ROLE OF AI IN NANO-SATELLITE CONSTELLATIONS FOR AUTONOMY

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The NewSpace revolution of the space technology has posed several challenges and at the same time, opportunities to expand the horizons of the relevant small satellite applications and their usability. This has bought several ambitious for making an impact for LEO region solving real-time problems and supporting life on earth and also in deep space. The scope for innovation and including unique technologies has been widened and essential to achieve the standards posed by this revolution in space technology and sciences. This paper will introduce some of the crucial approaches needed for using Artificial Intelligence (AI) for nano-satellite constellation operations and their maintenance. Certain unique techniques and implementation methodologies for nano-satellites under 100 Kilograms has been discussed. The literature study and extension to such major leap in the small satellite constellation with major emphasis on autonomy is presented with brief detailing. Adaptability, challenges, strategies and possible steps to enhance ease of applicability of AI in nano-satellite constellations is bought up to the focus. Management of these constellations effectively and techniques governing them remain need of the hour and have been briefly elaborated.

Key Words: NewSpace, Artificial Intelligence (AI), Constellations, Autonomy, Nano-satellites, Adaptability

1. Overview

The Small-satellite class of Nano-satellites group (10 to 100 Kilograms) is forming to be crucial centroid for majority of scientific and technological demonstrations in space mainly in LEO and deep-space. It has been evident since a decade that the constellations of these small satellites are of greater importance due to their enormous advantages in terms of data transfer and operations over a longer duration of time (in multi years based on mission objective). The NewSpace era has began with small satellites being at its focus and making creative changes to the space regions like Low Earth Orbits and deep space. The global revolution in this era has just changed the entire dynamics of space operation and related functions. In response to these rapidly growing NewSpace age, there have been several commercial reforms to redefine and adjust to the new and unique scenarios of this new and competitive commercial and academic space environment. As an analysis, [1] shows the real-time changes and standards norms to be defined to ensure that all portions of this NewSpace receive equal opportunities to initiate to contain the humanity for a responsible space behavior for this competitive environment but at the same time immensely benefitting and contributing to real-time problems of earth as well as the deep-space initiatives. Maximizing outputs under restricted resources and cost is the dimensioned scaled with this NewSpace generation for a long-term and productive sustenance for LEO and missions beyond.

Small satellites in the nano-satellite range (10 to 100 kilograms) are primarily areas of special interest due to the fact that the scope of research with this range is widely open with opportunities and critical challenges at the same time. Nano-satellites have great potential to be implemented in LEO and deep space for important real-time applications like disaster management, imagery, scientific experiments etc. The challenges include the space constraints and ability to have COTS-based subsystems to sustain in space environment effectively for a long-term without much hassle and minor maintenance both on-orbit and on ground respectively. The uncertain space environment with various perturbations, space debris, satellite traffic in LEO and in other regions in space, has increased the sensitivity of using these satellites effectively with safe and reliable operation for a designated period of time.

This paper and the research aligned in it has also same vision to develop systems and technology to enhance the utility of the nanosats for LEO and deep space with a constellation scenario for global outreach and sustained performance over time. The data availability to the end-user has became crucial for critical applications like disaster management and for rescue/emergency events. Hence, the nano-satellite constellations have become extensively researched and discoursed area of satellite engineering to enhance and extend the nanosatellite abilities respectively. Disaster management require faster and reliable data for relief assurance at the specific locations on urgent basis.

A constellation of nanosatellites is capable to deliver the data in as much short time as ten minutes per image or per pass. This will impact the amount of the life and resources lost significantly during the data reception period. Likewise, a well-defined constellation in deep space can also regulate the communication deficit issues and ensure stronger data links to be supported with tremendous impact. The global scenario of the nanosatellite constellations is evolving to mitigate the severe environmental risks that a (100-kilogram or less) satellite implementing several unique techniques and strategies aligning the best possible operation for a constellation in LEO region and slowly towards deep space.

2. Literature Study

This field of study is growing slowly but steadily in a global research environment but a lot of efforts are still under planning or observation. Still there have been certain advances in the industry to make progress with the Artificial Intelligence (AI) as the prime focus for attaining autonomy for the nanosat constellations.

An Italian company named ‘AikoSpace’ has developed a software library for achieving complete on-board autonomous for the small satellites using AI and is commercializing it for other prospective missions. Similarly, Intel in collaboration with ESA has made a major announcement that have made the first satellite (PhiSat-1/2) with intel technology to process data on-board with the help of AI. It is said that it costs under 100 USD to enable AI on the satellite and plans for future missions after learning from these two missions respectively. Likewise, there are intensive efforts globally to find a meaningful direction to apply AI in constellations with nanosats to overcome major problems and enhance overall utility seamlessly for long term usage of the constellated satellites.

