A new framework for design and development imaginary CanSat

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Abstract

In this paper, structure of IDAS CanSat that has been designed, constructed and tested in IUST, is presented. This paper includes a description of CanSat mission, design of mechanical subsystem, electronic circuits, and also an analysis of performance algorithms. One of the special features of IDAS is its very light weight in comparison with other congeners. This feature leads to a relatively complex design for mechanical subsystems including structure, reaction wheel and parachute. A Combination of freewheeling and balls and bowl ideas has been used to connect the parachute to the CanSat structure. This joint keeps the CanSat movement perpendicular to the ground. The parachute has been designed for high safety margin (in weight and speed), to satisfy the expectations of stability along with the reaction wheel. With the stability resulted, imaging was done without any mechanical disturbances and with high quality. In the electronic subsystem, we have used an ARM microcontroller to control the camera. Camera's data, due to their high volume, were stored on SD card and sent to ground station if necessary. As the microcontroller operates in high clock frequency, it offers CanSat complex and varied operationally such as release detection and data handling. Release detection algorithm is sensitive to CanSat acceleration. This is a new approach and reduces the probability of faulty detection. After release, CanSat tries to achieve its goal and take pictures from ground while reading, storing and sending the sensors data to the ground station. To verify these functions, we implemented several tests and experiments.

Keywords: *CanSat - Imaging Mission - Reaction Wheel - Stability*

Introduction

Constructing a CanSat is based on a modern educational approach, to simulate satellite missions, by designing, constructing, testing and launching an ultra-small system [1]. This concept is used for training students in several branches such as aerospace and atmospheric sciences, aerodynamics, thermal management, system control, electronics design, programming and communication systems [2][3]. Such usages benefit from miniaturization and force electronics industry to design and develop advanced general purpose and low cost chips like microcontrollers, sensors and actuators. Miniaturization has direct relation to complexity of CanSat systems [4]; this project also helps to introduce applied research the educational process [5]. As designing and constructing a Cube-Sat and placing it in the orbit is an expensive and time consuming process, by expanding the CanSat field, we can achieve results in cheaper and less time-consuming processes. A year after professor Robert J. Twiggs offered it in Stanford university in 1998[6], a group of Japanese and American students, made their CanSat and launched it [7].

In this project, constructing a CanSat which can fit in a cylindrical package with a diameter of 66mm and height of 115mm is investigated. Maximum acceptable weight for this CanSat was 350gr. This CanSat contains subsystems such as command and data handling[1], stabilization, structure, communication [13], power and retrieval. C&DH subsystem receives data from the sensors and camera while storing and sending them to the communication subsystem throughout the mission by an ARM microcontroller. Besides, the system will be stabled by reaction wheel, during the mission. Stability subsystem not only uses a reaction wheel, but also benefits from a parachute with semispherical shape and freewheeling joints for better stability. System structure is shaped as a rectangular cube and its components are mounted on stratum and are slides, so that they can be changed easily. Retrieval subsystem consists of two components –parachute and buzzer- for safe landing and recovering, respectively that help CanSat to complete its mission. In the imaging mission, CanSat is released from 500 meters above ground and should take images from land along the path. In addition, during flight time, CanSat should record and send environmental data like temperature, air pressure, accelerometer, gyroscope data etc. Pictures should be taken perpendicular to ground, without any mechanical disturbances and with high quality. Other advantages of IDAS CanSat are the use of IMU, special joint of parachute, sliding stratums, small dimensions and ultra-light weight in comparison with other congeners. It should be mentioned that power needed for CanSat is supplied by a Li-polymer battery. Besides, data are stored on a SD card and communicated to ground station. In this paper, we study the mission, mechanics of the system, electronics circuits, operation algorithm and ground station design, respectively.

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[1] C&DH

A brief on mission

IDAS CanSat is launched with a balloon to 500 meter height. After release, CanSat is activated from standby mode by autonomous algorithms. In the standby mode, all modules are turned off except release detector, but in active mode, all modules are active and data is read and stored on SD card. Along the path, IDAS should take pictures from ground and send them with other necessary information to ground station. Besides, after landing, buzzer can ease the retrieval.

Mechanical design

Mechanical design of CanSat consists of three parts: structure, parachute and Reaction wheel. Structure, made of multi_style plate (2mm thickness) in dimensions of 111*35*49 mm and with the sum of parachute and foam cover, exceeds 195gr and 52*40 mm. In comparison with the weight limitation in this class (maximum 350gr), the 155gr weight margin is brilliant.

