ve böylelikle şirket markasını sponsor olunan özne ile ilişkilendirmesi, kurumsal görünürlüğün geliştirilmesi açısından sıklıkla kullanılan bir uygulamadır [12].

2.1.3. İmaj oluşturma

İmaj, genellikle bir kişi, kurum veya durum üzerine oluşan görüşlerin değerlendirilmesi olarak açıklanırken; kurum

https://doi.org/10.55212/ijaa.1037738

için fiziksel görüntüler, kurumsal iletişim ve davranışı; kişi için ise beden dili, dış görünüm, içinde bulunulan ortam ve davranış şekillerini ifade eder [13]. Kurum imajı, bir kuruluş nezdinde bireylerin belleğinde oluşan algıların toplamını ifade ettiği için, kurumlar açısından bütünleyici bir faktör olarak görülür. Kurumsal imaj, kuruluşların hedef kitlelerin yanında duygusal olarak nasıl ifade edildiğiyle ilgilidir. Her kuruluş, aktif oldukları toplum içerisinde iyi bir şekilde tanınmak ve hitap ettikleri bütün hedef kitlelerinin zihninde kendisiyle ilgili olumlu bir imajın yer etmesini arzu eder. Çünkü kurumla alakalı kitlelerin belleğinde oluşan olumlu bir imaj, kuruluşların etkin oldukları alanlarda daha fazla büyümesine ve aynı zamanda kâr oranlarından büyük bir artışın yaşanmasına imkân sağlamaktadır [9]. Kurum imajını arttırmak ve hedef kitlenin algısında daha çok yer almak isteyen kurumlar, sponsorluk faaliyetlerine önem vererek görünürlüklerini arttırırlar.

Sponsorluk faaliyetinde en temel amaç, karşılıklı yarar elde edebilmektir. Firmaların sponsor olmalarındaki amaçlar, firma ile alakalı toplumsal farkındalığı arttırmak, hedef pazarda aktif rol oynayabilmek, satın alma kararı veren kişiler üzerinde olumlu bir imaj etkisi bırakmak, medya yönetimini etkinleştirebilmek ve satış amaçlarını ve rakamlarını gerçekleştirebilmektir [14]. Kurum imajını geliştirmek veya pekiştirmek, sponsorluk uygulamasının diğer amaçları arasındadır. Günümüz rekabet dünyasında ürünler ve markalar arasındaki fark giderek azaldığı için, rekabette önde olmak isteyen kurum ve kuruluşların kilit noktası imajdır. Sponsorluk da bu açıdan yalnızca pazarlama amacı olmanın ötesinde kurumlarda imaj oluşturan veya var olan imajı pekiştiren bir iletişim aracı olarak görülmeye başlanmıştır [15].

Gerçekleştirilen sponsorluk etkinliklerinin hangi alana ait olduğu, alanın büyüklüğü ya da organizasyonun çeşidi, organizasyonun işlevleri kurum ve marka imajını etkileyebilmektedir. Özellikle sponsorluk türü, organizasyonun gerçekleşme sıklığı, pazarlama stratejilerinin sponsorluk icraatı sırasındaki rolleri marka imajına doğrudan etki edebilmektedir. Kurum ve markanın değişik alanlardaki organizasyon kişi ya da olaya sponsor olması kuruma karşı iyi bir imajın öne çıkmasını sağlayabilmektedir [16].

2.1.4. Tanıtım faktörü

En genel anlamda kamu yönetiminde halkın, işletme yönetiminde ise firma çalışanlarının aydınlatılması, alınan kararların veya gerçekleştirilecek uygulamaların hedef kitleye açıklanması olarak nitelenebilen tanıtma faaliyetleri yalnızca söz konusu uygulamadan veya kararlardan etkilenebilecek kişilerin bilgilendirilmesi ile sınırlı değildir. Aynı zamanda ilgili örgüt ya da objeye karşı bir sempatinin oluşturularak hedef kitlenin zihninde olumlu bir imaja dönüşmesinin sağlanma görevini de yerine getirmektedir [17]. Tanıtım yalnızca ürün ve hizmetleri hedef kitleye sunmakla kalmaz; aynı zamanda tanıtımı yapılan öğe için pozitif algı oluşturmayı amaçlar.

Tanıtım vurgulanacak mesaja hem itibarlı hem de uygun bir araçla dikkat çekmek ve bu mesajın farkındalık yaratarak iletilmesi için tasarlanmıştır [18]. Tanıtım bir kurum, kuruluş, ürün, hizmet, kişi ya da yer hakkında bilgi vermek, talep yaratmaktır.

