International Journal of Engineering Sciences & Research Technology

(A Peer Reviewed Online Journal)
Impact Factor: 5.164

IJESRT

IJESRT

INTERNATIONAL JOURNAL OF ENGINEERING SCIENCES & RESEARCH TECHNOLOGY

ARTIFICIAL INTELLIGENCE IN MARS MISSIONS AND SPACE EXPLORATIONS

K. Hari Priya[1] & Gaurav Sharma*[2]

[1]B.Tech Student, ECE Department, CVR College of Engineering, Hyderabad, India

*[2]Assistant Professor, ECE Department, CVR College of Engineering, Hyderabad, India

DOI: 10.5281/zenodo.3632484

ABSTRACT

Artificial intelligence in space exploration is gathering momentum. Over the coming years, new missions look likely to be turbo-charged by AI as we voyage to comets, moons, and planets and explore the possibilities of mining asteroids. The history of AI and space exploration is older than many probably think. It has already played a significant role in research into our planet, the solar system, and the universe. AI, and in particular ML, still has a long way to go before it is used extensively for space applications, but we are already beginning to see it implemented into new technologies. One area in which the potential applications of AI are being thoroughly investigated is in satellite operations. For instance, when analysing massive amounts of Earth observation data or telemetry data from spacecraft, ML plays an important role. In addition, it is becoming more common to find ML systems analysing the huge amount of data that comes from each space mission. The data from some Mars rovers is being transmitted using AI, and these rovers have even been taught how to navigate by themselves. Because it takes radio waves up to 22 minutes to travel between Earth and Mars, these robots must make some decisions without commands from mission control. Its development has come a long way over the last couple of decades, but the complicated models and structures necessary for ML will need to be improved before it can be extensively useful. Any data can then be collected and fed back to robots with artificial intelligence, who can process it and decide on a course of action.

KEYWORDS: Rovers, Terraforming ,Chemcam , Navcam , Exoplanets , Transiting Exoplanets.

1. INTRODUCTION

Since the beginning of civilization, humanity has wondered whether we are alone in the universe. Now two possibilities exist: “Either we are alone in the universe or we are not,” Both are equally terrifying. As NASA has explored our solar system and beyond, it has developed increasingly sophisticated tools to address this fundamental question. Artificial Intelligence, Cognitive Automation, and Machine Learning can boost the way of satellite communication and the way we deal with space technology. Thousands of satellites orbit Earth. Some take pictures of the planet that help meteorologists predict weather and track hurricanes. Satellites looking towards Earth provide information about clouds, oceans, land and ice. Some take pictures of other planets, the sun, black holes, dark matter or faraway galaxies [1]. They also measure gases in the atmosphere, such as ozone and carbon dioxide, and the amount of energy that Earth absorbs and emits[2]. These pictures help scientists better understand the solar system and universe. What is difference between a regular satellite and a satellite that is little intelligent than the regular one? Well, the regular one can perform all the tasks mentioned above, but the artificially intelligent satellite can perform all the tasks that a regular satellite can perform and has an AI software ."This software grants us the ability to troubleshoot the robotic systems required to handle increasingly complex tasks of exploration, while they are millions of miles and perhaps light years away from Earth”. Within our solar system, NASA’s missions are searching for signs of both ancient and current life, especially on Mars and soon, Jupiter’s moon Europa. Beyond our solar system, missions, such as *Kepler* and *TESS*, are revealing thousands of planets orbiting other stars which are called as exoplanets. Robots and Satellites with AI are being deployed to monitor weather life is possible on the other planets such as mars. Sending a robot to space is also much cheaper than sending a human. Robots don’t need to eat or sleep or go to the bathroom. They can survive in space for many years and can be left out there—no need for a return trip! Plus, robots can do a lot of things that humans can’t. They can withstand harsh conditions, like extreme temperatures or high levels of radiation.

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

Robots can also be built to do things that would be too risky or impossible for astronauts. We can send robots to explore space without having to worry so much about their safety. Of course, we want these carefully built robots to last. We need them to stick around long enough to investigate and send us information about their destinations. But even if a robotic mission fails, the humans involved with the mission stay safe.

2. PRESENT APPLICATIONS

i. The Earth Observer 1 (EO-1)

Satellite is a good example. Since its launch in the early 2000s, its onboard AI systems helped optimize analysis of and response to natural occurrences, like floods and volcanic eruptions a*s shown in fig(1).* In some cases, the AI was able to tell EO-1 to start capturing images before the ground crew were even aware that the occurrence had taken place[3].

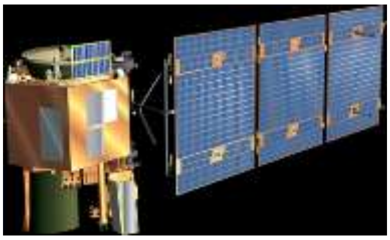


Figure 1.Earth observer 1 (EO-1)

***ii. Sky Image cataloging and Analysis Tool (SKICAT*)** has assisted with the classification of objects discovered during the second Palomar Sky Survey, classifying thousands more objects caught in low resolution than a human would be able to. Similar AI systems have helped astronomers to identify 56 new possible gravitational lenses that play a crucial role in connection with research into dark matter.

iii. AI's ability to trawl through vast amounts of data and find correlations will become increasingly important in relation to getting the most out of the available data. ESA's (European space agency) **ENVISAT** produces around 400 terabytes of new data every year—but will be dwarfed by the Square Kilometre Array, which will produce around the same amount of data that is currently on the internet in a day.

