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Design of a Model Satellite Consisting of Container and Payload for the Teknofest 2023 Competition

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Abstract

This work presents the design of a model communication satellite featuring an autonomously separable mission mechanism. Focusing on originality and efficiency, the model satellite is designed in two parts: the container and the payload. The model satellite is configured with software and necessary mechanical-electronic components to gather relevant data with the sensors placed on the payload. The design emphasizes mobility and simplicity to meet the requirements of Teknofest model satellite competition 2023. The development process adhered to specific work packages, culminating in the configuration of components to meet vehicle requirements. Subsequent to hardware and mechanical development, the software development process commenced in three distinct phases: hardware integration, communication software, and ground station software, each essential for autonomous missions.

Keywords: Model Satellite, Payload, Container, Telemetry Transmission, Satellite Structure, Mechanical Design, Hardware Design, Software Design

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Teknofest 2023 Yarışması için Taşıyıcı ve Faydalı Yükten Oluşan Bir Model Uydu Tasarımı

Öz

Bu çalışma, otonom olarak ayrılabilen bir görev mekanizmasına sahip model bir haberleşme uydusunun tasarımını sunmaktadır. Özgünlük ve verimliliğe odaklanan model uydu, taşıyıcı ve faydalı yük olmak üzere iki parça halinde tasarlanmıştır. Model uydu, faydalı yük üzerine yerleştirilen sensörlerle, ilgili verileri toplamak için yazılım ve gerekli mekanik-elektronik bileşenlerle yapılandırılmıştır. Tasarım, Teknofest Model Uydu Yarışması 2023'ün gerekliliklerini karşılamak için mobilite ve basitliği vurgulamaktadır. Geliştirme süreci, belirli iş paketlerine bağlı kalarak, araç gereksinimlerini karşılamak için bileşenlerin yapılandırılmasıyla sonuçlandırıldı. Donanım ve mekanik geliştirmenin ardından, yazılım geliştirme süreci de donanım entegrasyonu, iletişim yazılımı ve yer istasyonu yazılımı adımlarında üç ayrı fazda gerçekleştirildi.

Anahtar Kelimeler: Model Uydu, Görev Yükü, Taşıyıcı, Telemetri Iletimi, Uydu Yapısı, Mekanik Tasarım, Donanım, Yazılım

1. Introduction

In accordance with the Turkish Space Agency (TUA), a Satellite is a compact celestial object traversing an orbital trajectory around a celestial body. These satellites manifest in two primary classifications: Natural Satellites, and Artificial Satellites. The latter encompasses a spectrum of specialized categories, including Communication Satellites, Meteorology Satellites, and Astronomy Satellites [1].

The popularity of satellites in modern applications is conspicuous, with communication and observation emerging as the foremost domains of their utilization [2], [3]. One of Turkey's first steps in satellite research took place on 23 April 1979 with the inauguration of AKA-1 (Ankara-1), the first indigenous satellite ground station. A milestone in Turkey's venture into satellite technology was the launch of Turksat 1A, the nation's first domestic satellite, on January 24, 1994. After this historic event, Turkey has witnessed a progression in satellite initiatives. This pivotal establishment laid the groundwork for subsequent advancements, including the achievement of data transfer at a velocity of 140Mb/s, employing a 1310nm wavelength through fiber optic cables. This breakthrough not only amplified channel capacity in communication but also played a pivotal role in augmenting public awareness about Satellite Systems [1], [4], [5].

Satellite Systems, instrumental in diverse sectors such as communication and imaging, have evolved into indispensable components of contemporary technology. The integration of distinct containers and mission mechanisms has further enhanced their efficacy. Concurrently, the relentless march of technology has engendered the design and implementation of autonomous functionalities, expanding the spectrum of tasks that Satellite Systems can autonomously undertake on a daily basis [6], [7].

Today, model satellite technology is appreciated and promoted. Various model satellite competitions are organized in Turkey and worldwide:

- TEKNOFEST Model Satellite Competition: Organized as part of TEKNOFEST, Turkey's largest technology festival, this competition has been held since 2018 and is the most prestigious model satellite competition in Turkey. Teams launch their own designed and manufactured model satellites to perform various tasks that meet the competition requirements.

- Istanbul Technical University (ITU) Model Satellite Competition: This competition has been organized by ITU since 2004 and is one of the oldest model satellite competitions in Turkey. Teams launch their own designed and manufactured model satellites to perform various tasks.
- Middle East Technical University (METU) Model Satellite Competition: Organized by METU since 2007, is one of the most prestigious model satellite competitions in Türkiye. Participants are expected to design a model satellite that will fulfill the specified missions.
- CanSat is organized by NASA and is known as the oldest model satellite competition with a history dating back to 1999. Participating teams are expected to design a Can-sized model satellite and are also asked to fulfill the specified tasks.
- CubeSat Design Competition: The CubeSat competition has also been organized since 1999. The model satellites that will participate in the competition are expected to be 10 cm x 10 cm x 10 cm in size and are expected to fulfill various tasks.

In model satellite competitions, participating students are expected to acquire skills such as electronic circuit modeling, control software design, mechanical calculations and design, project management, teamwork and effective presentation during the design and prototype production of a model satellite.