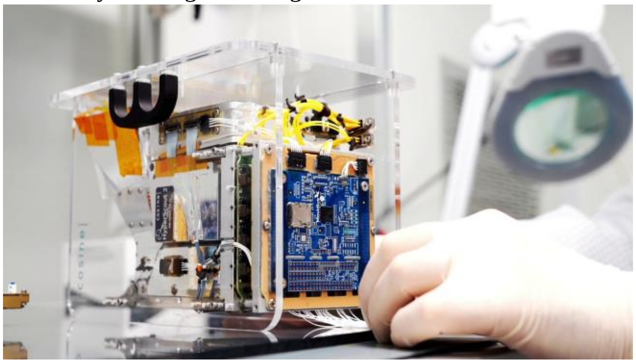

Fig. 7. PhiSat under demonstration.

Not only LEO or deep-space missions, NASA plans to use AI for having a trip to the Sun and explore new planets. NASA’s collaboration with Space Systems Loral is evident for the same and AI could really change the way satellites were seen before and reach starts and discover the unknown potentially with few resources. The plans are underway and is making strategies for the same.

From the research fraternity, there is a lot going with understanding the implementation needs of AI on various levels in synch with current nanosatellite technologies. The systems engineering remains one of the most prominent areas to develop AI effectively. One such examples is [2] where the authors give in-depth techniques and processes to systematically implement AI-based systems and explore this technology. The challenges involved in implementing AI effectively is detailed in [3] with reasoning and ways to adopt the change in space dynamics. The machine-learning using TensorFlow has been demonstrated by [4] and detailed the applications specifically on smallsat platforms respectively. Being specific to the autonomy that is intended, [5] gives simulation modelling insights on the autonomous navigation support for smallsat constellations. Detailing the similar concept in a different scale, [6] gives more insight on the ways the future of the space missions looks like with autonomy in major applications and what it means to have it for NewSpace challenges and maintain robust and sustainable space systems.

3. Problem Definition

Though nano-satellites have distinct capabilities these days to adopt the objectives and tasks similar to the traditional bigger satellites, there are concerns to have a deeper look into. Apart from the usual size and mass constraints, there are adaptability, reliability, temperature sensitivity (COTS systems), longevity of the functions to fully attain the mission objective, exchange resources like power and data effectively and efficiently as needed and so on. The scope of research is wide enough with several topics to be addressed.

But when it comes to advanced and extensive use of the nanosats as a constellation for dedicated applications like disaster management, then the challenges are on bigger scale as the following:

- How fast the data can be relayed and received on ground?
- Which technology can adopt to the space environment and still give breakthrough performances?
- How in such size and mass constraints, the systems could operate to relay the data and perform their daily tasks as needed?
- Not only data transfer, how on regular basis, the operations can be handled in a scale of a constellation? And still be healthy in-orbit?
- How the operations can go fully autonomous without human intervention?

Though there can be many other questions and concerns over a time of continuous constellation operation. But the main aim of this paper is the make necessary strategies to determine the possible extensive use of Artificial Intelligence (AI) in the nanosat constellations for the applications of disaster management and moon region respectively. It is primary goal of this research is making efforts towards making the operations as autonomous as possible using technology like AI to solve real-time problems on Earth and on Moon to enhance the speed of operation, exchange valuable resources on-board like power and system information among satellites and the ground stations, control of the satellites in an orbit they are in, avoid external objects and create safety for itself autonomously.

Fig. 8. Problem definition and AI benefits

4. Challenges for a full-scale AI implementation

The nanosat constellations have been performing well delivering certain valuable data to the end-users which is expensive but with high quality and desired resolution. The major SAR companies like ICEYE, Planetlabs and Capella have been providing world-class imagery to the customers worldwide. But still expensive for the Asian customers to utilize them fully without compromising on number of scenes per day. Hence, there is a need to build multiple small satellite constellations to compensate this huge requirement for imagery and important data/information globally, in this paper, for Asia specifically.

There are several other issues and parameters to be deeply analyzed for a full/large-scale implementation of the AI for the nanosat constellations. Few of these challenges are demonstrated in [7] through real-time implementation and industrial experience from Airbus. The reference briefly explains the issues to initiate and retain the implementation of AI in long run in regard to the processing units on satellite. In other reference [8], the challenges in collision avoidance implementation of AI is discussed in detail. Hence, a huge range of possibilities of AI implementation comes with a package of challenges and important concerns which cannot be overlooked.