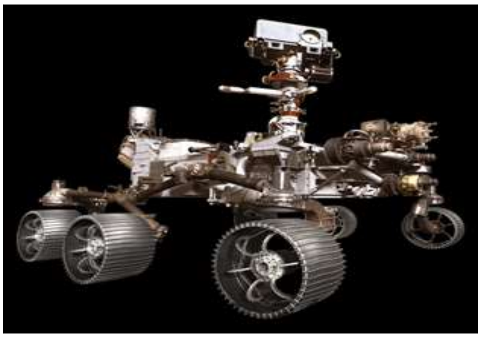


Figure 2. Mars rover 2020

iv. AI Readying for Mars: AI is also being used for trajectory and payload optimization. Both are important preliminary steps to NASA's next rover mission to Mars, *the Mars 2020 Rover,* which is, slightly ironically[4], set to land on the red planet in early 2021. See Fig(2).

v. An AI known *as **AEGIS*** is already on the red planet onboard NASA's current rovers. The system can handle autonomous targeting of cameras and choose what to investigate. However, the next generation of AIs will be able to control vehicles, autonomously assist with study selection, and dynamically schedule and perform scientific tasks. See Fig(3).

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

Figure. 3 NASA already launched three Rovers

3. ARTIFICIAL INTELLIGENCE USED IN THESE ROVERS

The AEGIS software system was originally developed for the Mars Exploration Rover (MER) mission and has been operational on the Opportunity rover since 2010. This is how AEGIS sees the Martian surface. All targets found by the A.I. program are outlined:[5] blue targets are rejected, while red are retained. The top-ranked target is shaded green; if there's a second-ranked target, it's shaded orange. These NavCam images have been contrast-balanced. As shown in Fig(4).

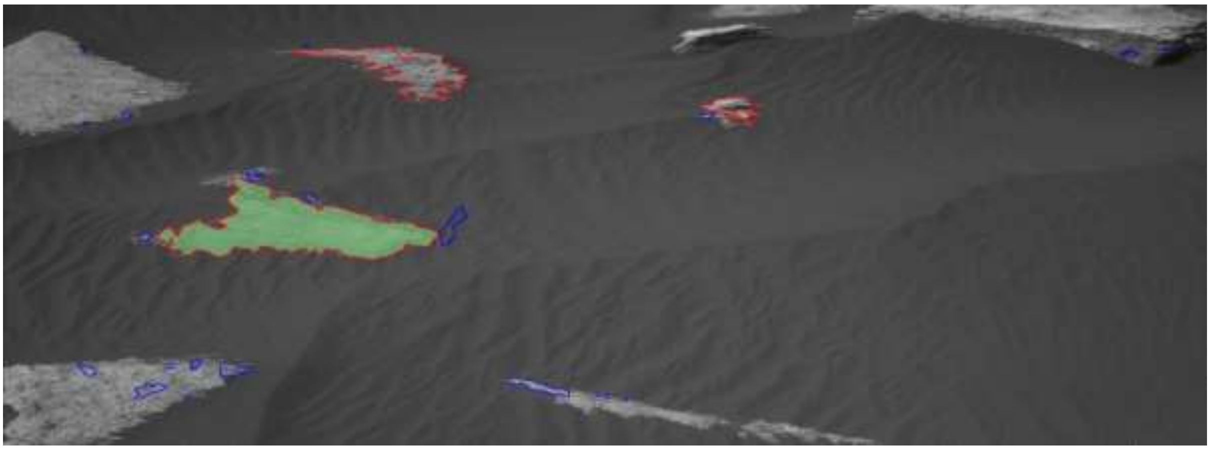


Figure. 4 AEGIS sees the Martian surface

i. Artificial intelligence is changing how we study Mars:

A.I. software on NASA's Curiosity Mars rover has helped it zap dozens of laser targets on the Red Planet this past year, becoming a frequent science tool when the ground team was out of contact with the spacecraft. This same software has proven useful enough that it's already scheduled for NASA's upcoming mission, Mars 2020. The AEGIS software, or Autonomous Exploration for Gathering Increased Science, has been used to direct Curiosity's *Chem Cam*instrument 54 times since then. It's used on almost every drive when the power resources are available for it [27]. The vast majority of those uses involved selecting targets to zap with ChemCam's laser, which *vaporizes small amounts of rock or soil and studies the gas that burns off.*

AEGIS allows the rover to get more science done while Curiosity's human controllers are out of contact. Each day, they program a list of commands for it to execute based on the previous day's images and data. If those commands include a drive, the rover may reach new surroundings several hours before it is able to receive new instructions. AEGIS allows it to autonomously zap rocks that scientists may want to investigate later. AEGIS has helped the science team discover a number of interesting minerals. On separate occasions, higher quantities of chlorine and silica were discovered in nearby rocks, information that helped direct science planning the following day[26]. AEGIS has increased the total data coming from ChemCam by operating during times when the rover would otherwise just be waiting for a command.