In this study, a model satellite design was realized for Teknofest 2023 Model Satellite competition. The model satellite designed in the study has functionalities to meet the competition qualifications. After the model satellite ascends with a rocket or drone and descends to a height of approximately 400 meters at medium speed, it is divided into two parts as container and payload. In addition to transferring parameters such as speed, position, pressure and temperature to the ground station via sensors on the payload, the model satellite has real-time imaging capability through a built-in camera and is designed to continuously transmit images to the ground station throughout its operational phase. In addition, the data from the sensors on the payload can be sent to the ground station without any interruption and visualized at the ground station through the designed software user interface.

1.1. Literature Review

In a study focusing on very small-scale satellites, two innovative model satellite designs called "SpaceChip" and "PCBSat" were proposed. These designs introduced the concept of very small model satellites and emphasized the miniaturization and cost reduction of satellites. The "SpaceChip" integrates all components on a single microchip and the "PCBSat" utilizes mass-produced printed circuit boards. Initial evaluations have shown significant cost savings compared to existing technologies [8].

In 2011, researchers analyzed the various uses of satellites and their miniature models, highlighting applications in communications, weather observation, data collection and even military purposes. That study emphasized the advantages of model satellites, such as fast and low-cost development processes and simpler launch procedures. In the study, a successful model satellite measuring altitude-dependent temperature and pressure variations was demonstrated with a low-budget design [9].

Bulut et al. successfully designed and built a model satellite named "Vecihi" in accordance with the CanSat 2013 competition requirements. Vecihi transmitted sensor data wirelessly during its orbital flight and stored additional sensor and image data on the model satellite. Simple and cost-effective solutions were prioritized in the design of the model satellite, and the innovative aspects included an adapted quadcopter aerodynamic braking system for increased durability and a protection system inspired from egg [10].

Also in 2013, a study emphasized the critical role of ground stations in the success of CanSat. A new, platform-independent ground station software designed specifically for CanSats was presented. Built using C#, the station offers enhanced reliability and functionality and enabled users to monitor multiple parameters and send control commands simultaneously [11].

Kızılkaya et al. introduced a novel descent control system designed for a CanSat participating in the 2016 International CanSat Competition's Mars Glider theme. Prioritizing simplicity and reliability, the system ensured no interference with the CanSat's electronics. The authors proposed its adaptation for other glider projects and highlight the educational value gleaned through competition participation. The proposed system have earned the Tenderfoot Award at CanSat 2016 [12].

In 2019 Islam et al. proposed a satellite design packed within the limited space for the CanSat competition. Their novel design featured an independent parachute recovery system and successfully accomplished the primary mission of real-time atmospheric parameter sensing (temperature, pressure, altitude) and a secondary mission of image capture for later analysis [13].

In another work, the researchers focused on the design of the container and payload of a CanSat. Polylactic Acid (PLA) carbon fiber was chosen as material with its advantages of lightness and strength. Also, as a novelty, a blade mechanism was integrated into the structure for controlled descent. The achieved results showed that the chosen structure for the container and payload successfully completed the mission. [14].

In another study focused on minimizing satellite structural mass with particularly aluminum honeycomb panels, the authors investigated various configurations to achieve mass reduction. They compared the performance of the novel hexagonal structure formed from honeycomb panels with conventional container designs and the proposed hexagonal design resulted in a significant 15% mass reduction [15].

A more recent study focused on designing a small satellite for the 2021 CanSat Competition. The proposed model satellite was designed to have the capabilities of real satellites, such as real-time telemetry and measurement of environmental data such as temperature, altitude or atmospheric pressure. The design had novelties such as cost-effectiveness and small scale. The model successfully completed the competition missions [16].

In a recent study presented in 2023, researchers aimed to minimize the body weight of a model satellite without sacrificing robustness through an optimization study. Designing the optimization problem to include the calculation of static and dynamic loads acting simultaneously on the model satellite at launch, the researchers achieved a 30% mass reduction in the satellite structure with this novel approach [17].

2. Materials and Methods

The main task of the participating teams in The Teknofest Model Satellite competition is as follows. The model satellite should be designed as two parts: Container and Payload. The model satellite will be lifted to an altitude of 500-700 m and released. After a fall from a height of up to 400 m, the payload and the container will be separated. The payload will send a telemetry packet to the ground station every second from the time it is powered on until it lands on the ground. Additionally, the data will be saved to an SD card on the payload. In addition, data coming to the ground station will be plotted in real time and video images from the payload can be watched simultaneously. The Teknofest Model Satellite Competition consists of the following stages: Plan and Organization Review (POR), Preliminary Design Review (PDR), Critical Design Review (CDR), Qualification Review (QR), Flight Readiness Review (FRR) and Post Flight Review (PFR). This study has met the requirements within the scope of POR, PDR and CDR reports. In the POR phase, the project plan is created, and the team organization is determined. During the PDR phase, preliminary designs were studied and tests to be carried out at the equipment, subsystem and system levels were planned. In the CDR phase, the details of the model satellite design were determined, and the equipment and subsystems were tested.