Kurum ve kuruluşlar sponsorluk faaliyetlerini, diğer tutundurma çabalarıyla, ulaşılamayan hedef pazarlara ulaşmak, tanıtımı yasak olan mal veya hizmetlerin tanıtımını sağlamak, toplumsal sorumlulukları yerine getirmek için tercih etmektedirler. Bununla beraber işletmeler, tüketicilere faydalı etkinliklerde bulunduklarının mesajını ileterek, çıkar grupları üzerinde iyi niyet ve kurum ismi ile ilgili olumlu çağrışımların meydana gelmesini sağlamaktadır. Bunun sonuncunda da tüketicilerin sponsor kurumun ürününü alma olasılığı artmakta ve çıkar grupları ile olumlu ilişkilerin gelişimine katkı sağlamaktadır [19]. Sponsorluk faaliyetinin günümüzde birçok amaçla etkin olarak kullanıldığı söylenebilir. Özellikle tanıtım faktörü açısından ele alındığında, reklam yasağı olan ürünlerin (sigara, alkollü içecekler, sakinleştirici ilaç vb.) kitle iletişim araçlarında duyurulmasını sağlamakta, marka adına var olan durum hakkında ya da bir değişiklik hakkında tüketicilerine bilgi vermek amacıyla etkin olarak kullanılmaktadır.

Yeni sponsorluk faaliyetlerinin etkin kullanımını sebebi, işletmenin piyasada tanınma oranını arttırmaktır. Bu hedefin gerçekleşmesinde, destekleme alanının popülaritesi öne çıkmaktadır. Örneğin, Aria işletmesi, Galatasaray, Fenerbahçe, Beşiktaş ve Trabzonspor’a sponsor olduktan sonra piyasada tanınma oranını önemli derecede

https://doi.org/10.55212/ijaa.1037738

arttırmıştır [20]. Tanıtım, kurum ve kuruluşların piyasaya sunmuş oldukları ürün ya da hizmeti, hitap edecekleri hedef kitlelerinin bilgilendirilmesi amacıyla yapılan çalışmalardır. İşletmelerin hedef kitleye iletmek istediği tanıtım mesajlarının ayrıntılı bir şekilde aktarılması ve tanıtılması; sponsorluk faaliyetleri çerçevesinde daha etkili bir şekle dönüşmüştür.

2.2. Kurumsal sponsorluk türleri

İşletmeler belirlemiş oldukları hedeflere ve hedef kitlelere ulaşmak amacıyla, farklı sponsorluk alanlarını ve çeşitlerini tercih ederler. Çünkü kurum ya da kuruluşlar, sponsorluk faaliyetlerinde bazı amaçları ön plana alırken, diğer sponsorluk amaçlarına da katkı sağlamak isterler.

Sponsorluk etkinlikleri sürekli tekrarlanan logo, kurumsal renk ve görüntünün farkına varılması ile kurumsal kimliğin tanımlanmasına ve yerleşmesine katkı sağlamaktadır. Her işletme benzer sponsorluk dalıyla, işletmenin hedef kitlesinin dikkatini çekemeyeceği olasılığından, önceden saptandığı hedeflere ve hedef kitleye ulaşmak için farklı sponsorluk alanlarını ve türlerini tercih etmek durumundadır [1].

Sponsorluk türleri amacına göre çeşitlilik göstermektedir ve bununla ilgili araştırma yapılan kişilerce, üzerine uzlaşılmış bir sınıflandırma modeli bulunmamaktadır. Çalışma gereğince ele alınan kurumsal sponsorluk türleri; (Güçlü, 2001; Akyıldız ve Marangoz 2008; Canöz ve Doğan 2015; Aktaş, 2011; Özer, 2011; Karadeniz, 2009; Dibb ve Simkin, 2013; Spais ve Johnston, 2014; Okay, 1998; Taşdemir, 2001) spor sponsorluğu, kültür- sanat sponsorluğu, fuar ve festival sponsorluğu, sosyal sponsorluk, medya sponsorluğu, mecra-seyahat sponsorluğu şeklindedir.

• **Spor Sponsorluğu:** Spor sponsorluğu, sponsorluk faaliyetleri arasında en geniş yeri alan türdür. Spor sponsorluğunun geniş kitlelere hitap edebilmesi nedeniyle, işletmeler arasında özellikle ürünlerini veya hizmetlerini bu kitlelere tanıtmak isteyen şirketlerce tercih edilir. Bunun sebebi spor, hedef kitle ile iletişim kurma imkânı sağlayan ve neredeyse bütün dünyada anlaşılan ve aynı dili konuşan bir sponsorluk alanıdır [21].

Bu tür sponsorluk dalında temel işleyiş, sponsor olan işletmenin, faaliyetlerinde kullandığı kişi, kurum veya etkinlik için finansal destek sağlaması şeklinde gerçekleşir [22].

• **Kültür- Sanat Sponsorluğu:** Sponsorluk türleri arasında en fazla payı alan spor sponsorluğundan sonra bu sponsorluk türüdür. Kültür - sanat sponsorluğunda mali yönden yapılan destekler, hizmet şeklinde yapılan desteklere oranla daha çok ön plandadır.