One special features of our CanSat, as shown in Figure 3, is the use of slides for stratums, so that electronics circuits are accessible and also, length of CanSat can be decreased notably.

Parachute, is another important part of mechanical design that causes proper landing speed and safe landing in addition to protecting electronics components and structure. Besides, landing speed and damping disturbances helps to improve imaging quality. This goal can be achieved by Reaction wheel and parachute with proper dimensions.

To calculate minimum parachute radius, we use formula eq.1.

$$r = \sqrt{\frac{2mg}{\pi C_D \rho V^2}} \qquad (1)$$

By replacing parameters with following values, proper radius can be obtained: (parameters are considered for worst case)

m: CanSat mass: 350gr

g: gravity acceleration: 9.81 m/s^2

C_D: drag coefficient for sphere: 1.5 [9]

V^2: speed by power of two in the landing moment: 25 m/s

ρ: air density: 1.147 kg/m^3

So we have:

$$R = 0.25 \text{ m} \qquad (2)$$

In this system, as shown in Figure 6, freewheeling has been used to connect the parachute to structure, to increase stability.

One of the solutions to create the required stability is the use of Reaction wheel. This component is a disk with relatively high inertia which rotates by an electric motor with nearly constant speed. As external inertias (air resistance, etc.) cause instability of CanSat, the rotating Reaction wheel neutralizes these effects and results in higher quality pictures. Thus, rotating a Reaction wheel by an electric motor with high speed can enhances the overall stability. This is done with rotating in opposite direction of CanSat rotation.

$$h_{total} = I_{satellite}\,\omega_{satellite} + \sum I_{wheel}\,\omega_{wheel} \qquad (3)$$

CanSat has more inertia and less angular speed in comparison to the wheel. As we know, angular momentum is the product of inertia and angular speed; thus we can reach equilibrium state between angular momentum of CanSat and Reaction wheel. So, we can prevent CanSat disturbances along x and y axis. This is shown in eq.3.

In IDAS CanSat, we have used a joint of coin like plate and an electrical motor to construct the wheel. It should be mentioned that as the inertia of the wheel increases, speed decreases. But, considering the limitations, we used a disk with a weight of 7.2gr and radius of 25mm.

Processor

Processor was chosen from among 32-bit microcontrollers; Controller used is ARM series, Cortex M4, STM32F407VGT6 [12] and by using a Phase Locked Loop (PLL), can get to 168MHz clock speed. This microcontroller has a complete set of communication protocols such as I^2C, SPI, SDIO, USART, etc. The mentioned protocols have been used in the CanSat. We used C++ programming language and Keil IDE to program microcontroller.

Camera

Camera is an important component for CanSat's mission. So, for reliable and acceptable performance, we choose a camera module (Zm-serial-camera) with serial output and baud rate of 115200 bps. We have used a MAX-232 interface for logic levels matching between camera and microcontroller.

This camera takes pictures with 96dpi resolution and various aspect ratios in JPEG format. Aspect ratio that we have chosen by default is 640 x 480 pixels that equals to 0.3 Megapixels. In Figure 8 you can see a sample picture taken by the camera.

Locating, connecting and routing

In the CanSat construction process, according to its special features, electronic components have been too much intertwined and circuits are very integrated. PCBs have been designed in four stratums; three of which are above the Reaction wheel and one of them is at the lowest point. All three upper stratums have been designed totally modular; to be easily mounted and demounted by connectors. In the first upper stratum, microcontroller and its related components are located. At the next stratum, SD card holder and camera initiator circuit are located. The third stratum contains power distribution circuits, pressure sensor, accelerometer, gyroscope and temperature sensors. The last stratum includes buzzer and camera. It should be mentioned that because of the lack of space, communication module has been placed diagonal through the stratums.