Under the PDR and CDR stages, initially, the selection of sensors and electronic components for the project was finalized. Subsequently, attention was directed towards the development, and testing of the mechanical subsystem, followed by the study of the landing control system design. The fourth phase entailed the design of the communication and data processing subsystem. Following this, the electrical subsystem was devised in the fifth phase, while the flight software was developed in the sixth phase. Lastly, the ground station interface program was designed to complete the project.

2.1. Electronic component and sensor selection

In this study, the design of an original model communication satellite model was performed. Alongside transmitting essential data such as speed, location, pressure, and temperature, our model satellite design incorporates a live imaging capability, enabling continuous transmission of images to the ground station during operation via an onboard camera. The developed software is geared towards enabling the model satellite to execute targeted tasks by employing algorithms that process sensor-derived data and relay it to the ground station. Data obtained by the model satellite's sensors is relayed to our designed ground station for collection and subsequent analysis. Furthermore, the ground station facilitates real-time tracking of satellite movements, with graphical representations and images of instant tracking data also transmitted to the ground station. The electronic components utilized in this study are given in Table 1.

Table 1. List of electronic components.

Components	Payload	Container
GPS	UBLOX M-8N GPS	-
Temperature	Adafruit BNO055 9-DOF Integrated Circuit	-
Pressure	BMP-280 Pressure Sensor	BMP-280 Pressure Sensor
Autogyro	Adafruit BNO055 9-DOF Integrated Circuit	-
Camera	Arducam Mega 5MP	-
Communication	RFD900X Telemetry	Holybro 3DR Telemetry
Processor	Raspberry Pi Zero	Raspberry Pi Zero
Battery	3s 2000mAh 30C	2s 1250mAh 30C
Antenna	15-50dB gain, 1.5dB noise factor, passive antenna (M8N) 868-900MHz Quarter wave monopole 2.1dBi (RFD900X)	433MHz active antenna, ~5dBi
Subsystem	Arduino SD card module	-
Subsystem	MG90 servomotor	-
Other	Buzzer	Buzzer
Other	Voltage Sensor	Voltage Sensor

After the model satellite gains altitude with a rocket or Unmanned Aerial Vehicle (UAV) and passively descends to an altitude of 400 m (+/- 10) at a speed of 12-14 m/s, the container and the payload on the model satellite are autonomously separated by a mechanism. Then, the telemetry data generated from the sensors in the payload mechanism is transferred to the ground station without interruption, and the determined task is successfully carried out. Data collection and transmission tasks set for the model satellite require high processing power. For this reason, Raspberry Pi Zero was chosen as the microcomputer on which the software will be developed. Single Board Computer (SBC) with ARM11 core provides high performance in data processing with its 1 GHz frequency and 512MB SDRAM hardware. In addition, the computer's communication ports (I2C, SPI, UART), CSI and USB connections for the camera, Mini-HDMI and MicrosSD ports for 1080P60 analog video transfer were preferred. Another feature in choosing the controller is that it has dimensions of 65mm×30mm×5mm. Thus, the controller can be easily placed inside the small satellite model and a compact structure will be created.

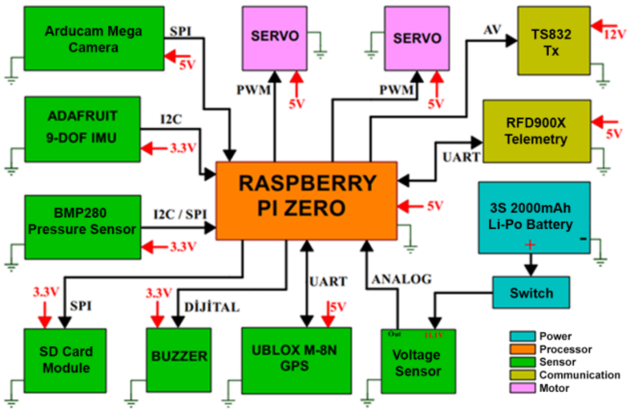

Fig. 1. Block diagram of the payload system.

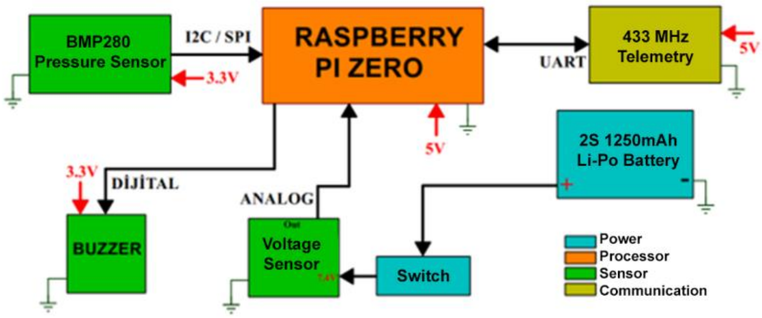

Fig. 2. Block diagram of the container system.

In the payload section, the Arducam Mega camera module was used to transmit the environmental image live to the ground station. The camera, which will be connected to Raspberry Pi Zero via Serial Peripheral Interface (SPI) protocol, can obtain images up to 2592×1944 (UHD) resolution and 30fps. The module, which has a speed of 8MHz, has low power consumption and weight.