Kültür – sanat sponsorluğu; müzik, film festivalleri, görsel sanatlar, alakalı radyo ve TV programları gibi kültür ve sanat içeriğini barındıran birçok farklı alanda gerçekleştirilebilir [23]. Kültür-sanat sponsorluğu alanında yapılan çalışmaların artmasının sebebi, son dönemde müziğin etkin gücü ve popülaritesinden kaynaklıdır. Coca Cola’nın Rock'n Cock festivali, Fanta'nın "bambucha" ve her sene değişen isimleriyle turneleri, Turkcell'in plaj partileri turnesi vb. bu daldaki sponsorluk çalışmalarına örnek gösterilebilecek çalışmalardır. Ayrıyeten "Sanatın ve Sanatçının Dostu" sözü büyük bir olasılıkla bilinçaltı çağrışımla Akbank’ı hemen hatırlatacaktır. Efes Pilsen'in "Blues Festival"i, Garanti Bankası’nın Londra’da müzede sergilenen "Türkler Bin Yılın Yolculuğu" sergisi verilebilecek diğer örneklerdir [24].

• **Fuar ve Festival Sponsorluğu:** Fuar sponsorluğu, ilgili sektörde faaliyet gösteren tüm paydaşların geniş katılımlı bir şekilde bir araya geldiği bu organizasyonlarda, sponsor kuruluşa yönelik algı ve tutumun geliştirilmesi ve kurum imajının üst seviyeye çıkarılması açısından önemli fırsatlar sunmaktadır [25].

• **Sosyal Sponsorluk:** Sosyal sponsorlukta toplumun ihtiyacı olan alanlara yönelik faaliyetler yürütülmektedir. İçinde bulundukları toplumun bir öğesi olarak sponsorluk çalışmalarında bulunan firmalar, sosyal katılımın ve toplumsal sorumluluk bilincinin ispatlanması amacıyla toplumun ihtiyaç duyduğu alanlarda kar amacı taşımadan türlü çalışmalar yapmakta, böylece bilinirliklerini artırmak, imajlarını geliştirmek gibi amaçlarına da ulaşmaktadırlar [26].

• **Medya Sponsorluğu:** Günümüzde önemli bir etkileşim ve iletişim aracı olan televizyon ve radyo gibi geleneksel

https://doi.org/10.55212/ijaa.1037738

medya unsurlarının arasına internet ve sosyal medya araçları da eklenmiştir [27]. Kitle iletişim araçları arasında yer alan radyo ve televizyon yayıncılığı, çok geniş kitlelere hitap etmesi bakımından sponsorluk çalışmalarının temel ilgi alanını oluşturmaktadır. İnternet ve sosyal medya sponsorluğu günümüzde en az geleneksel medya sponsorluğu kadar ilgi çekmekte olan bir alandır. Sosyal medyanın etkileyici iletişim özellikleri ve CRM uygulamalarını etkin bir şekilde desteklemesinin, kuruluşların sponsorluk mesajlarının yayılması ve doğru hedefe yönlendirilmesi açısından önemli bir aşama kaydedilmesine yol açmaktadır [28].

• **Macera-Seyahat Sponsorluğu:** Bu sponsorluk türü dağcılık, araştırma gezileri, dünya turu gibi olayların desteklenmesini kapsar. Bu tarz sponsorluklar dayanıklılık, güç gibi durumlara bağlı olduklarından başarısızlık riski taşır. Ancak bu sponsorluk türünde de kuruluşların veya firmaların imajını yükseltme şansı oldukları için tercih edilmektedir [9]. Bu alanda tek bir sponsor olacağı gibi birden fazla sponsor da olabilir. Bu kuruluşlar materyal, donanım sağlama ve direkt olarak parasal katkıda bulunabilirler [29]. Macera seyahat sponsorluğuna örnek olarak; Red Bull markasının 2012 yılında 39.045 metreden atlayan Felix Baumgartner' a sponsor olması gösterilebilir. Bu etkinlik haftalarca dünyanın gündeminde kalan ve oldukça başarılı pazarlama faaliyetlerinden biri olarak gösterilebilir. Bu etkinlikte Red Bull markasının sponsorluğu milyonlarca kişi tarafından takip edilmiştir. Etkinlik için ayrılan 7 aylık sürecin sonunda 140.000 kişi Facebook' tan, 235.000 kişi Twitter' dan Red Bull sayfasını takip etmişlerdir. Atlayışın gerçekleştirildiği tarihte Red Bull' un Red Bull Stratos sayfasında 270.000 kişilik bir artış gözlemlenmiş olup şu anda 1 milyona yakın takip edeni bulunmaktadır. Bu atlayış tüm zamanların en çok izlenen etkinliği olarak (8 milyon) tarihe geçmiştir.

3. Kurumsal İmaj İnşası: Sponsorluk

Rekabet dünyasının kızıştığı ticaret dünyasında var olmak ve pazar alanında uzun yıllar boy göstermek isteyen işletmelerin güçlü ve olumlu bir imaja sahip olması ve bu imajı her daim koruması gerekir. Bu imaja ulaşabilmek için işletmeler, yalnızca tüketiciye sundukları mal veya hizmetteki memnuniyete değil, ayrıca iş birliği içerisinde olukları diğer kurumların, rakiplerinin ve medyanın gözünde de olumlu ve etkili bir yapıda görünmelidir.