Before AEGIS was implemented, this downtime was so valuable that the rover was instructed to carry out "blind" targeting of ChemCam.[6] As it was carrying out commands, it would also fire the laser, just to see if it would gather interesting data. But the targeting was limited to a pre-programmed angle, since there was no onboard ability to search for a target.

Half the time it would just hit soil -- which was also useful, but rock measurements are much more interesting to scientists with the intelligent targeting AEGIS affords, Curiosity can be given parameters for very specific kinds of rocks, defined by colour, shape and size. The software uses *computer vision to search out edges in the landscape*; if it detects enough edges, there's a good chance it has found a distinct object. Then the software can rank, filter and prioritize those objects based on the characteristics the science team is looking for [25]. AEGIS can also be used for fine-scale pointing . When Curiosity's operators aren't quite confident they'll hit a very narrow vein in a rock on the first try, they sometimes use this ability to fine-tune the pointing, though it only came up twice in the past year. The upcoming Mars 2020 rover will also include AEGIS, which will be included in the next-generation version of ChemCam, called SuperCam. That instrument will also be able to use AEGIS for a remote RAMAN spectrometer that can study the crystal structures of rocks, as well as a visible and infrared spectrometer.

ii. Mars 2020 Rover's autonomous scientific instrument **PIXL**, which makes extensive use of AI. Its purpose is to investigate whether there have been life forms like stromatolites on Mars. Extremely high definition images of the components of rocks and mud as taken by PIXL, the Planetary Instrument for X-ray Litho-chemistry. On the Mars 2020 rover, PIXL will have significantly greater capabilities than previous similar instruments sent to Mars. Rather than reporting bulk compositions averaged over several square centimeters, it will identify precisely where in the rock each element resides. With spatial resolution of about 300 micrometers, PIXL will conduct the first ever petrology investigations on Mars, correlating elemental compositions with visible rock textures.

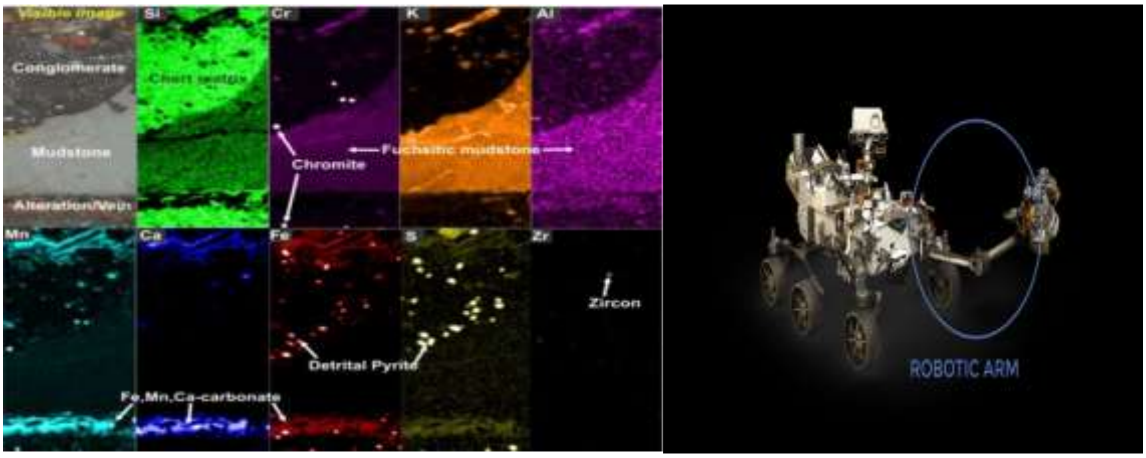


Figure. 5 Petrology investigation

PIXL's microscope is situated on the rover's arm and needs to be placed 14 millimetres from what we want it to study. That happens thanks to several cameras placed on the rover. It may sound simple, but the handover process and finding out exactly where to place the arm can be likened to identifying a building from the street from a picture taken from the roof.[7] This is something that AI is eminently suited for. AI also helps PIXL operate autonomously throughout the night and continuously adjust as the environment changes—the temperature changes between day and night can be more than 100 degrees Celsius, meaning that the ground beneath the rover, the cameras, the robotic arm, and the rock being studied all keep changing distance. As shown in Fig(5).

iii. First Mars, Then Moons

Mars is likely far from the final destination for AIs in space. Jupiter's moons have long fascinated scientists. Especially Europa, which could house a subsurface ocean, buried beneath an approximately 10 km thick ice crust. It is one of the most likely candidates for finding life elsewhere in the solar system. While that mission may be some time in the future, NASA is currently planning to launch the James Webb Space Telescope into an orbit of around 1.5 million kilometers from Earth in 2020. Part of the mission will involve AI-empowered autonomous systems overseeing the full deployment of the telescope's 705-kilo mirror. As shown in Fig(6). The James Webb Space Telescope, also called Webb or JWST, is a large, space-based observatory, optimized for infrared wavelengths,[8] which will complement and extend the discoveries of the Hubble Space Telescope. It launches in 2021.