Few of the major concerns and challenges that can put forward in the form of questions as below are:

- How the radiation hardware and related traditional equipment revolution or changeover is possible to overcome lack of an upgrade to the same? as AI requires high -tech systems and equipment to implement it on satellite?
- Standard process or procedures to attain systematic AI implementation for nanosat constellations?
- What would it take to operate an average sized (50) constellation of nanosats effectively using AI?
- COTS implementation for AI effective enough to carry huge operations and maintenance deficits?
- AI Software libraries and related upgrades as per traditional operating systems reliable and robust?
- Is anomaly management for AI related systems to avoid unnecessary human intervention effective?
- Resource limitation with AI effectively manageable?

The list of these challenges keeps growing but the major relief from AI implementation is the benefits out weigh the challenges once recognized and solved thoroughly. These challenges vary from mission to mission and situation to situation as whole but what remains is the overall feasibility and ease of data transfer and several such advantages for nanosats to out perform on daily basis when constellated. [7] also mentioned about the neural network issues with AI to design and maintenance the frameworks and tools is also a crucial matter to demonstrate highly efficient satellites in operation over human intervention. This paper will be restricted to define challenges in operating AI and possible strategies in overcome them with NewSpace environment of the nanosats for not only LEO but also for lunar missions in near future respectively.

5. Areas of application (LEO and LO – Constellations)

The areas of Artificial Intelligence applications are very broad spoken but limited in implementation yet due to various factors involving it. However, this paper will mainly focus on the applications of AI in nanosatellite constellations briefly with some details on simulations to give an overview of how these nanosats can operate and perform in much upgraded accuracy in synchronization with AI for a long-term effective sustenance.

Below are the major applications in a constellation scenario effective for both LEO and LO where AI can be highly effective and change the NewSpace dynamics once for all:

5.1. Mission Planning and operations

The mission planning and operations are complex and relatively cumbersome to manage and operate for a constellation of nanosatellites as the errors and related detectability of the same are difficult and many a times immeasurable in many forms for both deep space and LEO. AI can really make this simpler and adds immense support to the entire constellation with its logics and predictions mimicking the human ability.

5.2. Data relay (collecting and organizing)

In constellations using the nanosatellites, the one major application for AI can be the used for data relay among satellites and to the ground station ultimately. The inter-satellite linking with optical communication (laser) is a major area of research in these scenarios in recent times. The visibility from satellite to satellite remains crucial to make control among satellites possible within and outside the same plane respectively. The data speed and quality of the it will vary in-orbit but AI can support in aligning these operations effectively and maintain the stability of satellite-to-satellite data transfer. The intent is to make the data available to the end-user as early as it is processed as required. The technology upgrade that AI can give will be of prime importance for major data relay operations in LEO and LO.

5.3. Navigation and Orbit Control

The coverage for a constellation and its optimization plays a prominent role in the applications like disaster management, critical data utilization locations and many others. This has been traditionally done over years manually and through embedded ground algorithms operated by the engineers with minimum control and low outputs from the optimizers. With as many as 50~100 satellites in LEO and managing the optimality of each plane/orbit is a difficulty of higher levels. Hence, AI can support from on-board implementation of the same and advice satellites to take the most optimal path to reach the ground station at the earliest time possible with revised orbital parameters for the navigation aspect of the constellations.

On the other hand, the orbit control (formation) in each plan is highly valuable for the constellation to maintain their positions as intended my mission design for a long term. AI can monitor and regulate the distance between satellites to satellite appropriately and exchange the data and other information in a timely manner as needed.

5.4. Collision Avoidance and Maneuvering (Debris and Co-satellites)

In many situations, even with individual satellites in LEO are getting conjunction due to huge amount of space objects (debris or other satellites) in the close vicinity. There are various events in the past that debris or other spacecrafts have collided and formed another debris adding to the current situation adversely. The situation goes with a constellation as well. As the nanosatellites are rather smaller and have higher chances to be hit by smaller sized debris or satellite and create bigger damage it to and stop the execution of the constellation operation overall. The situation of conjunction while operating in a constellation itself with the other satellites in same of different planes is a complexity of a large scale in itself.

Hence, sufficient capabilities in-orbits are inevitable to maneuver the satellites away from potential collision and secure the satellites in their respective planes. In the recent times, this is fairly a possibility that even lunar environment is going to be crowded with ample of missions as several countries take their space programs towards moon as an important strategic area of operation.

AI is one technology which can fill this vacuum of tremendous importance for the space situational awareness domain. This makes a safer environment for their smooth functioning during their lifecycles and perform as aligned with the mission design objectives respectively

5.5. Mission Risk Assessment and Mitigation

The mission risk at system and environmental levels have to be analyzed thoroughly when it comes to a constellation of nanosatellites. Not only knowing the risks but also mitigating them precisely and making best possible scenario for non-collision and damaging consequences.

Several attempts in the recent past has been made to enhance and upgrade the space safety policies and make space available for all through common determination and updated systems and understanding about the space situations globally.