İyi yöneten, stratejik hareket eden, varlığını sürdürdüğü toplumun faydası için işler yapan, çevre, kültür, sanat konularına duyarlı, katılımcı, iyiliksever gibi olumlu izlenimler; işletmeler için zaman içerisinde iyi bir kurum imajına dönüşür. Bu olumlu imaj sayesinde, tüketiciler bu kuruma ve ürünlerine bağlanarak, işletme veya markaları her türlü zorluklara karşı koruyarak ve kriz dönemlerinde sorunların daha kolay ve hızlı çözümlenmesine yardım edecektir [30]. Kurumsal imaj, bir kişinin ya da kişiler grubunun bir kurum hakkındaki akılcı ve duygusal değerlendirmelerinin tümü olarak ifade edilebilir [31].

Kurum imaj, bir kurumun vizyonunu, misyonunu, amaçlarını, politikalarını, uzak ya da yakın çevreye bakış açısını hedef kitlelere ileten bir unsurdur [32]. Bir kuruluşun, pek çok yönüyle, hem kendi iç bünyesinde yer alan bireylerin hem de dış hedef kitlelerin zihinlerinde, kendisine ilişkin izlenimler oluşturması ve sürdürmesi mümkündür. Bu noktada, kuruluşu algılayanların bakış açılarına ve algılama biçimlerine göre değişiklik gösterebilecek olan imaj, kurumun kendi aktifliğiyle oluşturmuş olduğu imajdır [33].

Kurumsal imaj, bir işletme hakkında tüketicilerin, toplumun, ürün veya hizmetlerini ulaştırdığı müşterilerinin, rakiplerinin, beraber iş yürüttüğü diğer kuruluşların ve kitle iletişim araçlarının edinmiş oldukları izlenimlerdir [34]. İşletmelerin kamunun faydasını gözeterek yaptıkları harcamalar karşılığında imaj geliştirme ve duyurum beklentileri söz konusudur. Sponsorluk, bu beklentilere cevap veren bir araçtır ve imaj geliştirmeye yönelik sponsorluk uygulamaları yaygınlaşmaktadır. Bu noktada, kurum imajının finanse edilen veya materyal destek sağlanan belirli olay ve gösteriler ile bağdaştırılıp, geliştirilmesinde ve sosyal sorumluluğun vurgulanmasında sponsorluk faaliyetleri ön plana çıkmaktadır. Doğru seçilmiş bir sponsorluk uygulaması işletmenin görünürlüğünün arttırılması, korunması ve geliştirilmesini sağlayarak işletmenin satış faaliyetlerini ve kredibilitesini olumlu yönde etkilemektedir. Sponsorluk faaliyetlerinde hedeflenen imaj oluşumu ve bunun faaliyetlere yansıması uzun vadede gerçekleşmektedir [19].

https://doi.org/10.55212/ijaa.1037738

Sponsorluk; belirli beklentilerle birey veya örgütün spor, kültür-sanat, eğitim, sağlık, çevre ve diğer alanlarda birey ve örgütleri para, hizmet, personel veya teçhizat vererek desteklemesi şeklinde tanımlanabilir. Bir karşılıksız verme olmayıp hem sponsora hem de sponsore edilene karşılıklı menfaat sağlamaya yönelik bir iletişim etkinliğidir. Sponsorluk yoluyla sportif, kültürel ve sanatsal faaliyetleri çok sık takip eden bireyler üzerinde olumlu imaj yaratmak mümkündür [35]. Kurumlar gerçekleştirmiş oldukları sponsorluk faaliyeti sayesinde yalnızca dış hedef kitlenin değil, iç hedef kitlenin de algısındaki imajı yapılandırır ve güçlendirir. Bu sayede daha aktif ve verimli bir iş ortamı sağlanmış olur.

Pazara sunulan ürün ve hizmetlerin, benzerliğinin giderek artmasından kaynaklı olarak; işletmeler tercih edilen marka olabilmek için kurumsal imajlarını sponsorluk faaliyetleriyle, göz önünde tutup, pekiştirmeyi amaçlar.

4. Havacılık İşletmelerinde Yapılan Sponsorluk Faaliyetleri

Sponsorluk, bir halkla ilişkiler yöntemi olarak çeşitli alanların (sanat, spor gibi vb.) etkinliklerinin, kurum ve marka tarafından desteklenmesi ve bu sayede tüketicilere ulaşma ve onları etkileme amaçlarına ulaşma çabasıdır [36].

Havacılık işletmelerinde sponsorluk faaliyetleri önemli bir yer teşkil etmektedir. Diğer sektörlerde olduğu gibi havacılık işletmelerinde de sponsorluk, uzun vadeli bir yatırım ve kazanç aracı olarak görülmektedir. Öyle ki, havayolu işletmeleri spor, sanat, kültür vb. etkinliklere yalnızca destek olmak amacıyla değil, uzun vadede katkı ve getiri sağlamak amacıyla sponsor olmaktadırlar [2]. Kurumlar arası rekabetin ve çeşitliliğin yaşandığı günümüzde dünya çapında başarılı olan ve adından söz ettiren havayolu işletmeleri çeşitli spor branşlarında takımlara isim, stadyum, forma gibi alanlarda sponsor olmaktadır. Havayolu işletmeleri spor alanında olduğu gibi medya, kültür-sanat ve çevre gibi faaliyetlerde de sponsorluk sağlamaktadır.