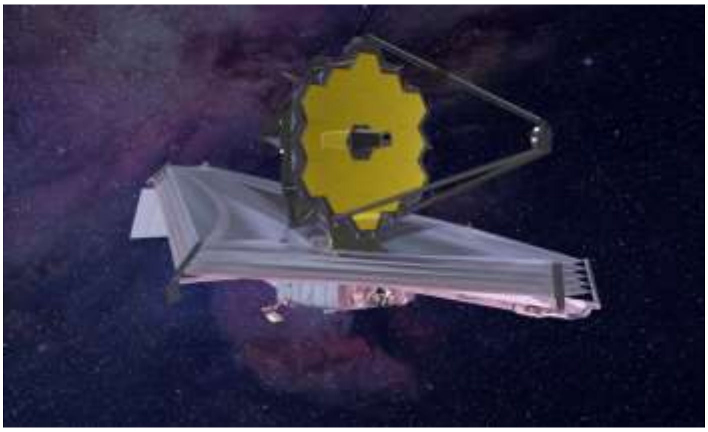


Figure .6 James Webb Space Telescope

The distances between Earth and Europa, or Earth and the James Webb telescope, means a delay in communications. That, in turn, makes it imperative for the crafts to be able to make their own decisions. Examples from the Mars Rover project show that communication between a rover and Earth can take 20 minutes because of the vast distance. A Europa mission would see much longer communication times. Both missions, to varying degrees, illustrate one of the most significant challenges currently facing the use of *AI in space exploration[9]*. There tends to be a direct correlation between how well AI systems perform and how much data they have been fed. The more, the better, as it were. But we simply don't have very much data to feed such a system about what it's likely to encounter on a mission to a place like Europa. It has been estimated that the oceans on Mars would have covered between 36% and 75% of the planet. See Fig(8).

Jupiter's moon, Europa's trailing hemisphere in approximate natural colour. The darker regions are areas where Europa's primarily water ice surface has a higher mineral content. See Fig(7).

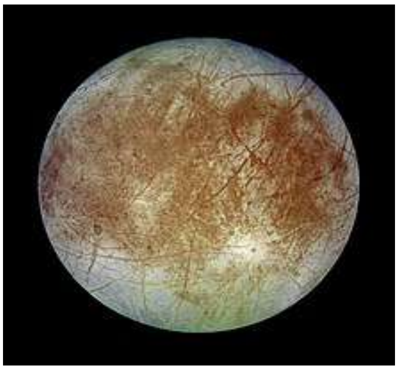


Figure. 7 Jupiter's Moon Europa

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

Figure.8 Water on Mars

iv. Terraforming Our Future Home

Further into the future, moon-shots like terraforming Mars await. Without AI, these kinds of projects to adapt other planets to Earth-like conditions would be impossible. Autonomous crafts are already *terraforming* here on Earth. Bio-Carbon Engineering uses drones to plant up to 100,000 trees in a single day. Drones first survey and map an area, then an algorithm decides the optimal locations for the trees before a second wave of drones carry out the actual planting. As is often the case with exponential technologies, there is a great potential for synergies and convergence. For example, with AI and robotics, or quantum computing and machine learning[10]. Why not send an AI-driven robot to Mars and use it as a telepresence for scientists on Earth? It could be argued that we are already in the early stages of doing just that by using VR and AR systems that take data from the Mars rovers and create a virtual-landscape scientists can walk around in and make decisions on what the rovers should explore next. As shown in Fig(9).

Figure (9): Terraforming of Mars

4. AI USED IN EXPLORATION OF EXOPLANETS

Exoplanet – Any planet beyond our solar system. There are at present two planet hunting telescopes: *KEPLER* and *TESS.*

Figure. 10& 11 KEPLER TELESCOPE and TESS TELESCOPE

i. *The Kepler space telescope* is a retired space telescope launched by NASA to discover Earth-size planets orbiting other stars. Named after astronomer Johannes Kepler, the spacecraft was launched on March 7, 2009, into an Earth-trailing heliocentric orbit. See Fig(10)

ii. *The Transiting Exoplanet Survey Satellite* (TESS) is a space telescope for NASA's Explorers program, designed to search for exoplanets using the transit method in an area 400 times larger than that covered by the Keplermission[11]. It was launched on April 18, 2018 atop a Falcon 9 rocket. Launched by SpaceX. See Fig(11).