AI incorporated in satellites and ground systems can be one good solution to assess risk and mitigate as required by the current on-orbit situation to avoid any kind of destruction in the plane with other satellites or LEO objects.

5.6. On-orbit Maintenance and Servicing

Several companies and research institutes are focusing on developing crucial mechanisms for making the repair and maintenance on-orbit in a simple but effective manner using robotics as a primarily technology to solve issues as complex or simple as they can be. The servicing period of each satellite can also vary case by case but it is an essential part of the constellation operations to make every satellite go through a critical check and analyses once in a given interval of time and comply with the international norms effectively and document the same for records.

AI is still under examination to be implemented to the on-orbit maintenance and servicing as this technology can be an acting human onboard the satellites and each to an extent that all the nanosatellites constellated can coordinate the maintenance and servicing tasks among themselves on the aligned schedules. The combination of robotics and AI will be a ground-breaking experiment in the orbits to solve some of the most critical constraints to solve issues in orbit for a constellated satellite.

5.7. Autonomous Ground Stations

The efficient data reception is the key to all the operations that the constellation of nanosats would send through their mechanism of transferring as designed as per the mission objectives. The questions that arise that how these satellites coordinate to align the data to a particular ground station? How many ground stations are essential for the optimal data sending and receiving process to be smooth and hassle-free? What is the process to process and store the incoming data each time? and so on. The optimal number of ground station arrangement for a global constellation is also a major concern to make real-time use of the received data.

AI is already being used for aligning and organizing these concerns in a systematic approach for both individual and constellations. But the significant space proven missions have not yet been achieved for fully adoptable autonomous operations for the nanosatellite-based constellations for a long term.

5.8. Launch Assistance (LEO and LO)

The rocket industry worldwide is growing rapidly for launching small satellites (and constellations) aggressively and expected to be a 29.6 USD billion (as per the Marketsand Markets webpage). The demand to supply is expected to be hand-in-hand and well balanced with adequate upgrades in technology and overall small satellite operations.

In the specific case of nanosatellites (<100 kilograms) constellations, the AI has to play an important role even for the launchers to assistance and give a systematic alignment and approach to sense, measure and guide the launch of a rocket towards the planned and destined orbit respectively. This will change the dynamics in nanosatellite industry effectively propelling the launches and reducing the loss due to damages or burning out of the rockets at some stage of the launch.

5.9. Human – AI (combined space exploration and assist)

Artificial intelligence (AI) is not only for the nanosatellite constellations or individual satellites, but also for a human assistance in deep space and even in LEO for human space flights for commercial applications or space tourism. The nanosatellite constellations will be crucial to assist astronauts in specific missions to LEO and Moon to get them communicate with earth continuously and with AI, autonomously as well. Often the communication takes time to be effective for LEO operations for the astronauts to make a contact and solve critical issues as instantly as possible. But with effective utilization of nanosat constellations, it will be a huge relief and a cost-effective solution for majority of the human space operations to built a sustainable space environment for all missions for the sake of humanity.

6. Strategies to build robust constellations (with AI)

The strategies usually can be termed as complex and complicated for assigning a particular task or process/procedure to get a job done. But though AI implementation in nanosats can seem to be complex but adopting simple solutions and methodologies can change the scenarios and way it appears to be.

This paper is to align those strategies for implementing AI and its role in nano-satellite constellations for effective operating and management in Low Earth Orbits (LEOs) and Lunar orbits supporting the Artemis missions from NASA and beyond. Below is step-wise emphasis on major areas of strategically aligning the AI matters for LEO, Transfer and Lunar regions respectively.

6.1. AI for LEO constellations

There are several ways the AI can be strategized for the nanosat constellations in a methodical approach for long term and sustainable duration in space. The major application envisioned by this research is disaster management while in LEO region of operation. The main reason for it is that the global users in various parts of the globe are inquisitively requiring and looking for data which is predominantly helpful in disaster situations and operate trustworthy information from it for relief provision and resource restoration simultaneously. With AI, the tasks and efficient operation can be paced up and provide additional support to the operations team to focus on other critical issues rather than regular or repetitive concerns. The following strategies can be proposed to solve some of the implementation issues of AI for nanosat constellations for LEO respectively.

6.1.1. Step-wise alignment of AI to COTS (hardware)

It has been observed that the COTS and traditional systems and equipment are not aligned thoroughly with AI technology due to the lack of upgrade satisfying the AI norms for operation. This has been discussed and concerns raised several times over time to establish a system to fully upgrade the COTS and CONOPS thoroughly matching the requirements of AI in real-time functions. The lean 6-sigma method and regulation can be an important tool for aligning the COTS systems and usually utilized equipment for nanosat constellation designing and testing.