Havacılık işletmeleri spor, sanat ve toplumsal faaliyetlere sponsorluk yaptığı gibi bağlı olduğu ülkenin imajı adına da önemli bir etkiye sahiptir. Bu doğrultuda yapılacak olan sponsorluk faaliyetleri hem havacılık işletmeleri için hem de ülkeler için önemli bir stratejik güç oluşturmaktadır. Havacılık işletmelerinde hem kurumun hem ülkenin stratejik bir öneme sahip olabilmesi için yapılan sponsorluk faaliyetlerinden hedeflenenin ötesinde katkı sağlaması beklenmektedir. Bu doğrultuda yapılan sponsorluk faaliyetleri sonucunda da maddi bir kazanç elde edilmesi havacılık işletmeleri için sponsorluğun önemini göstermektedir.

2018 yılında hava yolu endüstrisi, 800 milyar doları aşan geliriyle, geleneksel anlamda sponsorluk alanındaki görünürlüğüyle en rekabetçi biçimde yatırım yapan sektörler içerinde yer almaktadır [37]. Bu kapsamda havacılık işletmelerinin, toplum üzerinde kendi şirketleriyle ilgili bir iyi niyet algısı oluşturabilmek, marka bilinirliklerini arttırabilmek, kurum imajlarını geliştirebilmek, yeni hedef pazarlara ulaşabilmek, müşteriler üzerinde farkındalık yaratabilmek, satışlarını ve pazar paylarını arttırabilmek, rakiplerle rekabette avantaj sağlayabilmek amacıyla sponsorluk faaliyetlerine yöneldikleri söylenebilir [2].

4.1. Türk Hava Yolları'nın sponsorluk faaliyetleri

Türk Hava Yolları firması, sponsorluk alanında gerçekleştirdiği çalışmalara hem yerel hem küresel ölçekte büyük ölçüde bütçe ayırmakta ve marka görünürlüğünü arttırmak, tanıtım faaliyetlerini aktif tutmak adına dinamik bir sponsorluk politikası izlemektedir.

Sponsorluk alanında kazanılan iletişim faaliyetleri çerçevesinde yapılan çalışmalar sayesinde (reklam, tanıtım, organizasyon vb.), THY küresel çapta bir marka olarak Türkiye'de ve dünyadaki en kapsamlı iletişim planlarından birisine sahiptir. Dünyanın 100'den fazla noktasında 360 derece, profesyonel iletişim çalışmaları yürütülmektedir. Bu sponsorluk kapsamında yapılan ilk faaliyette uluslararası düzeyde imza töreni düzenlemek olmuştur. Türk Hava Yolları'nın dünyanın 30 farklı ülkesinde faaliyet gösteren PR ajanslarının kendi ülkelerinden getirdikleri gazeteciler bu törende hazır bulunmuşlardır. Ayrıyeten sponsorluk çerçevesinde saha içerisinde ve saha dışında birçok farklı mecrada THY reklamları yer almış, uydu üzerinden izlenebilen Barça TV ve kulübün diğer yayın

https://doi.org/10.55212/ijaa.1037738

organlarında anlaşma süresince yer verilecek reklamlar da dahil edilmiştir. Yakın süreçte takım oyuncuları Messi, İbrahimovic, Xavi gibi ünlü futbolcuların oynayacağı reklam kampanyaları ile THY yine uluslararası TV kanallarında yayına girmeyi hedeflemektedir. Bu nedenle ilerleyen zamanda tanıtımdan başlayarak tüm sponsorluk sürecinde iletişim çalışmaları birçok farklı mecrada devam edecek ve bunun gerçekleşmesi için sosyal medyadan çizgi üstü reklamlara kadar çeşit çeşit iletişim kanalı var olacaktır [20].

Havacılık alanında gerçekleştirilen sponsorluk etkinlikleri, kurumsal imajı güçlendiren markalar arasında Türk Hava Yolları kurumu yer almaktadır. THY etkin olduğu hem yerel hem küresel ölçekte uyguladığı sponsorluk faaliyetlerinde önemli bir bütçeyi gözden çıkartmakta ve hedef kitlenin zihninde kalıcılığını arttırmak için aktif bir sponsorluk politikası sürdürmektedir.

THY'nin son yıllarda küresel sponsorluk pazarında, özellikle spor sponsorluğu alanında yaptığı iş birlikleri, kuruluşun dünya genelinde en büyük havayolu şirketleri içinde yer alma vizyonuyla uyumlu bir şekilde önemli kazanımlar ortaya çıkarmıştır. Yurtiçinde 49, uluslararası ölçekte 257 olmak üzere dünyanın toplam 124 ülkesindeki 306 noktaya uçuş gerçekleştiren THY, dünyada sponsorluğa en çok yatırım yapan 10 havayolu şirketi arasında kendisine yer bulmaktadır [38].

Türk Hava Yolları kurumun gerçekleştirmiş olduğu bazı sponsorluk etkinlikleri şunlardır [39]:

• **Türkiye A Milli Basketbol Takımı:** Basketbolun en önemli destekçilerinden biri olan THY, Türkiye A Milli Basketbol Takımı'nın ana sponsorluğunu üstlenmiştir.

