Development of an Arduino Based Picosatellite-OBC

Umesh Shinde[1], Mr. Rohit Bokade[2], Ms. Supriya Bhide[3], Prof. Harsh Bhor[4]

K. J. Somaiya Institute of Engineering and Information Technology, Sion, Mumbai-400022

Abstract

Development of NanoSatellites has begun with the rise of miniaturisation of electronics. With the advent of small satellites, performing experiments in space has become more feasible and easier. The small size makes it possible to launch multiple satellites in a go. It also results in less utilisation of resources, thus making it feasible for researchers to send small experiments over these satellites, owing to the reduced costs of satellite development. The small size does introduce constraints and challenges like adequate power generation due to reduced surface area, motion control due to small size which makes the process of dampening the rotations slower, fitting experiments in the small volume, among few others. The satellite design standard proposed by us, aims to take care of all the posed challenges and constraints with a robust design, while ensuring feasibility of the same in terms of economic support and easy availability of equipments and facilities.

I. INTRODUCTION

Prof. Bob Twiggs introduced the concept of pocketqubes in 2009[11]. With the rise of miniaturization of electronics, there has been a boom in the development of small-satellites. Several universities and organizations have started developing their own nano-satellite initiatives around the world. In most of the cases, the development is concentrated around one of the major nano-satellite standards, viz:- a)CubeSats, b)PocketQubes, c)TubeSats. Although the development in this field has an exponential growth, the given pace is not well distributed over different demographics. The reason for this is closed source development of such projects, costly development and non-availability of several technical facilities and parts in certain geographies. It aims to develop an open- source, extensible, flexible and robust nano-satellite bus which could lead to easier and faster development of such nano- satellite initiatives.

1.1 Nano-satellite bus:- A nano-satellite mission is basically developed by connecting the experiments of equipments that a given project team wants to launch and use in space to a proper "Bus" or a combination of circuits which provide all the essential resources required to operate the experiment. General components that are part of a bus are as follows:-

1.1.1 Command and data handling (CDH) system- This includes the main controller which controls all the functionalities of the system and reacts to different command issued to it in a proper manner to bring about a desired task.This includes use of a microcontroller and a specially designed firmware for it to operate combined with the proper peripheral interface development to give it an access to different peripherals onboard.

1.1.2. Communication and telemetry - This sub-system includes the transceivers, antennas and different rf signal conditioning systems for enabling the uplink and downlink of data to and from the space module with a ground station. This sub-system is desired to do the signal conditioning and filtering of data and provide it to CDH over a specified data bus. It is also required to collect health parameters of different sub-systems onboard either through CDH or directly and communicate with them periodically to the ground receivers.

1.1.3. Attitude determination and control-As per the pointing accuracy requirement posed by antennas as well as the on-board payloads, the space module needs to align itself with respect to the surface of earth's sub-point i.e. the point just below the geodetic coordinates of the space-module.

1.1.4. Power management-This system essentially is the heart of the entire bus as it provides the required electrical power to different subsystems and components of the bus. As the space module is a remotely operated device, the power management system is essential for generating and conditioning the power from sources like solar panels or thermoelectric generators. The power management system is also tasked to ensure that a given equipment is powered with properly regulated power while tracking the maximum power point of the source at the same time with dynamic loads and changing source voltage as per position of the space-module inan orbit.

1.1.5. Structures and thermal subsystem- Low earth orbit being a very harsh environment where the system needs to face rapid increase and decrease in temperature forming a cycle of +120 degrees to -40 degrees in a period of 90-100 minutes, while also dealing with an excessive amount of radiation and ionizing particles travelling with very high momentum, it becomes essential the given system and experiment id enclosed in a robust structure, which not only protects it from the impacts and radiation, but also acts as an insulator toprotect the rapid change in temperature. Structure subsystemalso needs to take care of antenna and panel deployments along with development of structure for dissipating extra heat from the system to protect it from overheating. It also accounts for other auxiliary structures such as deployment-switches and remove before flight pins.