For the precise positioning capability of the designed satellite, a 72-channel Ublox GYGPSV1 NEO M-8N GPS module was used. Location control and tracking can be done using GPS with the universal asynchronous receiver-transmitter (UART) protocol, and it is possible to obtain location information with high precision. The module, which has an accuracy range of 2-2.5 m, met the desired requirements in the model satellite project and was easily integrated into the microcontroller, providing comfortable use.

Telemetry was used to transmit data generated from the sensors on the model satellite to the ground station in real time. In this context, RFD900X telemetry module was chosen to use in the payload. The most important factor in choosing the specified telemetry is the ability to transmit up to 40 kilometers with a properly configured system. Transmission can be made uninterruptedly and at high speeds with the transmitter with 1000mW high output power. The module, which sends packet data via MAVLink protocol, is compatible with many RF modules and has open-source software, providing great ease of use. 433MHz YRRC Radio telemetry module is used for the container. Telemetry, which can transmit data up to 5000 m under maximum conditions, communicates with the UART protocol and can be easily integrated into the ground station software. The transmission power of the telemetry transmitter is 1000mW. In addition, the fact that the module is compatible with many RF modules and has open-source software provides great ease of use.

AutoGyro sensor was added to the system to generate the data that the payload will transfer to the ground station with the telemetry module. The sensor, connected via I2C protocol, produces pressure, altitude, altitude difference, descent speed, temperature, roll, pitch and yaw values and transmits them to the ground station via the RFD900X telemetry module. Adafruit BNO055 9-DOF 9-axis model was preferred as the Inertial measurement unit (IMU) Sensor. By using this sensor, absolute position, angular velocity vector, acceleration vector, magnetic field intensity vector, linear acceleration vector, gravity vector and temperature data can be obtained quickly and with high precision. Since the sensor has dimensions of 20 mm×27 mm×4 mm and a mass of 3 g, it is easily integrated into the system.

High accuracy DF-Robot BMP280 digital pressure sensor was preferred to obtain pressure values on the container and payload. In addition to pressure measurement, this sensor can measure temperature with an accuracy of 0.01 ℃ and a range of 0 ℃ - 65 ℃. Working with I2C protocol, the sensor produces pressure data in the range of 300~1100 hPa with ± 1 hPa absolute and ± 0.12 hPa relative accuracy.

When the payload is separated from the container, it is separated by a separation mechanism consisting of 2 servo motors. The preferred MG90S Model servo has a torque of 2 kg/cm and a rotation angle of 180 degrees. Servo motors, with their small size and mass of 13 g, support mass and space optimization.

TS832 Transmitter and RC832 Receiver were used to transfer camera images from the payload to the ground station. The operating distance of this receiver and transmitter, which has a capacity of 48 channels, is 5 kilometers. The TS832 Transmitter has 60mW output power and is compatible with 5.8GHz receivers. All images received via the model satellite can be transmitted uninterruptedly to the ground station via the RC832 Receiver.

A voltage sensor based on the voltage divider principle was used to read the voltage values of the batteries of the container and the payload and send them to the microcontroller. The sensor, connected to the microcontroller via analog ports, supports input voltages in the range of 0-25V. SD card module was used to save sensor data depending on the task load to the SD card. The module was connected to Raspberry Pi Zero via the SPI protocol. The buzzer component was preferred so that the payload and container can be easily found after passive landing.

Lithium Polymer batteries were preferred to provide the necessary power to the system. Leopard-Power 3S 2000mAh 30C capacity batteries were used in the container, and 2S 1250mAh 30C capacity batteries were used in the mission load. The required power calculations for the systems were made in the electrical subsystem design section.

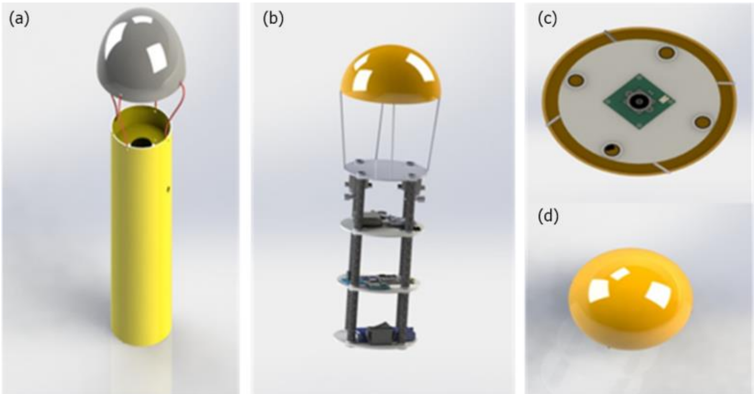

Fig. 3. Render images of (a) the container (b) the payload (c) the bottom view of the payload and (d) the upper view of the payload.

2.2. Development of the mechanical subsystem

The container is produced from PLA material using a 3D printer and coated with glass fiber and polyester. Glass fiber increases the strength and ensures that the container has a rigid structure. Glass fiber does not conduct electricity, thus preventing damage to electronic devices and does not disrupt the transmission of electromagnetic waves (Fig.3).