Operation Algorithm

As our CanSat should perform a complex and accurate mission, thus, making a regular and ordered operational algorithm with accurate time sequences and events is vital. Since CanSat will be turned on during flight, the first step in this algorithm is to perform some health monitoring routines for each part. So, after turning on the CanSat and all the modules, the accuracy and performance will be tested and reported to ground station. After that, CanSat stops till the occurrence of release event, detected by an accelerometer. In this part, we had several choices such as air pressure differential; if the air pressure increases for some consecutive moments, it means that the height decreases; thus we can deduce the release event occurrence. But this routine is not accurate and reliable. Chance of faulty detecting is one of these problems; Because of atmospheric phenomena, air pressure can change suddenly by some Pascal's. In this case, release may be detected wrongly. On the other hand, for detecting the increase in air pressure (as a result of decrease in height) pressure data should be read for several consecutive moments, which means some vital moments after the release will be lost. Besides, a few meters decrease in height (by system disturbances) that is not necessarily made by gravity acceleration, will be detected as release. Due to these points, reading CanSat acceleration and comparing it with gravity acceleration, is an accurate and reliable approach. Then, neither atmospheric phenomena nor disturbances with acceleration less than that of gravity, affect the measurement. In addition, as measuring gravity acceleration is not necessary for consecutive moments; vital post-release moments are accessible to the mission.

After the release and detection by accelerometer, all events will occur with timed sequences. Control of sequences is done by a built-in RTC in microcontroller. After the release, RTC starts working and then, the time from release, accelerometer and pressure sensors data are sent to ground station and saved on a SD card. Also, after the release, for a period of few seconds (i.e. 5 seconds) an image is taken by the camera.

This procedure continues till CanSat detects the 100 meters altitude above the ground; after a while (for example 2 minutes, counted by RTC), CanSat stops reading sensors data.

Sending and storing data is performed as follows: whole data is stored on an SD card while sending to ground station. Besides, this procedure is implemented flexibly due to bandwidth and data refreshing limitations: Camera's data assigns most part of the bandwidth and so most part of the time to themselves; if camera takes a picture with low quality (and low volume) the data is sent to ground station synchronously while storing on SD card; but if the picture has high volume (and high quality) these data are stored on SD only to be recovered later and the bandwidth will be saved for other data.

Another capability of IDAS CanSat is recording and sending all events such as turning on or off different modules, performance of actuators, accelerations, etc. while receiving them in ground station. In addition to being stored on the SD card, these data are sent to ground station. This feature makes it possible to implement a hardware-in-the loop simulator which can simulate CanSat condition synchronously according to the data received. The full algorithm is also shown in Figure 2.

Ground station

Ground station software is designed to receive data and display them online in a user friendly environment. Graphical User Interface (GUI) of ground station has a multilayer design; it means that GUI can display information in numerical form on main part of software and synchronously store data necessary for plotting them. Thus, by choosing one or more of plots, the next layer of software activates and plots show information from beginning of mission till now. These layers report information and CanSat status synchronously.

Designed software has a data management system and to prevent filling up memory in long time missions, omits plots information without omitting plot. In addition, at offline layer, software stores data every second in a text file. Storing data takes place in such a way that in every frame, data are stored in a text file and the file will be closed. This feature causes the text files to be accessible at any time during mission. Besides, it reduces the probability of data being deleted, in case of errors, to zero.

As the lengths of frames sent by CanSat vary during the mission (because of different reload time of sensors and existing picture data in some frames) different volumes of data will be sent to ground station in different rates. Thus, to prevent data loss, for frames which arrive sooner than expected, and due to sending data to software in a fixed time period, ground station board stores data on a SD card first, and sends them to computer then. In this way, receiving data, takes place more reliably.

For receiving and displaying data in software, opcodes are assigned to each command or data. Software has designed as such that if any of these opcodes is changed by reasons like noise, rest of data can be recognized, recovered and displayed. This method, divides each frame of data to separate parts due to noise robustness; for example, to demonstrate pressure, we use format like this:

preXX,\n\r

In this case, "pre" is opcode for pressure, XX is data read from sensor and three characters ',' , '\n' , '\r' indicates end of pressure information.

Now if disturbance causes error in transferring data, and "pae" is received instead of "pre", for example, as this opcode is unknown, the software ignores data stream till finishing characters (i.e. ',' , '\n' , '\r') are received. In this way, software doesn't get error and further data are accessible and can be processed.

GUI, as shown in Figure 1, not only displays information and data, but also demonstrates CanSat condition continuously. This information contains system kernel activation status, communication system, etc. Indicating CanSat condition performed by lighting up of green bulbs for each subsystem. In another part of software, information from various sensors is displayed, including: accelerometer, gyroscope, barometer, temperature sensor data and the time from release. This part of software is called online information. At the next part, with choosing one or more graphs, sensors information (from start time of mission till now) is displayed in a real-time and graphical environment. It should be mentioned that the picture of software environment was taken when only some of the sensors were activated.