II. RESEARCH BACKGROUND

In recent times Pocketqube standard has emerged as a new go-to standard for educational and technology demonstration missions due to more than 6x reduction in volume and 4x reduction in launch mass. Increasing miniaturization inelectronics and the development of more efficient photovoltaiccells has created an opportunity to extend the usage for even commercial purposes e.g. NOOR-1A and NOOR-1B pocketqubes developed by Stara Space recently launched by Albaorbitals, have demonstrated the capabilities of pocketqubes as a part of a commercial Earth-Observation flock. Although there have been several independent pocketqube missions in recent times e.g. FossaSat-1, Alt-1, Smog-p, TRSISat etc., when it comes to the deployment provision for all of these, they are mostly dependent on Albapods by Abla-orbitals. There are other players like LibreSpace foundation with their pico-bus are slowly coming up as alternatives for deployers, but their high cost and high mass(making launch cost higher) still make them an infeasibleoption for low budget missions. A lot of commercial off the shelf CDH buses, comm. modules, structures are available in the market for suppliers like ISI-Space, GOM-Space, Pocketqubeshop etc., however, these CDH, Power management and comms. Modules are either too expensive or too complex with a huge learning curve for educational or other low budget missions. The biggest hurdle in making space-tech accessible to students or small businesses apartfrom the cost is restrictions, regulations and rare availability ofSpace grade materials and components or technologies involved in developing a satellite.

III.LEGAL GUIDELINES AND DEBRIS MANAGEMENT

Pocketqubes can provide the most promising use through vast distributed networks or swarms. But this very aspect contributes a great deal to the space debris. Space debris has been one of the most important and rising concerns. Pocketqubes being smaller in size have a longer orbital life and on becoming non-functional, can pose a great threat to other missions in the LEO. It was stated by The Inter-Agency Space Debris Coordination Committee (IADC) in 2007that, "This IADC and some other studies and a number of

existing national guidelines have found 25 years to be a reasonable andappropriate lifetime limit." [15].
De-orbit manoeuvres are complex and some pocketqubes fail prematurely. Therefore the best way to assess the orbital life time with respect to space debris mitigation is the non- operational case [9]. The orbital lifetime has been analysed using the free ESA-DRAMA software tool [17]. Along with mass, size launch date is also an important parameter for input. as atmospheric densities in LEO vary due to the 11-yearsolar cycle. On conduction of sensitivity analysis it was revealed that, a launch at the 01-01-2019 provides average results on orbital life-time, while launch dates on 01-01-2024 and 01-01-2028 provide results which are near the lower and upper orbital life time, respectively. Figure 2 provides theresults for the same with minimum and maximum mass [9].