The electronic equipment housing in the payload was accommodated within circular cross-section plates crafted from PLA material via a 3D printer. These plates were secured together using metric 3 (M-3) bolts and nuts, forming a tight fit connection with carbon fiber pipes. PLA was chosen for the chassis due to its effective vibration damping properties, ease of production, and cost-effectiveness. Carbon fiber pipes were selected for their high strength, rigid structure, and capacity to support stable task execution. Parachute attachment was facilitated through holes drilled on the plate above the payload system (Fig.3).

The separation mechanism, designed for simplicity and optimal performance, ensures stability and cost-effectiveness in fulfilling its designated function. The separation mechanism works by rotating the drive shaft 180º, that is, half a turn, by means of two servo motors. Thus, the circular shaft retracts and separates from the holes in the container mechanism, causing the duty load to fall in free fall (Fig.4). The parachute on the free-falling payload opens because of the air currents that occur during the fall, and a healthy passive landing is achieved. The parachute was stacked neatly on the container and the parachute ropes were connected through the holes drilled on the container cylinder. The container has a length of 300 mm, an outer diameter of 113 mm and an inner diameter of 108 mm. For the separation mechanism, holes with a diameter of 8.5 mm were drilled on both sides.

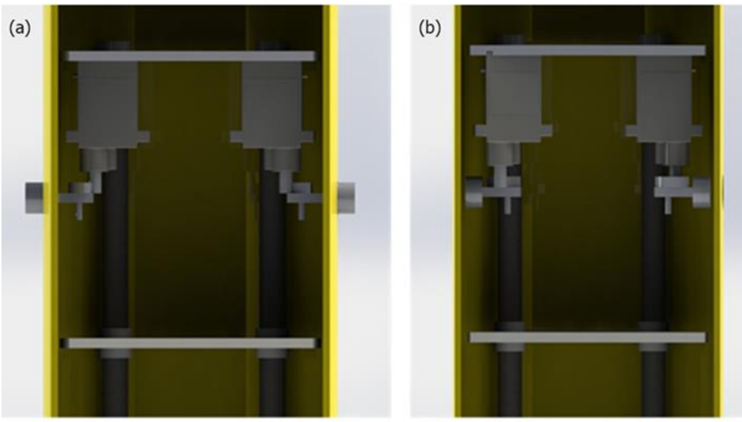

Fig. 4. Render images showing (a) the engagement and (b) the separation states of the separation mechanism.

Table 2. Mass budget of the payload and the container.

Section	Components	Mass (g)	Source of Information
Payload	Payload plates	82	Application Result
	Payload carbon fiber pipes	14	Application Result
	Separation mechanism	12	Application Result
	Servo motor x 2	13x2	Datasheet
	Raspberry Pi Zero	9	Datasheet
	Arducam mega camera	15	Datasheet

	Adafruit BNO055	5	Datasheet
	UBLOX M-8N GPS	17	Datasheet
	Voltage sensor	1	Datasheet
	RFD900X telemetry	16	Datasheet
	Buzzer	3	Datasheet
	SD card module	5	Datasheet
	TS832 transmitter	14	Datasheet
	3S 2000mAh Li-Po battery	126	Datasheet
	Power distribution card	12	Datasheet
	Power control switch	20	Datasheet
	Total Mass:	**379 g**	
Container	Container load	241	Application Result
	STM32F4 BlackPill	9	Datasheet
	BMP280 pressure sensor	2	Datasheet
	Voltage sensor	1	Datasheet
	Holybro 3DR Telemetry	10	Datasheet
	Buzzer	3	Datasheet
	2S 1250mAh Li-Po Battery	58	Datasheet
	Power distribution card	12	Datasheet
	Power control switch	20	Datasheet
	Total Mass:	**356 g**	

In the mechanical subsystem design studies, the mass budget of the container and payload was also calculated. A mass budget was created by calculating the datasheet data of the equipment to be used in the design and the material masses of the body designs. As a result of the designs and optimization studies, the total mass of the container and payload was found to be 735 g (Table 2). The total mass of the designed model satellite met the requirements of the competition which is 730 g +/- 20 g.

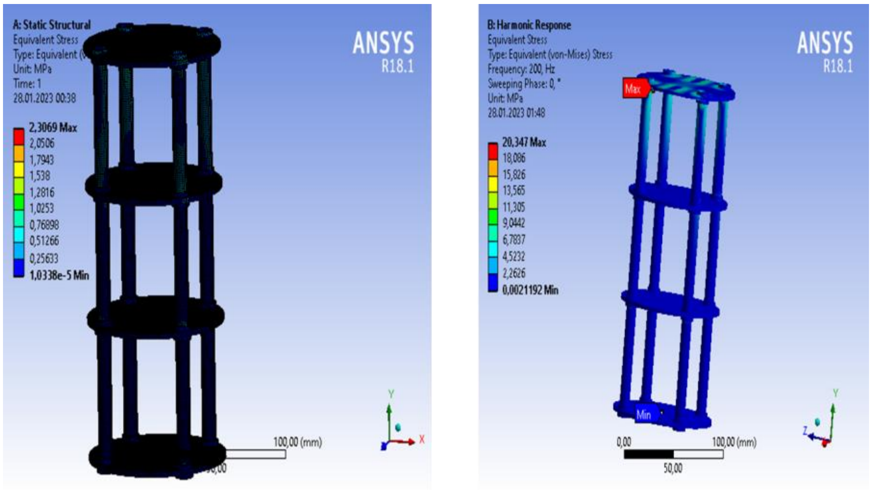

Fig.5. Static and Modal (Vibration) Analysis with Ansys Workbench.