NASA's Kepler discovered 2,682 exoplanets during its tenure and there are more than 2,900 candidate planets awaiting confirmation. Kepler's finds also allow astronomers to begin grouping exoplanets into types, which helps with understanding their origins [28]. Our solar system now is tied for most number of planets around a single star, with the recent discovery of an eighth planet circling Kepler-90, a Sun-like star 2,545 light-years from Earth. The newly-discovered Kepler-90i – a sizzling hot, rocky planet that orbits its star once every 14.4 days – was found using machine learning from Google. Machine learning is an approach to artificial intelligence in which computers "learn."[12] In this case, computers learned to identify planets by finding in Kepler data instances where the telescope recorded signals from planets beyond our solar system, known as exoplanets.

The discovery came about after researchers Christopher Shallue and Andrew Vanderburg trained a computer to learn how to identify exoplanets in the light readings recorded by Kepler – the minuscule change in brightness captured when a planet passed in front of, or transited, a star. Inspired by the way neurons connect in the human brain,*this artificial "neural network"* sifted through Kepler data and found weak transit signals from a previously-missed eighth planet orbiting Kepler-90, in the constellation Draco. While machine learning has previously been used in searches of the Kepler database, this research demonstrates that neural networks are a promising tool in finding some of the weakest signals of distant worlds.

Other planetary systems probably hold more promise for life than Kepler-90. About 30 percent larger than Earth, Kepler-90i is so close to its star that its average surface temperature is believed to exceed 800 degrees Fahrenheit, on par with Mercury. Its outermost planet, Kepler-90h, orbits at a similar distance to its star as Earth does to the Sun. As shown in Fig(12).

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

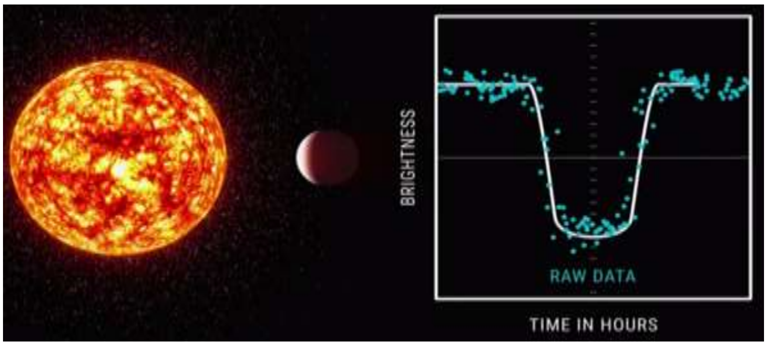


Figure. 12 Kepler-90i has been discovered by Kepler telescope using AI

The Kepler-90 star system is like a mini version of our solar system. You have small planets inside and big planets outside, but everything is scrunched in much closer. First, they trained the neural network to identify transiting exoplanets using a set of 15,000 previously-vetted signals from the Kepler exoplanetcatalogue[13]. In the test set, the neural network correctly identified true planets and false positives 96 percent of the time. Then, with the neural network having "learned" to detect the pattern of a transiting exoplanet, the researchers directed their model to search for weaker signals in 670 star systems that already had multiple known planets. Their assumption was that multiple-planet systems would be the best places to look for more exoplanets. See Fig(13).
The Transiting Exoplanet Survey Satellite (TESS) will discover thousands of exoplanets in orbit around the brightest dwarf stars in the sky. In a two-year survey of the solar neighborhood, TESS is monitoring the brightness of stars for periodic drops caused by planet transits[14][15][16]. The TESS mission is finding planets ranging from small, rocky worlds to giant planets, showcasing the diversity of planets in the galaxy. Astronomers predict that TESS will discover dozens of Earth-sized planets and up to 500 planets less than twice the size of Earth. In addition to Earth-sized planets, TESS is expected to find some 20,000 exoplanets in its two-year prime mission. TESS will find upwards of 17,000 planets larger than Neptune. Whether NASA's newest space telescope, when it eventually gets into orbit, finds intelligent life in the universe is anybody's guess, despite the hopes, dreams and mathematical probabilities espoused by scientists and star-gazers alike. But TESS, the short name for the Transiting Exoplanet Survey Satellite, will be taking intelligence into orbit with it, in the form of new equipment, navigational computers, cameras and *artificial intelligence* that can parse the data it collects.