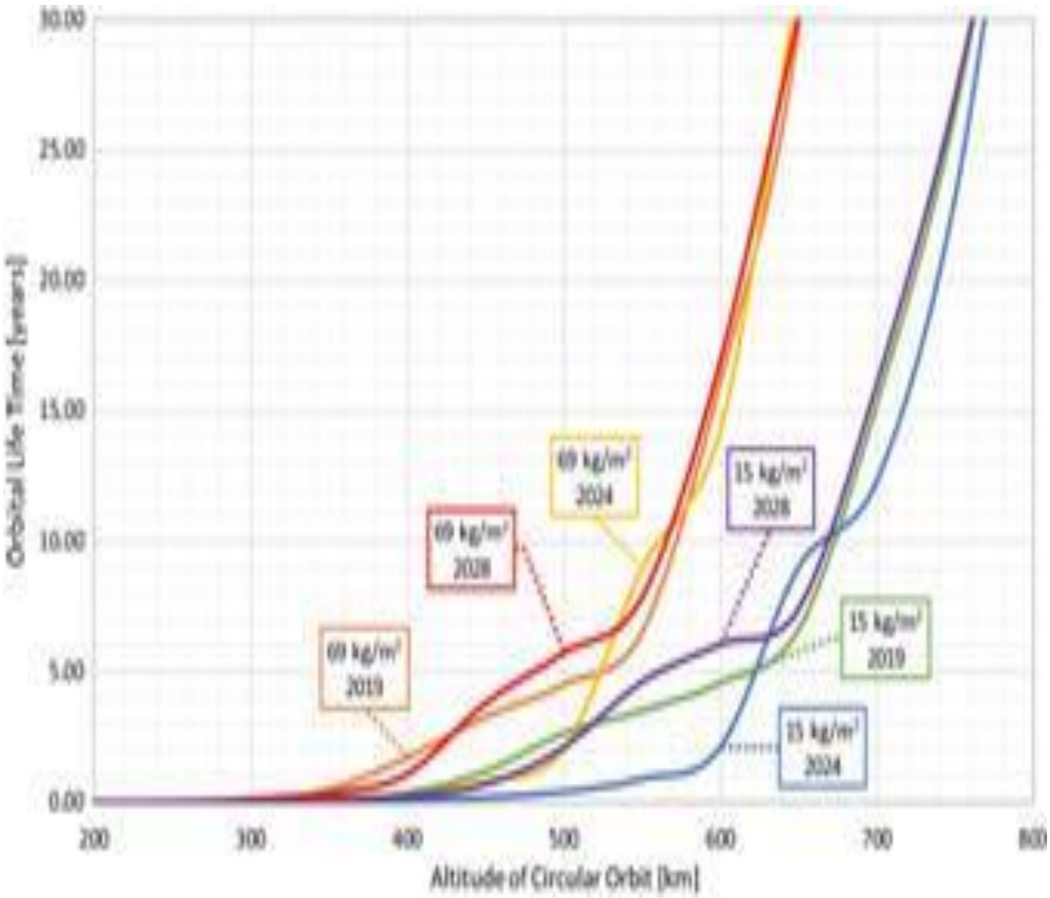


Fig 2.: Comparative study to analyse orbital life based onsatellite mass and launch date.

IV.CONSTRAINTS FOR PICOSATELLITES IN LEO (LOW EARTHORBIT)

The space environment poses many challenges to picosatellites. The miniature size of picosatellites poses a great challenge of adequate power generation. The small size results in a smaller surface area, thus limiting the number of solar cells that cover the surface of the satellite. Deployable panels are often chosen as a solution to solve this problem. But deployable panels too can pose a risk, as the number of moving parts in space is directly proportional to the chances of failure of those mechanisms. Thus to be able to generate adequate power from solar cells without any deployable panels, selection of good quality space grade solar cells is essential. Connect along with it an efficient MPPT(Maximum Power Point Tracker) and a highly efficient solar batterycharger, so as to to get maximum output. Another challenge posed is space constraints for design of payloads that can be fitinto a small space. For communication in S band, a 3P satellitewith no deployable panels would work. But for applications requiring to communicate in X, Ka, Ku bands requiring higher data rates, would require more power and thus deployable panels with the added complexities would be required. The space environment adds up another problem of outgassing, where certain materials vaporize in vacuum. Thus the materials used to develop the satellite are to also be chosen carefully, such that they can handle extreme temperature fluctuations, vibrations and other rapid environmental changes.

V. STANDARDS

5.1 Mechanical requirements

Number of Units (P)	External dimensions without backplate(mm)	Sliding backplate dimension (mm)
1P	50x50x50	58x64x1.6
2P	50x50x114	58x128x1.6
3P	50x50x178	58x192x1.6

Table1. Pocketqube Standard Dimensions[10]

5.1.1 Mass Requirements

Size	Maximum Mass
1P	250g
2P	500g
3P	750g

Table2. Pocketqube Standard Mass Limitations[10]