Before production, the system that was designed underwent static, modal, and harmonic response analyses using a CAE program. The analysis was performed on the Ansys Workbench program (Fig.5). This allowed for the identification of potential mechanical and structural issues before production, enabling revisions to the design. In the analysis phase, attention was paid to meshing processes and was checked based on element quality and skewness values. Boundary conditions were accurately defined to reduce the margin of error in the analysis. The analysis concluded that no deformation would occur in the material. To ensure the robustness of our design, we analysed mechanical performance using Ansys software. This analysis focused on also withstanding an 8G force. Ansys software analysis verified that the mechanical design meets the key requirement of withstanding 8G forces.

2.3. Landing control system design

During the design phase of the landing control system, separate parachute dimension calculations were conducted for both the payload and the container, based on the mass specifications established in the mechanical subsystem design phase. Parachute surface area was calculated according to Eq. 1:

$$Sp = \frac{2 \times m \times g}{v^2 \times \rho \times Cd} \tag{1}$$

In the equation, *Sp* denotes the surface area, *m* represents the total mass, *g* signifies the gravitational acceleration (9.81 m/s^2), *v* denotes the speed, *ρ* represents the air pressure (1.225 kg/m^3), and *Cd* symbolizes the drag coefficient (0.5). This equation is used to ensure that the parachute descends slowly to the ground and minimizes damage to the rocket. It provides the balance between the weight of the rocket and the drag force [18]. The diameter of the parachute represents the area within this equation, and a circular parachute is generally considered. With calculated total masses of 735 g and 356 g, and the expected speeds of 13 m/s^2 and 7 m/s^2, the corresponding parachute surface areas were determined as 0.1364 m² and 0.2183 m², respectively, for the total system and the payload separately.

2.4. Communication and data processing subsystem

The RFD900X telemetry module in the payload is equipped with an 868-900MHz Quarter Wave Monopole antenna. We opted for a single antenna to minimize mass and ensure reliable communication. However, the system supports the use of two antennas if needed. The antenna, featuring a Reverse Polarity SubMiniature version A (RP-SMA) connection, has a signal gain of 2.1dBi, enabling transmission distances of up to 40 km under optimal conditions. In comparison, the Holybro Telemetry antenna has a transmission distance of 3-4 km under similar conditions.

We also conducted comparisons between dipole and monopole antennas for telemetry. The monopole antenna, covering half the area of the dipole antenna, boasts nearly twice the gain (5.2 dBi). However, it has a radiation resistance of 36.5Ω, half that of the dipole antenna. Following these comparisons, we determined that the Quarter Wave Monopole antenna best ensures continuous and robust communication, which is critical for our application.

All the data that is carried on a telemetry packet is shown at Table 3.

Table 3. Telemetry packet format and its description.

Veri Formatı	**Data Example**	**Description**
<PACKET_NUMBER>	<2>	Number of each telemetry packet
<SATELLITE_STATUS>	<4>	A numerical value that shows the state of the model satellite at the time of mission. (0-7)
<ERROR_CODE>	<0>	The telemetry data of possible errors that may occur. (0-5)
<TIME>	<12:43:26>	Real time clock data. (Hour:Minute:Second)
<PRESSURE1>	<1079.2>	Pressure data from the payload (pascal)
<PRESSURE2>	<1032.3>	Pressure data from the container (pascal)
<HEIGHT1>	<320>	The height of the payload above the ground. (m)
<HEIGHT2>	<125>	The height of the container above the ground. (m)
<HEIGHT_DIFF>	<195>	Difference between HEIGHT1 and HEIGHT2 (m)
<LANDING_SPEED>	<6>	Landing speed daya (m/s)
<TEMPERATURE>	<23>	Temperature data from the payload (°C)
<BATTERY_VOLTAGE>	<10.65>	Voltage value of the battery (V)
<GPS1_LATITUDE>	<39.48137>	The latitude of the payload.
<GPS1_LONGITUDE>	<29.89837>	The longitude of the payload.
<GPS1_ALTITUDE>	<324>	The altitude data of the payload taken from GPS.
<GPS2_LATITUDE>	<39.48695>	The latitude of the container.
<GPS2_LONGITUDE>	<29.89529>	The longitude of the container.
<GPS2_ALTITUDE>	<129>	The altitude data of the container taken from GPS.
<PITCH>	<80>	The angle of inclination of the payload on the pitch axis. (°)
<ROLL>	<45>	The angle of inclination of the payload on the roll axis. (°)
<YAW>	<60>	The angle of inclination of the payload on the yaw axis. (°)
<TEAM_NUM>	<211334>	Model satellite competition team number

2.5. Electrical subsystem design

During the electrical subsystem design phase, our primary objective was to establish a power budget. This budget was formulated by analyzing the power requirements of the components installed on both the container and the payload. Subsequently, the selection of batteries to power the entire system was carefully determined.