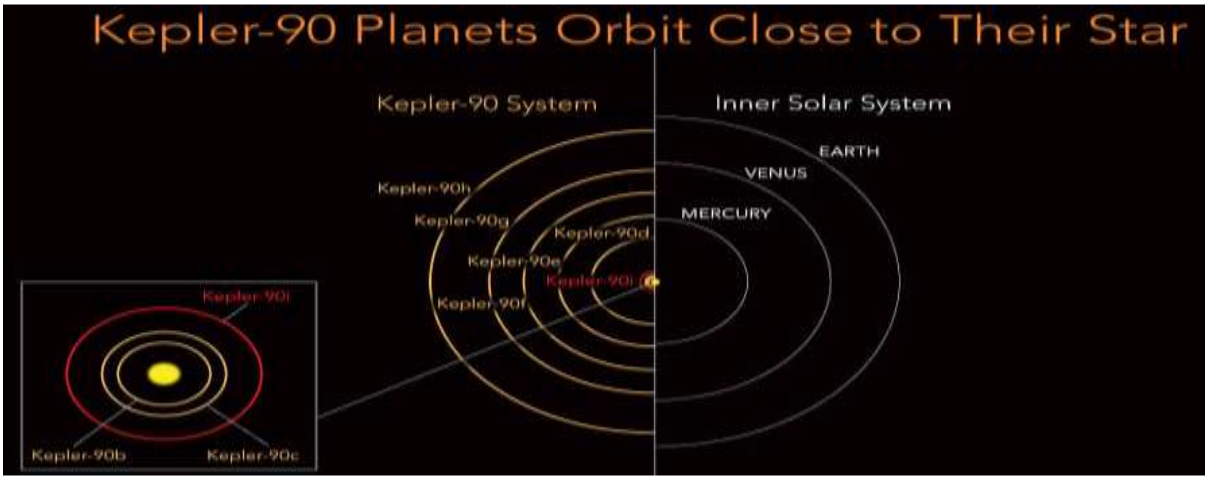


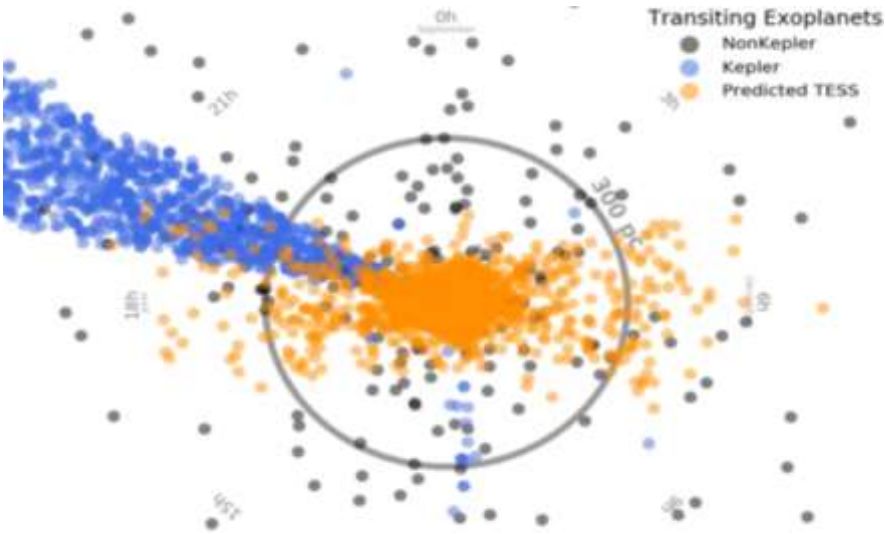
Figure.13 Kepler-90 is a planetary system observed just like our solar system

iii. Reading the Sky : For one thing, AI can help scientists see what TESS is looking at. Like Kepler, TESS will use the "transit" method for identifying planets. Kepler's camera sensors don't exactly take a picture of a planet, but look for the dimming effect caused by a planet passing in front of its star. That process can be complicated by other factors, such as the presence of other planets, the fact that the dimming effect can be very slight, and

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

other vagaries that contribute to false positives[17]. As a result, the teams behind Kepler and TESS must analyze a lot of data, which is where AI comes in. AS Shown in Fig(15). That kind of analysis could make TESS data more valuable in its wide search of the skies. Kepler, which is expected to run out of fuel and finally quit in a few months, has a pretty narrow field of vision, and looked at stars as far as 3,000 light years away. TESS will look closer to home, but with a much broader view, with its four cameras scanning an area 400 times larger than Kepler did, while focusing on stars and planets within 200 light years.

Transiting extrasolar planets are the known extrasolar planets that pass in front of the stars as seen from Earth[18][19]. There are also two transiting solar system planets as seen from Earth, Venus and Mercury. Note that this category does include planets that were detected by radial velocity first.



Figure(14) : Transiting Exoplanets through Kepler and Tess telescopes

5. ROLES OF ML AND DL, THAT LAY PATHS TO ACHIEVE AI

Artificial intelligence can be achieved through *machine learning (ML),* which teaches machines to learn for themselves. ML is a way of "training" a relatively simple algorithm to become more complex. Huge amounts of data are fed into the algorithm, which adjusts and improves itself over time. In ML, machines process information in a similar way to humans by developing artificial neural networks. This type of artificial intelligence has taken major leaps forward since the dawn of the internet. *Deep learning (DL)* is a specialised technique within ML, whereby the machine utilises multi-layered artificial neural networks to train itself on complex tasks like image recognition[20]. This can happen via supervised learning (e.g. feed the system Moon and Earth pictures until it can successfully identify both types) or unsupervised learning, where the network finds structure by itself. As shown in Fig(15).