GUI software is designed in a way that if any error occurs, it restarts without any error message or data loss, and will be ready for receiving data.

Data receiving board

Data receiving board is the interface between receiver antenna and GUI software. This board is responsible for establishing a continuous errorless data stream between the antenna and computer. Received data from CanSat are stored on a SD card first and sent to computer gradually.

Tests and assessments

Nature of IDAS CanSat design (especially after concept and preliminary design phases) requires continuous assessment and several tests in various aspects and finally, monolithic tests; Because, in addition to theoretical information, using new concepts must be verified; Thus, for the CanSat, three levels of tests (with preset timing) for the whole system and several modular tests were considered. Parachute test (15 and 12 meters from ground), structure strength and parachute joints (22, 15 and 12 meters from ground), hardware test (flat test), communication module range test (500 meter distance), radio communication with ground station, whole system structural strength, parachute performance, Reaction wheel performance and stability (release from Milad tower and Tehran Azadi tower) are some of the tests done during constructing the CanSat. Last and final test was done during the “4th Iran CanSat competition” and IDAS CanSat achieved the 1st rank in its category. There is pictures of the tests in Figure 7.

Conclusion

What was mentioned above was the most important features of IDAS CanSat. As mentioned, during construction phase, several and various tests were executed. In fact, design and construction of this CanSat introduce a new design framework; Means reduction, fast computing and more stabilized structure are the important features of this framework.