Table 4. Power budget of the payload and the container.

Section	Components	Voltage (V)	Peak Current (mA)	Max. Power (W)	Min. Power (W)	Tolerance (W)	Mission time (s)
Payload	BMP280 press. sens.	1.7 – 3.6	1.12	0.0041	0.0192	0.0021	132
	Adafruit BNO055	3.3 – 5	50	0.25	0.165	0.085	132
	UBLOX M-8N GPS	3.3 – 5	23	0.115	0.0759	0.0391	132
	Voltage sensor	3	1.12	2.13	-	-	132
	RFD900X telemetry	5	1000	5	2.8	1.6	132
	Raspberry pi zero	5V	1000	5	5	-	132
	Servo motor	4.8 – 6.2	400	2.4	0.096	0.024	10
	SD card module	3.3 – 5	200	1	0.0165	0.0085	132
	Arducam mega cam.	3.3 – 5	154	0.77	0.66	0.34	132
	TS832 transmitter	12	200	2.4	-	-	132
	Buzzer	3.3	20	0.066	-	-	30
	Total Power:			**19.135 W**			
Container	Raspberry pi zero	5V	1000	5	5	-	132
	Voltage sensor	3	1.12	2.13	-	-	132
	BMP280 press. sens.	1.7 – 3.6	1.12	0.0041	0.0192	0.0021	132
	Voltage sensor	3	1.12	2.13	-	-	132
	Holybro 3DR Telemetry	3.3 – 5	100	0.5	0.33	0.17	132
	Buzzer	3.3	20	0.066	-	-	30
	Total Power:			**7.700 W**			

As a result of the calculations, the maximum power required for the payload was determined to be 19.135W. To power the payload system for 1 hour, the battery capacity was calculated as $(19.135W/11.1V) \times 1h = 1.724\ Ah$. Consequently, a 2000mAh 30C Li-Po battery was selected, which met the calculated requirements.

The power required for the container is calculated as 7.700 W. To power the system for 1 hour, the battery capacity is calculated as $(7.700W/7.4V) \times 1h = 1.04\ Ah$ For the container, we decided to use a 1250mAh 30C Li-Po battery, which can meet the calculated requirements.

2.6. The flight software

The flow diagram of the flight software for the model satellite is illustrated in the Fig.6. The flight control software was developed using the C language in both Visual Studio and Arduino IDE environments. Upon receiving the "System calibration" command from the ground station, the software initiates a series of tasks: it resets the sensors, sets the reference altitude to zero, resets the inclination angles, and calibrates the system. The software then proceeds to collect camera images and telemetry data from the model satellite's sensors, saving this information to the onboard SD card. Concurrently, all collected data is transmitted in real-time to the ground station.

After completing its readiness checks, the model satellite is launched via rocket and released at an altitude of 500-700 meters. The payload is separated from the container by a designated mechanism at an altitude of 400 meters (±10 meters). As an additional communication performance test, a 500 kByte video packet is transmitted from the ground station to the model satellite and stored on the SD card. Subsequently, the same video packet is transmitted from the model satellite to another ground station computer. Upon successful landing, the data transmission continues for an additional 10 seconds, during which the buzzer is activated.