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

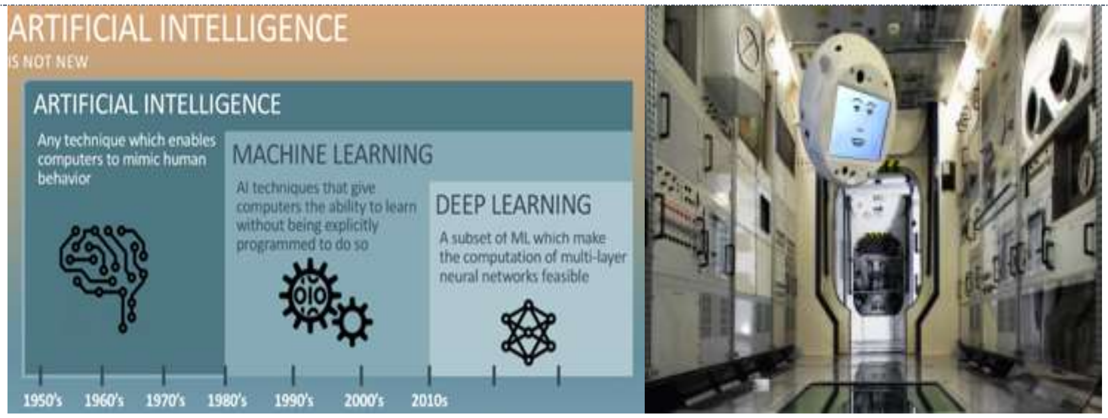


Figure.15 Artificial intelligence used in spacecrafts

Currently spacecraft need to communicate with Earth to do their job, but developing autonomous spacecraft that use artificial intelligence to take care of themselves would be very useful for exploring new parts of the Solar System and reducing mission costs[21]. An older study on autonomy requirements for future spacecraft constellations identified the necessary technology to improve automation, including autonomous navigation, automated telemetry analysis and software upgradability.

Deep learning systems learn through either unsupervised data feeding or reinforced learning. There are many possible applications of DL, including automatic landing, intelligent decision taking and fully automated systems. ESA's Advanced Concepts Team (ACT) is very active in this area. In particular the ACT has recently studied evolutionary computation, which involves writing computer code in such a way that all evolutions are considered. The better results are kept, and the worse are rejected — just like in biological evolution. One application of this has been to calculate the trajectories of the planets. As shown in Fig(16).

Figure. 16 Astro Drone

The ACT has also investigated using ML in the area of guidance, navigation and control. In particular, they looked into using big swarms of small robots that share their information in a network: if one robot learns from experience that a certain manoeuvre is beneficial, the whole swarm learns this [29]. This is called hive learning[22]. Other examples of AI activities that the ACT has supported include investigating a community science mobile phone app that will improve the autonomous capabilities of space probes and optimising star tracking systems. Under ESA's basic activities a number of studies have looked into using artificial intelligence for space applications and spacecraft operations. As shown Fig(17).

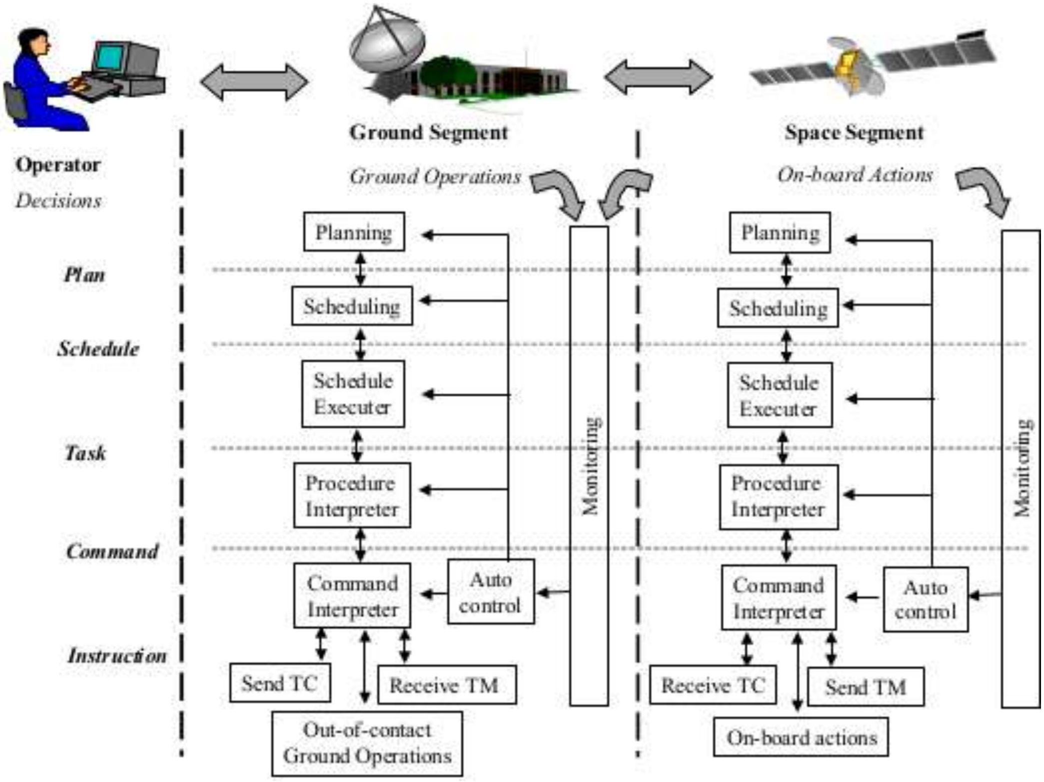


Figure. 17 Flowchart of Spacecraft Operartions

Space technology and space applications produce a huge amount of data, including spacecraft telemetry data and product data — the useful scientific data that a spacecraft gathers, for example information about Earth from an Earth observation satellite. Another application of ML includes analysing all this data[23][24]. One study carried out under ESA's Basic Activities inputted historical mission data into ML algorithms to search for new features useful for future telemetry checking, command verification and procedure writing processes.