• **Türkiye A Milli Futbol Takımı:** Türk sporunun önde gelen kurumlarından Türkiye Futbol Federasyonu'na 2008 yılından bu yana destek veren THY, yaptığı çalışmalarla Türk sporuna verdiği önemi göstermektedir.

• **Türkiye A Milli Voleybol Takımı:** Ülkemizin en başarılı olduğu spor dallarından biri olan voleybolda, A Milli Kadın voleybol takımı'nın göğüs sponsoru olarak THY yer almaktadır.

• **Galatasaray Spor Kulübü:** THY bu alanda da spor kulübünün ana ulaşım sponsoru ve 2019-20 sezonunda Avrupa kupalarındaki forma sponsoru olarak Galatasaray Spor Kulübü'ne destek vermiştir. Galatasaray Spor Kulübü'nün futbol, basketbol, voleybol takımlarının tümüne yönelik bir çalışma gerçekleştirilmiştir.

• **Trabzonspor Kulübü:** Türkiye'nin başarılı Anadolu kulüplerinden Trabzonspor'un ana ulaşım sponsorluğunu THY üstlenmiştir.

• **Başakşehir:** Türkiye'nin futbolun önde gelen takımlarından Başakşehir'in Avrupa kupalarındaki forma sponsoru olan THY, bu desteği 2019-20 sezonunda da sürdürdü.

• **Cumhurbaşkanlığı Türkiye Bisiklet Turu:** Dünyanın farklı ülkelerinden 150'ye yakın sporcunun katılımıyla gerçekleşen ve 100 ülkede canlı yayınlanan Türkiye Cumhurbaşkanlığı Bisiklet Turu'nun ana sponsorluğunu Türk Hava Yolları üstlenmiştir.

• **Turkish Airlines Euroleague:** 2010-2011 sezonundan sonra turnuva tümüyle Turkish Airlines EuroLeague adıyla düzenlenmeye başlandı Böylelikle, Turkish Airlines EuroLeague ismini ayrı bir marka olarak gerçek kılındı ve 2025 yılına kadar turnuvanın isim sponsoru olmaya devam edilmesi planlanıyor.

2000 yılından beri düzenlenen Avrupa basketbolunun en önemli organizasyonudur. 2010 yılında Paris'te gerçekleştirilen dörtlü finallere isim sponsorluğu yaptı ve Euroleague turnuvasına isim sponsoru oldu. 2020 yılına kadar devam eden bir anlaşma gerçekleştirildi.

THY sponsorluk faaliyetlerini gerçekleştirmeden önce hangi takımla sponsorluk anlaşması yapacağı konusunda detaylı bir çalışma gerçekleştirmektedir. Yapılan çalışmalar sonucunda taraftar yoğunluğu ve marka değerlerinin etkisi üzerinde Barcelona ve Manchester United takımlarının dünya sıralamasında ilk iki sırada yer alması ve kamuoyu tarafından tanınıyor olması THY´nin sponsorluk anlaşması yapması konusunda etkili faktörler arasında yer almaktadır. Manchester United takımının taraftar yoğunluğu Barcelona'nın ise bir sezonda kazandığı kupa sayılarının fazlalığı THY´nin imaj ve marka değeri konusundaki vizyonu ile paralellik gösterdiği söylenebilmektedir [20].

https://doi.org/10.55212/ijaa.1037738

Bu sponsorluk faaliyetleri haricinde THY, futbol alanında FK Sarajevo, River Plate, serbest dalış alanında Şahika Ercümen, buz hokeyi alanında IFK Helsinki, golf alanında Turkish Turkish Airlines World Golf Cup, basketbol alanında Super Bowl (Amerikan Ulusal Futbol Ligi (NFL) final maçı) ve İstanbul Maratonu gibi aktivitelere ve kişilere destek olmuştur.

Gerçekleştirilen bütün sponsorluk faaliyetleri kapsamında THY, kurumların marka geliştirme ve büyütme politikalarında uyguladığı sponsorluğun önemi ve işlevi açısından hem ulusal hem uluslararası araştırmalar kapsamında gittikçe önem kazanan sponsorluk faaliyetlerinin kurum stratejisine ve pazarlamasına sağladığı katkıyı ortaya koymaktadır.

4.2. Türk Hava Yolları'nın sponsorluk faaliyetlerinin tanıtım ve imaj çalışmalarına katkısı

Havacılık işletmelerinin doğru ve stratejik olarak, ileri görüşlülük becerisi ile anlaşmaya vardıkları sponsorluk anlaşmalarının işletmeye beklenenin ötesinde fayda sağlaması beklenmektedir. Yapılan sponsorluk anlaşmaları sonucunda kurumun sponsorluk amaçlarına ulaşması ve nihayetinde sponsorluğun ticari bir kazanca dönüşmesi, havayolu işletmeleri için sponsorluğun önemini açıkça göstermektedir [2]. Sponsorluk faaliyetleri, pazarda tutundurma çabaları ile ulaşılamayan hedef pazarlara ulaşmak, tanıtımı yasak olan mal/hizmetlerin tanıtımının sağlamak, toplumsal sorumlulukları yerine getirmek için kullanmaktadırlar. Bu süreçte işletmeler, tüketicilere yararlı faaliyetlerde bulundukları mesajını ileterek çıkar çevreleri üzerinde iyi niyet ve kurum ismi ile ilgili olumlu çağrışımlar yaratmaktadırlar. Bunun sonucu olarak tüketicilerin sponsor kurumun ürününü alma olasılığı artmakta ve çıkar çevreleri ile olumlu ilişkiler geliştirilebilmektedir [19].