The picture below signifies that lean 6-signma is most essential to strategically merging AI with COTS components across the nanosatellites systems aiming for constellations and contribute holistically to LEO and LO regions tremendously.

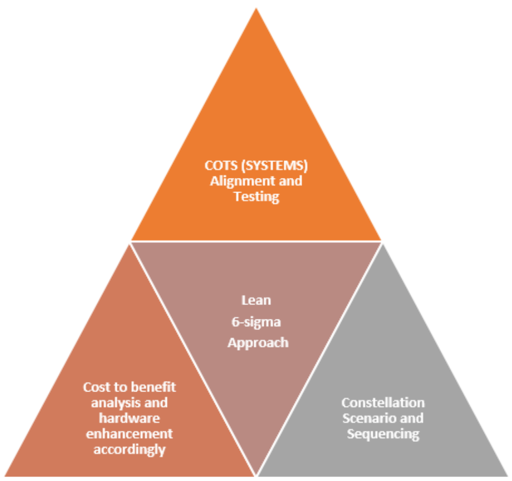

Fig. 28. Lean 6-sigma for hardware alignment to AI.

Giving a bit more emphasis and understanding over this aspect, [9] presents a description over the current lean practices to manufacture and development synergic systems for developing world which in fact is relatable to NewSpace and its systems respectively.

6.1.2. On-orbit Task Assessment and Relay

The one of the most crucial of all the tasks is regulating the tasks which AI can understand on orbit and manage the relay process of data from satellite to satellite and then to ground station. There have been real-time concerns that there is not much of the information for the AI to carry forward the operations for the following situations:

- When to perform a task if the data package does not have much information to pass to other satellite or ground station?
- Situational awareness of the satellite-to-satellite engagement or availability to relay data and when to perform a task autonomously?
- Is the information available for next immediate task to be performed?

These are few of the real-time challenges to accommodate the AI for nano-satellite constellation in LEO. There is huge possibility and in fact relief that there can be huge room for the on-board processing with terabytes of data can be relayed every day.

The 'on-orbit task assessment, resolution and relay' strategy of implementing AI will provide the operators with enough support for the processing of the data on-board, continuously perform operations which are repetitive and well-defined operations saving valuable time of the engineers to focus and determine the value of the received data.

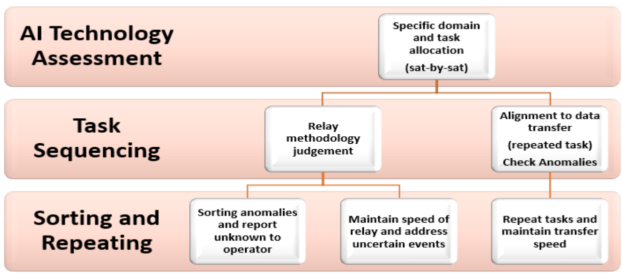

Fig. 30. AI strategy for tasking events.

There would be many different tasks at the same in orbit while satellite is performing its operations on day to day basis. Hence, AI is capable to assess day to day tasks and validate them to the operator for a note-worthy valuation of the entire constellation at once. The above-mentioned strategy is not only for data relay operation but also to sustain harsh space environment using AI extensively for timely alignment and re-alignment of the tasks when needed as the situation in orbit and make decisions as needed autonomously.

6.1.3. Trail-orient-repeat methodology

The sequencing of data relay shown above is one of the situations and strategizes to align AI to the nanosat constellations. But there are other major issues for which a well-defined strategy to utilize AI is inevitable. In order to maintain the constellation and comply with the basic regulations in their respective orbits, there must be a strategy to contain and stabilize the orbit when needed. This means if there is an obstacle in the orientation of the nanosatellites along their path, the AI should be able to alert the satellite and re-align it in the same plane avoiding and making a minimum probability to hit the unknown object. In the past there have been more cases of constellated small satellites crashing with the debris or other unidentified objects and this is expected to increase in the near future. Hence, effective and strategic implementation of AI algorithm can evade this situation and add to the safety of the nanosats effectively.

The picture below depicts the conjunction events in the recent past years at different altitudes referred from Eo portal of ESA.

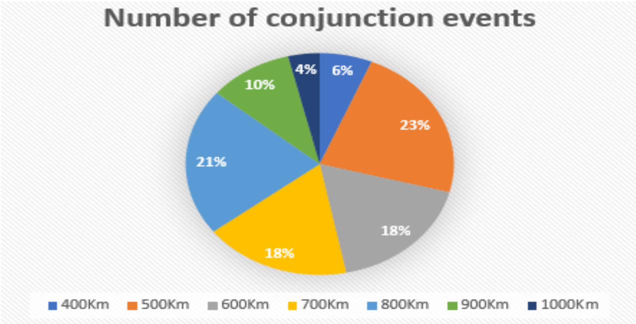

Fig. 31. Conjunction events at different altitudes.