5.1.2 Materials

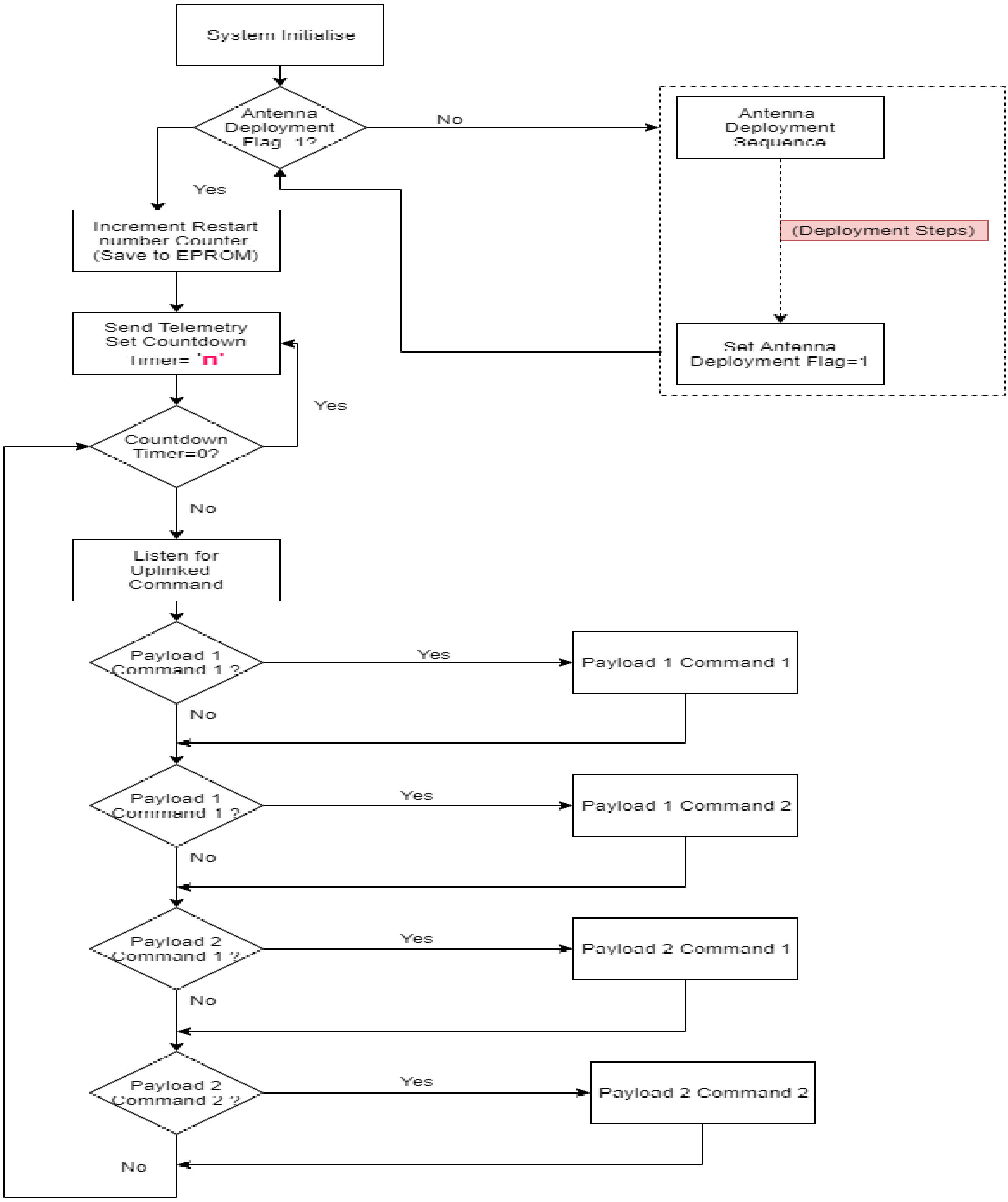
Structural materials used in PocketQube must be able to withstand rapidly changing environmental conditions.

The materials preffered are FR4, Aluminium (7075,6061,6065,6082)[10]. The metallic materials used that are in contact with the deployer should be hard anodized.

VI. PROPOSED SYSTEM REQUIREMENTS

The proposed system has been designed after studying various small satellites. The system has been designed in accordance with pocketqube standards. The flow diagram describes the sequence of events to be followed by the satellite after it is launched into the orbit by the launch vehicle. The system begins initialization followed by the antenna deployment. After successful initialization and deployment, the satellite begins working in the mission phase. The system working in brief is as shown in the following flow diagram Fig.: 3

Fig.: 3 System Flow Diagram



6.1 System Hardware and Software-

The design of the Nanosatellite bus is based around an open source microcontroller Atmega 328P. The power management system has so been designed that the components used are easily available and the design is easy to replicate. A proper attitude determination and control system as per the requirements posed by the payloads and communication system has been developed. The structure has so been designed so that it would require minimum use of advanced and expensive fabrication techniques. The communication and telemetry system has been designed with proper redundancy and link budget parameter requirements.

6.2 Details of Hardware and Software used-

Hardware:
- SPV1040
- ADS1115
- Atmega 328p
- DS3231
- MPU 6050
- MIC5250
- Neodymium N-22 grade magnets
- OV2640 camera module

Software:
- Arduino IDE
- EAGLE CAD
- Ki-CAD
- Fusion 360

The above components have been chosen after a thorough analysis of parameters like power consumption, size, ability and efficiency to work under extreme fluctuating conditions. The above components have also been chosen on the parameters of practical and economic feasiblity.