6. CONCLUSION

The space industry will tend to look for more autonomy in the devices they use, which is where AI can be a powerful tool. AI brings an *age of adaptability*. Thanks to AI, the time when an organization would dedicate millions of dollars for a system that couldn't evolve during its use is over. NASA already relies on spacecrafts and devices to explore the farthest space. Even Elon Musk, who wants to inhabit Mars, has defined AI as probably the "biggest threat" to humanity. So whether you like it or not, until we find another and better solution, you'll have to make do with AI for a while.

REFERENCES

[1] https://singularityhub.com/2018/10/07/ais-kicking-space-exploration-into-hyperdrive-heres-how/
[2] https://blog.eduonix.com/artificial-intelligence/artificial-intelligence-space-exploration/
[3] https://www.esa.int/Enabling_Support/Preparing_for_the_Future/Discovery_and_Preparation/Robots_in_space2
[4] https://www.nature.com/articles/d41586-017-00626-6
[5] https://arstechnica.com/information-technology/2018/12/unite-day2-2/
[6] https://www.nasa.gov/feature/goddard/2017/nasa-explores-artificial-intelligence-for-space-communications
[7] https://www.space.com/39984-mars-2020-rover.html
[8] https://www.nasa.gov/feature/goddard/2019/nasa-takes-a-cue-from-silicon-valley-to-hatch-artificial-intelligence-technologies

ISSN: 2277-9655
Impact Factor: 5.164
CODEN: IJESS7

[9] http://blog.re-work.co/how-nasa-uses-ai-for-space-exploration/
[10] https://www.geeksforgeeks.org/how-does-nasa-use-machine-learning/
[11] https://www.nasa.gov/press-release/artificial-intelligence-nasa-data-used-to-discover-eighth-planet-circling-distant-star
[12] https://exoplanets.nasa.gov/news/1565/discovery-alert-two-new-planets-found-by-ai/
[13] https://phys.org/news/2019-03-planets-artificial-intelligence.html
[14] https://emerj.com/ai-sector-overviews/ai-applications-for-satellite-imagery-and-data/
[15] https://archive.stsci.edu/kepler/
[16] https://www.shadowrobot.com/blog/ai-space-industry/
[17] https://www.business-standard.com/article/international/did-kepler-make-major-discovery-with-ai-s-help-nasa-to-reveal-on-thursday-117121100471_1.html
[18] https://www.nasa.gov/feature/nasa-is-taking-a-new-look-at-searching-for-life-beyond-earth
[19] https://www.esa.int/Applications/Telecommunications_Integrated_Applications/Technology_Transfer/AIKO_Autonomous_satellite_operations_thanks_to_Artificial_Intelligence
[20] https://www.nasa.gov/audience/forstudents/5-8/features/nasa-knows/what-is-a-satellite-58.html
[21] https://ieeexplore.ieee.org/document/7444544
[22] https://astrobiology.nasa.gov/news/pixl-a-new-nasa-instrument-for-ferreting-out-clues-of-ancient-life-on-mars/
[23] https://www.space.com/24903-kepler-space-telescope.html
[24] https://exoplanets.nasa.gov/tess/
[25] G. Sharma and A. Kumar, "3D Weighted Centroid Localization Algorithm for Wireless Sensor Network Using Teaching Learning Based Optimization," Communications in Computer and Information Science Information, Communication and Computing Technology, pp. 117–127, 2017.
[26] G. Sharma and A. Kumar, "Modified Energy-Efficient Range-Free Localization Using Teaching–Learning Based Optimization for Wireless Sensor Networks," IETE Journal of Research, vol. 64, no. 1, pp. 124– 138, Jul. 2017.
[27] G. Sharma and A. Kumar, "Fuzzy logic based 3D localization in wireless sensor networks using invasive weed and bacterial foraging optimization," Telecommunication Systems, vol. 67, no. 2, pp. 149– 162, May 2017.
[28] G. Sharma and A. Kumar, "Dynamic Range Normal Bisector Localization Algorithm for Wireless Sensor Networks," Wireless Personal Communications, vol. 97, no. 3, pp. 4529–4549, Mar. 2017.
[29] G. Sharma and A. Kumar, "Improved DV-Hop localization algorithm using teaching learning based optimization for wireless sensor networks," Telecommunication Systems, vol. 67, no. 2, pp. 163– 178, Aug. 2017.