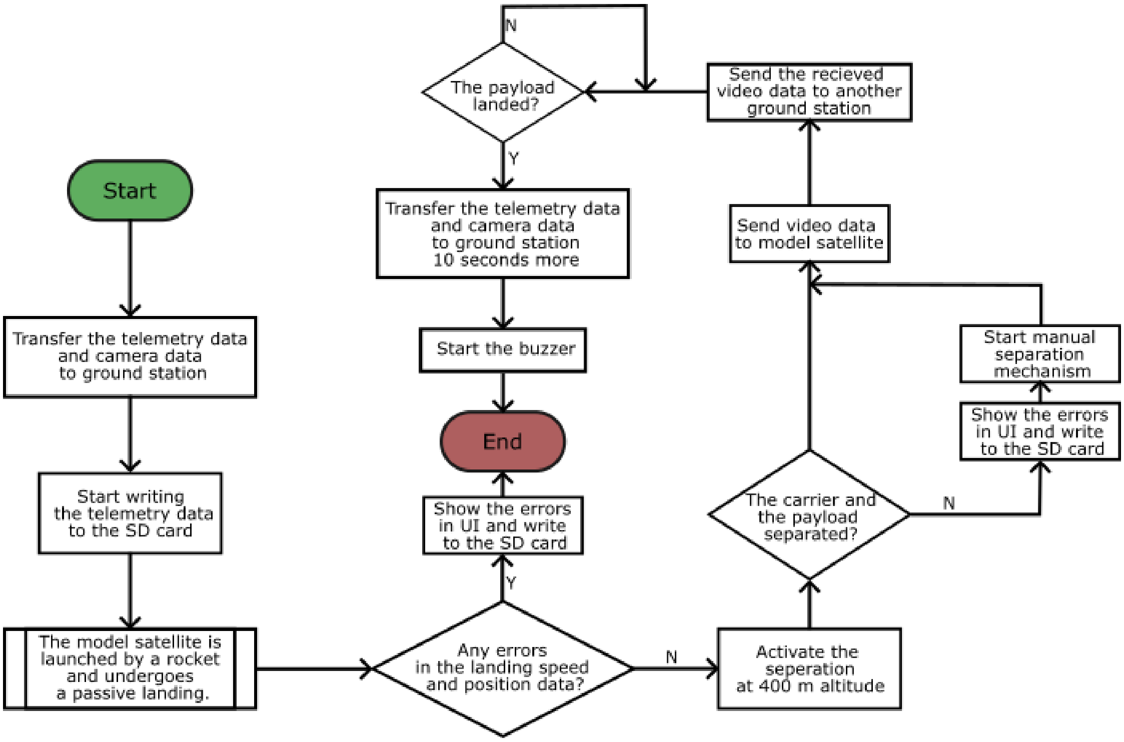

Fig. 6. The flow diagram of the flight software.

2.7. The ground station user interface

A user interface program was developed in C# using the .NET platform and Visual Studio Code environment. This interface allows manual control and tracking of the model satellite from the ground station when necessary, and it visualizes the data sent from the model satellite. Figure 7 illustrates a screenshot from this interface program.

The interface enables users to issue Start, Stop, and Calibration commands for the model satellite mission. Additionally, in the event of an error in the automatic separation mechanism, a manual separation command can be issued. Real-time data from the sensors onboard the model satellite is visualized within the interface, providing users with immediate insights. Moreover, the interface allows users to view camera images transmitted by the model satellite.

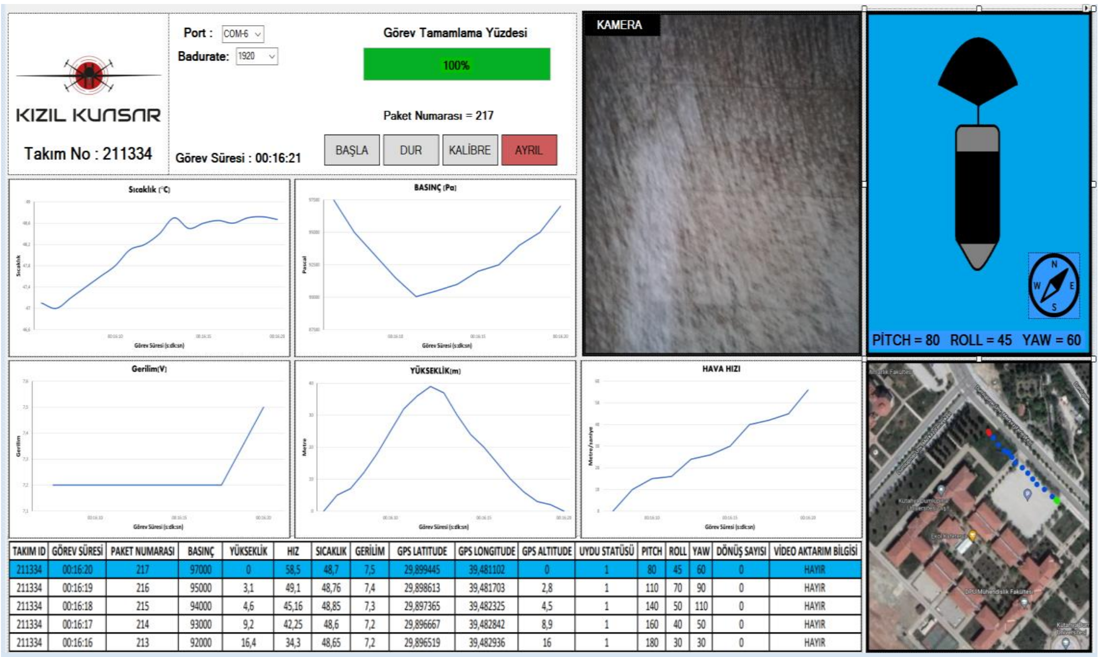

Fig. 7. The user interface of the ground station.

3. Results and Discussion

This study focused on the design and development of a model communication satellite with an autonomously separable mission mechanism for the Teknofest Model Satellite Competition 2023. The project prioritized originality, efficiency, and reliability, resulting in a satellite equipped with reliable software and suitable mechanical and electronic components with the Teknofest Model Satellite Competition requirements. The emphasis on mobility and simplicity ensured ease of transportation and deployment.

The development process followed a structured approach determined by the competition committee, from the initial hardware and mechanical design to the subsequent software integration and testing phases. In the PDR phase, the first designs were carried out by determining and selecting the electronic components. The design of electronic subsystems and the design steps of the mechanical body and subsystems were carried out at the CDR stage. Mechanical and electronic designs were made considering the requirements determined by the Teknofest competition committee. The mechanical performance and durability simulations of the subsystems were carried out using Ansys software and it was observed that the design met the critical requirements. A parachute design was prepared to control the landing of the subsystems of the design. The design of the communication module was also carried out in accordance with the telemetry package format determined to meet the competition requirements. The flight control software was developed in both Visual Studio and Arduino IDE environments using C language. Finally, the ground station interface programme was designed in C# using the .NET platform and Visual Studio Code environment. The first three phases of the competition were thus successfully completed, but the flight phase could not be started due to difficulties in meeting the deadlines.

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