VII. RESULTS

We conducted few temperature and pressure testing of our system bus. We also implemented and tested our on-board temperature sensor for its accuracy. We compared our readings against a standard reference device. We observed that our sensor recorded readings with an acceptable constant deviation, which can be constant rectified using offset correction techniques. The result obtained is shown in Fig.:4.

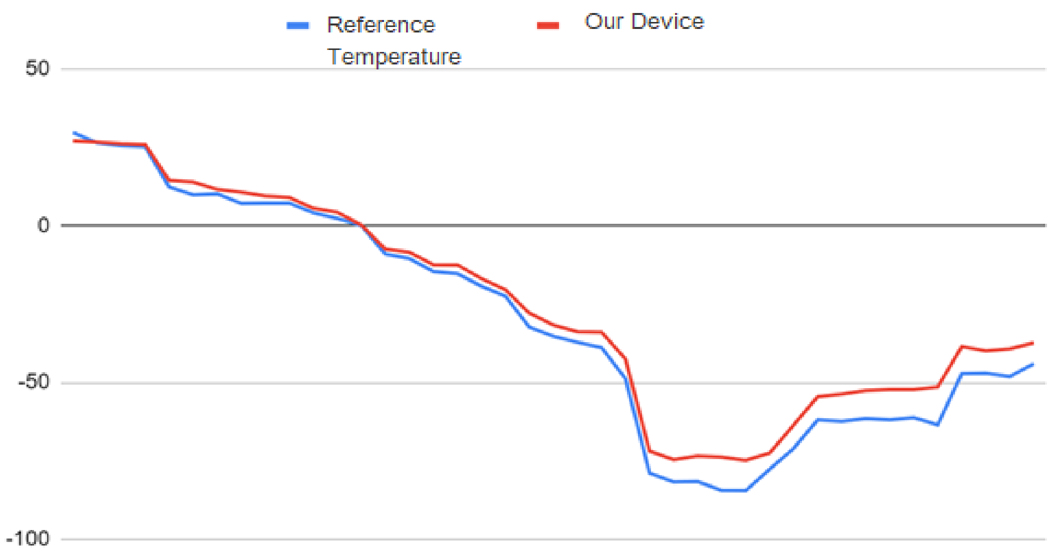


Fig.:4 Graph of Temperature readings of our sensor versus reference device

VIII. CONCLUSION

A robust, flexible and easy to use, pico-satellite on-board computer board was developed. Essential sensors like digital temperature sensor were implemented with minor constant offset in readings, with respect to a standard temperature sensor. the developed bus doesn't requires any special tooling or techniques to be available with developer, the bus could be designed on any PCB-CAD software using template boards and could be ordered online. The learning curve is low, due to vast amount of documentation and readymade libraries available in Arduino environment, the system is based on. The crowd-sourced software source also has resulted in crowd- tested software compatibility, giving rise to easier prototyping. The orbit lifes of different pico-satellite missions were studied and it was found that the orbital life increased exponentially with the increase in orbit height. To avoid space debris and easier orbital tracking of the pico-satellites, 400-500 Km orbit turned out as most favorable. European Space Agency's DRAMA simulation suit was utilized successfully to predict the orbit life. A generic software mock-up for flight software was developed as per the standards and was able to full fill the international requirements.

REFERENCES

[1] Bheema Rajulu, Sankar Dasiga, Naveen R. Iyer "Open source RTOS implementation for on-board computer (OBC) in STUDSAT-2" 2014.

[2] Thakur Anubhav, Parbat Sarwesh, Venkitachalam Narayan, Penmetsa Aditya Varma, Raghupathy Ajay Prasad, Muthuswamy Loganathan, D. Narayana Rao, Soorya Sriram, Muthusamy Venkatesh. "Novel low cost standardized Nano-Satellite structure bus for LEO missions" Publisher: IEEE 2013.

[3] Nikhil Pradeep Sambhus, Rahul Kulkarni, Prerana Jakhotia, Shreyas Kulkarni, Mugdha Bondre, Pritesh Chajed, Aniket Marne, Onkar Chaugule, Sendhilkumar Alalasundaram, Dhaval Waghulde "Project Management and Implementation of Hadwae and Software Interfaces Between Subsystems of Swayam Student Satellite Initiative" 2015.