Ulusal ve uluslararası pazarda faaliyet gösteren THY, rakiplerinden sıyrılarak hedef kitle üzerin marka farkındalığını arttırabilmek için sponsorluk faaliyetlerine her zaman önem vermektedir. Hem sponsor kurumun hem de sponsore edilen tarafın kazanacağı bir alan olan bu faaliyet sayesinde THY, yeni pazarlara açılarak avantajlar sağlamaktadır.

THY'nin gerçekleştirmiş olduğu sponsorluk faaliyetlerindeki en önemli amacı, kurum imajını geliştirmek ve tanıtım çalışmalarına katkı sağlamaktır. Sponsor olduğu etkinlikler sayesinde, THY yerel ve ulusal çapta yer alan spor, kültür – sanat ve medya etkinliklerinde boy göstermektedir.

Sponsorluk faaliyetleri ile işletmeler, hedef kitlenin duyarlı olduğu konularda çeşitli aktivitelere maddi ve/veya materyal destek sağlamaktadırlar. Bu faaliyetler sayesinde basınyayında işletme ile ilgili olumlu haberler yayınlanması sağlanmakta kurum imajı oluşturulabilmektedir [19]. Türk Hava Yolları kurumu, kurum imajını güçlendirmek, hedef kitleye hitap etmek, tanıtım çalışmalarına katkı sağlık için hem Türkiye'de hem de dünyada önemli spor kulüplerine, sporculara ve spor etkinliklerine destek olarak sponsorluk faaliyetleri gerçekleştirmektedir. Böylelikle THY, gerçekleştirmiş ve gerçekleştirmekte olduğu sponsorluk aktiviteleri sayesinde, kurum imajını arttırmış ve güçlendirmiş olup, hedef kitlenin zihnindeki imajını güçlendirmiştir.

Türk Hava Yolları kurumunun F.C. Bercelona ile yapmış olduğu sponsorluk anlaşması sonucu elde ettiği kazanımlar şu şekildedir [20]:

• THY, F.C Barcelona resmi sponsoru olması ve ilgili sponsorluğun tüm dünyayı kapsayarak küresel bir şekilde gerçekleştirilmesi,
• Futbolcularla ticari film çekimi yapma imkânının sağlanması,
• Küresel düzeyde sponsorluk haklarının hem imaj hem de oyuncular için geçerli olması,
• Anlaşmanın bir kısmının barter sistemiyle geçerli olması ve bazı uçuşların THY ile yapılması,
• THY sponsorluğunun saha kenar reklam panolarındaki logo gösterim hakkının sağlaması,
• Antrenman alanları, basın odası arka pano vb. mekanlarda logo ve görsellerin yer alması,
• Üyelik kartlarında logonun bulunması,
• F.C Bercelona'nın internet sitesinde THY sponsorluğunun sabit bir şekilde yer alması,
• Statta yer alan video perdesinde reklam gösterim imkânının sağlanması,

https://doi.org/10.55212/ijaa.1037738

• FCB dergisinde ilan hakkının alınması,
• Stat çevresinde yer alan en büyük reklam alanında sponsorluk yayının yapılması,
• Statta Türk Hava Yolları'na ait koltuk hakkının verilmesi,
• Statta etkin yapabilme hakkının sağlanması,
• Uluslararası üyelere emaling hakkının sağlanması,
• Fanlara yapılacak exclusive emaling hakkının sağlanması,
• Oyuncular tarafından imzalanmış forma alma imkânının sunulması,
• Camp Nou futbol sahasının dışında etkinlik gerçekleştirme olanağının tanınmasıdır.

Ayrıca Türk Hava Yolları firması, Manchester United'la yapmış olduğu anlaşma neticesinde yukarıda belirtilen kazanımların yanı sıra dünya çapında havacılık sektöründe lider olma yolunda bir adım daha attığı söylenebilir.

5. Sonuç

Kurum, kuruluş ya da şirketler; günümüz rekabet koşulları içerisinde tercih edilen marka olmak ve pazar yapısı içerisinde en çok satış alan ürün ya da hizmetleri üretmek için daima rekabet içerisindeler. Ürün benzerliği ve fazlalığının giderek arttığı günümüz ticaret dünyasında, başarılı bir işletme olabilmenin altın kurallarından biri sponsorluk faaliyetlerini önem vermektedir. Kurum ya da kuruluşların, ürettikleri ürünlerin veya sundukları hizmetlerin hitap edileceği kitleye uygun ve kitlenin gözündeki imaj algısını ve tanınırlığını arttırabilmek için etkili bir şekilde sponsor faaliyetlerini kullanması gerekmektedir. Bir kurumun maddi veya manevi açıdan gerçekleştirdiği sponsorluk etkinlikleri, ürettikleri ürün ya da sundukları hizmetin; hedef kitleye en etkili şekilde ulaşması ve kurum bağlılığını arttırması amacıyla çalışmalar yapmaktadır.