6.1.4. Autonomous Anomaly Track-and-Deal

The anomalies can be unpredictable in space with several issues to be instantly addressed like space debris, satellite to satellite close proximity, system malfunctioning (unknown anomalies) and so on. In nanosatellites, maintaining the respective orbits and their functions effectively for the constellation's lifecycle is challenging in itself. A strategy is needed to track these anomalies significantly and deal it with AI immediately to avoid the unnecessary interruption of the services or operation as a whole. This strategy be aligned with an AI algorithm to sense the issues within the system and make enough trails to overcome them on board. There can be threshold for letting it know to the operator when critical. Hence, the autonomy that the AI can add to the constellation for this particular portion of operation can be strategized as mentioned and pictorially depicts as below:

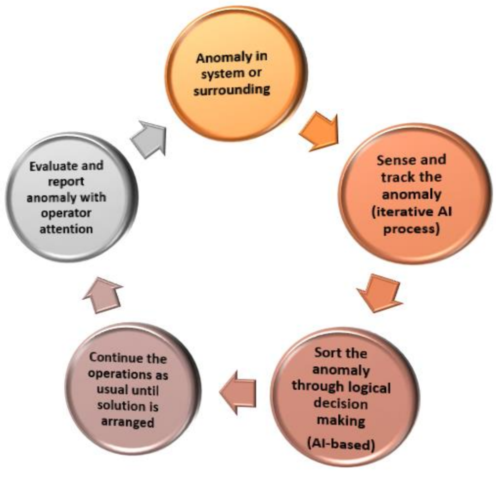

Fig. 33. Track-and-deal strategy with AI.

6.1.5. Room for uncertainty – Building Blocks and Chains

As it is a known fact that with increasing number of satellites and unknown and unidentified objects, the LEO region is crowded and has many uncertainties and anomalies of different variety and range. Hence, it is crucial to be ready with strategy to apply room or availability for unknown uncertainties and operational halt for any reason possible. The effects of perturbations, solar winds and solar radiation pressure has also to be taken into consideration effectively. The AI can be deployed for the same with predictive and probable algorithms can play a vital role in accessing the nature of the uncertainty at a broader level and wider spectrum respectively. The strategy to design this situation is named 'Building Blocks and Chains'. The reason for this is the prediction of a possible issue is first scanned through the embedded list of options and give out the most probable solution for it in the form of building suitability blocks and forming links (chains) from one probability to the other. This allows AI with ample room for judging the best possible problem with a best possible solution accordingly. This methodology has been tried and experimented for smaller ground projects but a full-scale nanosat constellation application is awaited and aspired in near future.

6.2. AI for transfer region operations

The transfer region is usually mentioned during the transport of the payload (satellite) from LEO to LO but the significance of the same is quite huge and needs attention in case of transferring the technologies from earth to Moon. This research envisions that the technologies developed, tested and evaluated for LEO, can be effectively utilized for LO considering the local conditions and environment respectively. Hence, due consideration is given to analyze the AI applicability to transfer region dynamics. For example, the CAPSTONE mission [10] lost contact with the ground stations on earth soon after attaining few stages. The trajectory used was a Ballistic Lunar Transfer (BLT) but with constant efforts from the engineers, the satellite was bought back to communication and is on the way to the Moon. If this is the scenario to just transfer a single nanosatellite to the Moon, then building a constellation of nanosatellites over Moon can be a unique challenge. The research is on-going to build the strategies to align a series of nanosats and related technologies to be transported to Moon's orbits. Using AI, this can be assisted in a better manner supporting engineers to take the best course of action continuously and attain the given mission as required based on the objectives aligned. Below are few of the strategies through which AI can be bought forward and implemented to enhance its utility in space missions and safety of the missions going beyond LEO respectively.

6.2.1. Object avoidance and velocity-change management

The one prominent utility of AI in transfer region can be the ability to track and avoid the obstructing and unidentified objects on the way to the lunar parking/station orbit. There is evidence from the past missions that the track/trajectory clearance and observation for the operators has been tough task even though the literature on this is limited. The AI capability can give enhanced assurance to the nanosat travel from the LEO stationed orbit to the final destination near Moon. The change in velocity which is to be consistently monitored for assisting satellites to propagate through the designed trajectory. It may be theoretically predictable and looks to be a simple task but practical scenarios are hectic and enthralling at the same time for the operators to ensure the velocity parameter is not exceeding the limited boundary conditions consistently until arriving at the designated orbit region. Hence, AI can assist and regulate the normal function of this parameter as well and reduce the human involvement as much as possible. So that the engineers can focus on many other crucial tasks to be aligned before the arrival of the nanosats at the given orbit according to the mission design accordingly.