[4] Bálint Dávid Olaszi, Viktor Józsa, József Ladányi "Energy management of a "PocketQube" satellite" 2015.

[5] Shreyas Kulkarni, Saurabh Bangade, Mayuresh Khadse, Dhaval Waghulde, Priyanka Aher, Kishor Gaikwad, Shantanu Thakurdesai. "Design and optimization of the on board DC/DC converters of Swayam satellite". Published in 2014 IEEE International Conference on Power Electronics, Drives and Energy Systems (PEDES).

[6] Armughan Shafique, Arslan Shabir, Zahid Sharif, Noman Shabbir,Muhammad Naveed Iqbal "Power Distribution System for PNSS-1 Cubical Satellite" 2015.

[7] Freddy M. Pranajaya, Robert E. Zee. "The Generic Nanosatellite Bus From Space Astronomy To Formation Flying Demo To Responsive Space". 2009 First International Conference on Advances in Satellite and Space Communications.tt5.

[8] http://www.50dollarsat.info/page1.html

[9] Bouwmeester, J., Radu, S., Uludag, M.S. et al. "Utility and constraints of PocketQubes". CEAS Space J (2020).

[10] Radu, S., et al.: The PocketQube standard (2018)

[11] Twiggs, R.: Making it Small. Cal Poly Developers' Workshop, San Luis Obispo (2009)

[12] Twiggs, R., et al.: The ThinSat program: flight opportunities for education, research and industry. In: 32nd Annual AIAA/USU Conference on Small Satellites (2018)

[13] United Nations Office For Outer Space Affairs and Committee on the Peaceful Uses of Outer Space, "Space Debris Mitigation Guidelines of the Committee on the Peaceful Uses of Outer Space," (2010)

[14] Fonod, R., Gill, E.: Magnetic detumbling of fast-tumbling picosatellites. In: Proceedings of the

International Astronautical Congress, IAC (2018)

[15] Inter-Agency Space Debris Coordination Committee. IADC space debris mitigation guidelines. IADC Sp. Debris Mitig. Guidel., Revision 1, pp. 1–10 (2007)

[16] Gelhaus, J., et al.: Upgrade of DRAMA, ESA's space debris mitigation analysis tool suite. In: 6th European Conference on Space Debris, vol. 2013, no. April, pp. 22–25 (2013)

[17] Prabhakar Subrahmanyam & Robbie Singh Sidhu. "Antenna Deployment Mechanism for Spacecraft Spartnik University Program: Scientific earth observation mission". IAA Symposium on Small Satellites for Earth Observation.

[18] Bhor HN, Kalla M. TRUST-based features for detecting the intruders in the Internet of Things network using deep learning. Computational Intelligence. 2022; 38(2): 438–462.

[19] Pinjarkar, V. U. ., Pinjarkar, U. S. ., Bhor, H. N. ., Mahajan, Y. V. ., Patil, V. R. ., Rajput, S. D. ., Kothari, P. ., Ghori, D. ., & Bhabad, H. P. . (2023). Student Engagement Monitoring in Online Learning Environment. International Journal of Intelligent Systems and Applications in Engineering, 12(1), 292–298.

[20] Bhole, V. ., Bhor, H. N. ., Terdale, J. V. ., Pinjarkar, V. ., Malvankar, R. ., & Zade, N. . (2023). Machine Learning Approach for Intelligent and Sustainable Smart Healthcare in Cloud-Centric IoT. International Journal of Intelligent Systems and Applications in Engineering, 11(10s), 36–48.

[21] Terdale, J. V. ., Bhole, V. ., Bhor, H. N. ., Parati, N. ., Zade, N. ., & Pande, S. P. . (2023). Machine Learning Algorithm for Early Detection and Analysis of Brain Tumors Using MRI Images. International Journal on Recent and Innovation Trends in Computing and Communication, 11(5s), 403–415.

[22] H. N. Bhor and M. Kalla, "An Intrusion Detection in Internet of Things: A Systematic Study," 2020 International Conference on Smart Electronics and Communication (ICOSEC), Trichy, India, 2020, pp. 939-944, doi: 10.1109/ICOSEC49089.2020.9215365.

[23] Gelhaus, J., et al.: Upgrade of DRAMA, ESA's space debris mitigation analysis tool suite. In: 6th European Conference on Space Debris, vol. 2013, no. April, pp. 22–25 (2013)