Kurum ve kuruluşlar, imajlarını geliştirmek ve pekiştirmek için sponsorluk etkinliklerden yararlanmaktadırlar. Rekabetin yoğun olduğu günümüz küresel dünyasında; ürün, hizmet ve markalar arasındaki benzerlik giderek arttığı için, bu faaliyetler ön planda tutulmaktadır. Sponsorluk aynı zamanda kurumların imajını oluşturan ve güçlendiren, tanıtımının etkili şekilde gerçekleştirilmesine kaynaklık eden iletişim aracıdır.

İşletmeler arasında en çok sponsorluk faaliyetinde bulunan havacılık sektörü; spor, sanat ve toplumsal faaliyetlerde gerçekleştirilir ve bu etkinlikler ülke imajı adına da önemli bir etkiye sahip olmaktadır. Havacılık alanında sponsorluk çalışmalarıyla önde gelen kurumlardan biri olan Türk Hava Yolları, kendi kurum imajı ve itibarı kadar; yerel ve ulusal çapta faaliyet gösterdiği için Türkiye'nin de imajını ve itibarını temsil etmektedir. THY'nin sponsor olduğu kişi, kurum veya etkinliklerdeki en önemli amacı, kurum imajını geliştirmek ve tanıtım çalışmalarına katkı sağlamaktır. Sponsor olduğu çalışmalar sonucunda, THY yerel ve ulusal çapta yer alan spor, kültür – sanat ve medya etkinliklerinde aktif rol oynadığı için havacılık sektöründe önemli konuma sahiptir.

Türk Hava Yolları'nın gerçekleştirmiş olduğu sponsorluk faaliyetlerine bakıldığında yerel bir işletmeden küresel bir firma konumuna erişme stratejisi taşıdığı gözlenmektedir. Yaklaşık son yirmi yıldır bu doğrultuda sponsorluk yatırımları yapan firma özellikle spor sponsorluğu alanında, küresel çapta bir Pazar alanına sahip olmak istediğinin kararlılığını göstermiştir. Özellikle gerçekleştirmiş olduğu Barcelona FC, Manchester United, Turkish Airlines Euroleague sponsorluk örneklerinin küresel çapta yer alması markaya olumlu geri dönüşler sağladığı ve geniş kitlelerle iletişime geçilmesine imkân sağladığı söylenebilir. THY firmasının en önemli hedeflerinden biri kitlelerle iletişime geçerek insanların zihninde güçlü ve güvenilir marka imajını canlandırmaktır ve bunu sürekli dinamik tutmaktır.

Spor sponsorluğunu bir pazarlama aracı olarak kullanan THY firması, dünyaca bilinen organizasyonlara, sporculara, kulüplere sponsorluk yaparak uluslararası boyutta kurumsal bir imaja sahip olduğu söylenebilir. Hedef kitleyle iletişime geçmek ve sürekli görünür olabilmek için sponsorluk uygulamasını kapsamlı ve titiz bir şekilde kullanarak sürekli olarak aktif ve popüler olduğu imajına vurgu yapmıştır. THY'nin sponsorluk çalışmalarına önem vermesinin nedenleri, kurum imajını pekiştirmek, hedef kitleye etkin bir şekilde ulaşmak, tanıtım çalışmalarına katkı sağlamak içindir. THY'nin gerçekleştirmiş ve gerçekleştirmekte olduğu sponsorluk etkinlikleri

https://doi.org/10.55212/ijaa.1037738

kapsamında, marka bilinirliğini arttırmış ve rakiplerinden farkını ortaya koyarak hedef kitlenin algısındaki imajını güçlendirmiştir. Çalışma kapsamında incelenen THY'nin sponsorluk çalışmaları örnekleri göz önünde bulundurulduğunda, kurumun daha çok spor ve sporcuya yönelik çalışmalarda bulunduğu ve destek olduğu tespit edilmiştir. Bu hareketteki amacı kavramsal çerçeveden elde edilen bilgilere göre kurumlar nasıl görünmek istiyorsa o alanda sponsorluk faaliyetleri yürütmelerindeki amaca bağlı olduğu söylenebilir. Bu nedenle THY da spor ve sporcuya yönelik çalışmalarıyla; etkin, dinamik, hızlı ve güçlü bir kurum imajına sahip olduğunun altını çizerek tanıtım ve imaj çalışmalarını desteklemektedir.

Authorship contribution statement for Contributor Roles Taxonomy

Ezgi Arpacı: *Writing - Investigation, Conceptualization, Methodology, Formal analysis.* **Merve Nur Tosun:** *Original draft, Methodology, Investigation, Writing – review & editing.* **Gamze Küçükcivil:** *Investigation, Methodology, Writing – review & editing.*

Conflicts of Interest: The authors declare no conflict of interest.

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