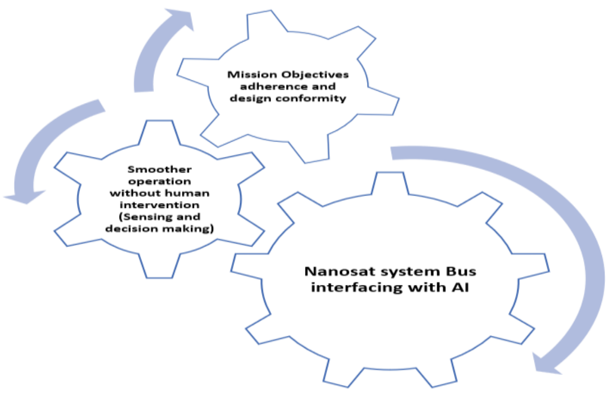

Fig. 36. Working mechanism for O-V and Delta-v

6.2.2. Autonomous sense-and-shot maneuvers

In the above section, the maneuvering database is discussed, but the ability to autonomously maneuver while on the path to destination (transfer region) is also crucial and needs immediately attention to avoid operations shutdown or any anomaly due to obstacles and unknown events while in trajectory. Hence, AI has to be assigned this task of making the maneuvers autonomously when needed and maintain the balance of fuel, system synergy and mission objectives intact. The planned strategy is named 'check-and-shot' maneuvering technique where the necessary system configuration is instructed through interfacing/embedding the AI algorithm to align the fuel and satellite trajectory as required. The maneuvering happens accurately as and when needed and possible delta-v and minor path changes are accommodated effectively. The AI will sense and measure the path and its surroundings and decide for maneuvering as needed. This will save a lot of human intervention and errors that may cause in the process and save and manage the fuel systematically.

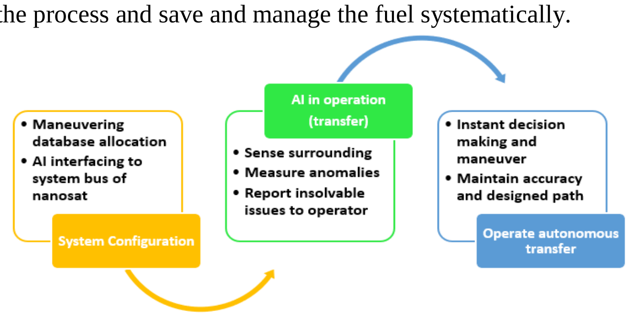

Fig. 38. Autonomous maneuvering strategy (transfer region)

From the above strategy, it can reflect with the NewSpace era which is competitive and hectic with many countries are aligning their economies and resources to reach moon and beyond as early as possible. In that scenario, AI will be inevitable in making nanosat constellations utility to the fullest and cost-effective. Even the transfer region would get crowded in no time and may need specific strategies to evade any uncertainties over time.

6.3. AI for Lunar constellations

NewSpace is a journey of competent technology, techniques to adopt and the change that needs to propel the nanosatellite range of satellites to a greater capability. The research relating to nanosatellites to be sent to Moon's unique orbits like NHRO and circular orientations with widened RAAN orbital element are all under experimentation. CAPSTONE [10] will be the first of a kind nanosatellite to embark on the NHRO orbit and experience the region for the first time making a way for Artemis-1 mission's GATEWAY to take the similar orbit.

AI will become a vital node for technology assistance for all the agencies participating in lunar missions significantly. The calculated reason being able to demonstration the advanced technology with utmost control on the orbits the satellites will be stationed. AI will give that edge to nanosatellites forming constellations in lunar environment supporting ground operations for Artemis mission and beyond.

Fig. 39. AI implementation in Lunar region

6.3.1. Arrival guidance and maintenance

The arrival at the desired location or orbit as planned is always tricky and poses challenges in terms of calculating the amount of fuel remaining, possible real-time delta-v needed etc. It is evident from the past missions that the logical thinking on-board and while arrival always is an approximation as per the ground calculations only. AI can really fill this gap and make things more visible to the ground operator through its real-time logical and real-time decision-making capability and make the final destination more probable and achievable meaningfully. Not only arrival, but also the maintenance of the orbits according to the lunar environment the nanosatellites will be placed, is prominent and crucial to execute its mission thoroughly.

Hence, the strategy is to maintain the in-built AI applications for this purpose and deploy them when ready for arrival at the destination. The maintenance of the orbit without decay in lunar environment is also a challenge for its unknown parameters to control and operate which AI can do sensing the real-time situations and give finite burns only when needed.