Figure 1 : Ground station graphical user interface software

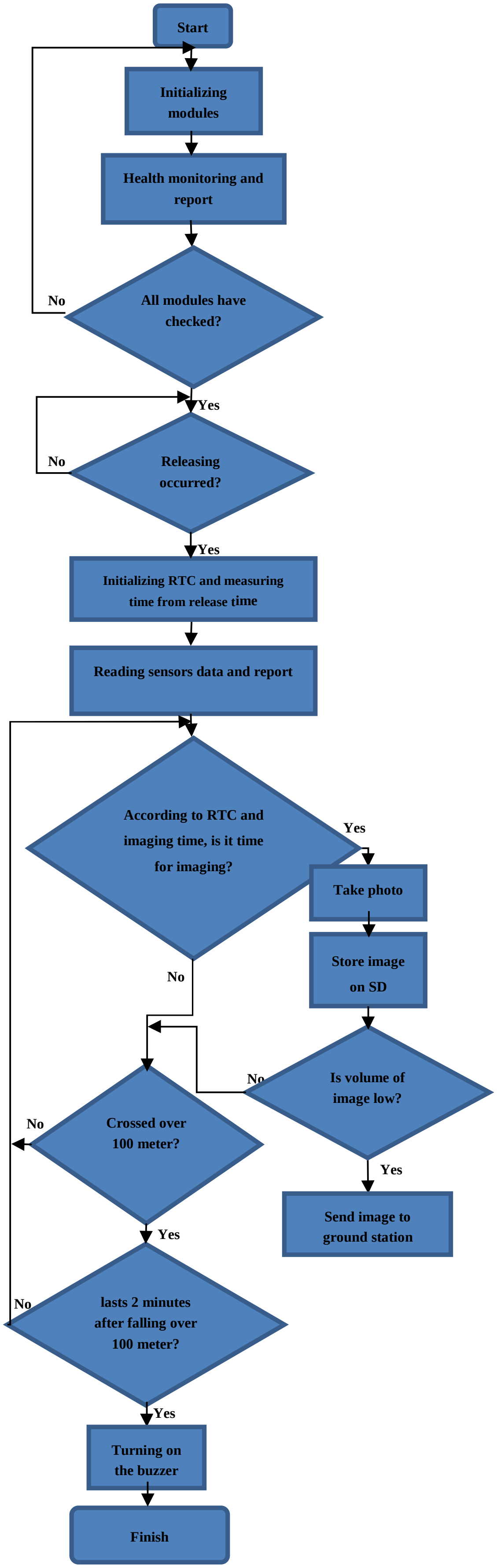

Figure 2 : Operation algorithm flowchart

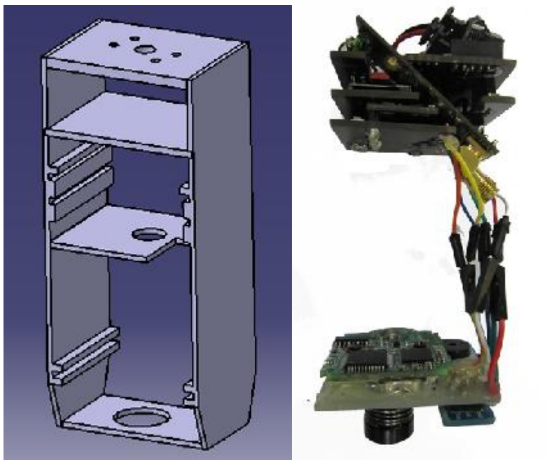

Figure 3 : Electrical Connection’s (Right) Structural Outline (Left)

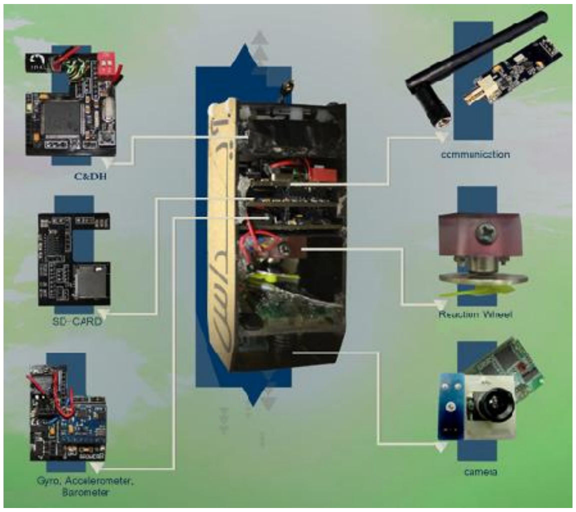

Figure 4 : CanSat layout structure with components

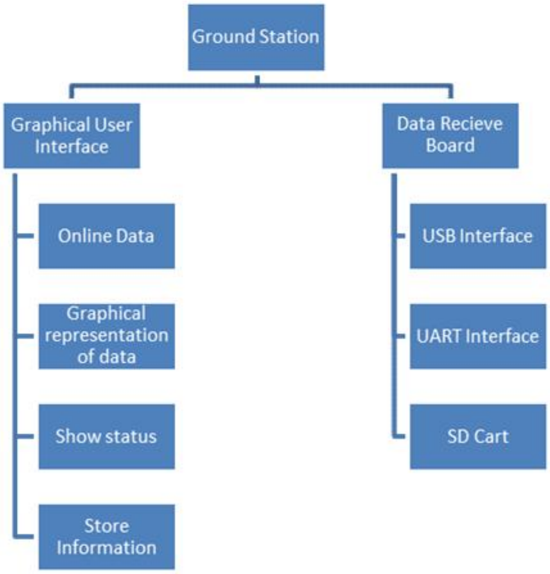

Figure 5 : Ground Station Diagram

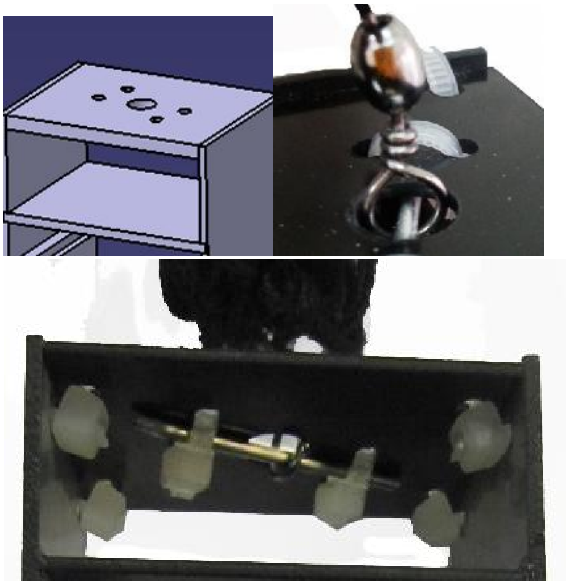

Figure 6 : Parachute joint to main body with freewheel. Top view (upper right). Designed with CATIA (upper left). Bottom view (bottom).

Figure 7 : CanSat testing in, a) Karaj airport (upper right), b) Tehran Milad Tower (upper left), c) Stability of IDAS CanSat (bottom)

Figure 8 : an image captured by CanSat

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