6.3.2. Target alignment and sustenance

The target alignment is to consistently making sure that the nanosatellite (in constellation or not), is performing as planned and targeted with the given orbital parameters and performance that it has to sustain for the given lifecycle. This is not only about maneuvers as mentioned in the sections above but an overall performance in a defined orbit as a target of the mission being carried out. In lunar region, the conditions and circumstances vary exponentially with several parameters changing and forming anomalies at variety of levels. For a nanosatellite being in a constellation, it is a bigger challenge than usual for an operator to make a perfect control for the entirety of the constellation to function in a synch regularly until its lifecycle. Hence, AI has to come into this scenario to regularly check and update the system, environment and performance parameters as per the real-time conditions and report them to operators once in a regular interval effectively. AI is to assist human intervention and make the entire process easy and effective for the constellation and its purpose.

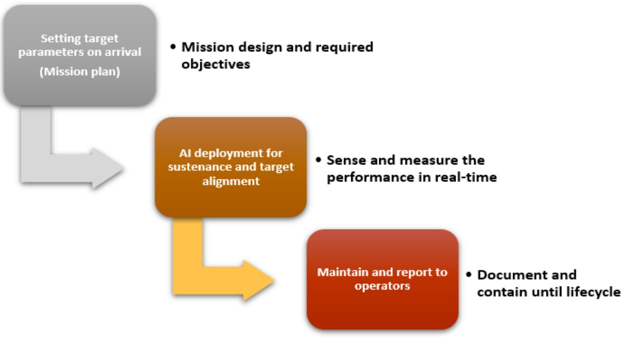

Fig. 41. AI strategy for alignment and sustenance

6.3.3. Lunar ambience-based COTS

The COTS for LEO is being tested and evaluated for the nanosatellite constellations but COTS are important for the lunar orbits as well considering a different and harsher environment with several unknown situations and related aspects yet to be discovered.

COTS are crucial for nanosatellite constellations even planned for lunar missions as they offer cost effectiveness in balance with effective performance if rigorously tested and characterized in similar conditions and ambience in lunar region. The advanced equipment for AIT and latest additions to the COTS family (advanced MEMS) are promising for this alignment and makes it easier to make systems with these COTS suitable even for lunar region and beyond.

At this stage, the AI can be aligned with these smaller systems for integration and testing for a robust operation and support for the ground operators in a long-term mission. This may take time to process and stabilize the supply chain in an appropriate manner for not only on-board data processing but also for assisting operations which added human intervention and errors significantly and making entire process much more accurate and simpler to focus on the aim of the mission and its results. Mainstream companies and major players are operating with minimum AI involvement yet but this is effectively increasing in implementation and several trails are in consideration. Human understanding cannot be replaced with AI due to human thinking is needed for several decision-making scenarios and operations but COTS-AI combination will make the future nanosatellite technology to be utilized in lunar environment effectively and contribute to the bigger missions like Artemis and others.

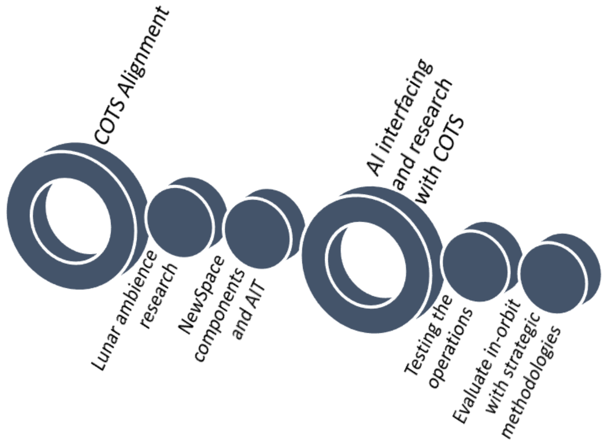

Fig. 42. AI strategy for COTS interfacing to AI for LO

7. Conclusion

This paper is dedicated to sustainable, low-cost, COTS-based nanosatellite constellation design and development in a strategic synchronization with Artificial intelligence for both LEO and LO regions for planned lifecycles. The real-time solutions of the betterment of humanity and deep space research is the sole purpose and alignment to the NewSpace generation of satellite technology. The resources and cost to be balanced with high accuracy and performance has always been a challenge to solve and research on. Over decades, nanosatellites have proven their abilities their individual missions but constellations are yet to prove their ability and survival for a long run for providing cost effective and worthy data for real-time applications for a global utility with optimal coverage for LEO. As Artemis mission begins a new generation of lunar exploration, nanosatellite constellations will play their pivotal roles in making life and processes simpler and reliable for the given mission periods and solve several issues in orbit. AI in both the cases will be an important addition to make human errors and flaws avoidable and form robust operation and management of constellations as per the mission objectives. This research aligns the strategies to overcome the current challenges and blockages to use to AI in full scale for wider operations and systems development.

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