Survey of Autonomous Systems in Space

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This paper examines the history and future applications of autonomous operations in space as a modern solution to an array of limitations that recent research has only just started utilizing and continues to explore. There is a complex history of autonomous operations in space and some of its potential benefits include reducing production rates, costs, communication delays, and dangerous environments that pose threats to human life. The construction of the International Space Station is a prime example of quality work that took over twenty years to complete with human intervention. Research over the past couple decades have led to working designs and pathways for future development. NASA developed an Autonomous Voice Assistant prototype for one of their existing command programs, the NASA Platform for Autonomous Systems. In January of 2021, NASA funded CubeSat Pathfinder for Autonomous Navigation to develop a low cost navigation and architecture platform. The applications of autonomous technology can be infinitely compounded by the dynamic capabilities of mechanical operation, robotics, AI, and code infrustructures. Autonomy would cut time and cost challenges for building satellites, taking photographs, transportation, and adaptive controls. Human safety in testing, exploration of unknown environments, and risk management would not be so prevalent as a primary concern. Outside of astronautical applications, the impact of autonomous technology can reach a global scale including agricultural efficiency, ground transportation, and menial tasks in entry level jobs, which affects the disabled community in competing efficiencies and cost. The legal and ethical impacts are still in consideration with regards to patent law, as well as the implications of sharing information, research, and analysis between nations. Autonomous systems have the potential to transform modern technology in many aspects.

I. Introduction

Autonomous operations in space have occupied researchers' strategies for the past fifty years. It is a modern solution to an array of limitations that recent research has only just started utilizing and continues to explore. Some of the more prevalent constraints that have potential to be overcome include: production rates, cost, communication delay, and dangerous environments that pose threats to human life. The purpose of translating modern operations to autonomous systems is primary for efficiency and expanded exploration in functions that are currently limited by the required human intervention.

The applications of autonomous technology can be indefinitely compounded by the dynamic capabilities of mechanical operation, robotics, AI, and code infrustructures. NASA developed an autonomous voice assistant platform for one of their existing command programs, NPAS. Caltech worked on a design for next generation flying ambulances. Human safety in testing, exploration of unknown environments, and risk management would not be so prevalent as a primary concern. The impact of autonomous technology, outside of astronautical application, can extend on a global scale to increase efficiency in agriculture, ground transportation, and entry level jobs. Some controversy may arise as the need for humans in the workforce becomes more and more obsolete. The legal and ethical impacts are still in consideration with regards to patent law and the implications of sharing information, research, and analysis between nations. Consciousness of the human mind and procedural code play significant roles in the breakdown of ethics and the laws that surround new technology are often ambiguous and can be easily manipulated. A human's capacity to think, adapt, and consider conscientiousness may not be replicated in an autonomous system, which may inflict hesitation in the rapid expansion of the many applications of this technology.

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II. Autonomous Systems Over Time

The International Space Station exceeded ten years in its making, in part due to its mass, weight, and many components. It would have been impossible to build completely on the ground and then launch up into space in one piece; there is no spacecraft with that kind of capability today. However, the interaction between human and machine in space as well as the communication necessary to build such a structure can be remedied relatively easily when replaced with robotics, code, and artificial intelligence. Applied systems are being developed today to increase the efficiency of tasks that can be completed objectively and with basic instruction, to eliminate the need for human interference.

A. NPAS

NASA is working on a few projects that utilize an unspecified bridge connecting inputs from voice command or other inputs and programmed outputs with learning capabilities. In the Spring of 2020, NASA developed a Platform for Autonomous Systems (NPAS) to interact with their Autonomous Voice Assistant prototype. NPAS is a reusable and adaptive platform that incorporates tools and strategies for autonomous systems to advance anomaly detection, diagnostics, containing knowledge into a set of data, and awareness as well as predict failures and send alerts given a specified time or command. The four main components of this system include a speech recognition unit, a natural language processing unit, a bridge, and a voice interaction module. The only real usage in the past for this kind of technology was in NASA's high gas facility at the Stennis Space Center and their lunar habitat module. The voice commands are programmed for common phrases, and researchers are developing a code that enables learning and adaptation to recognize the individual in control so that multiple can be used simultaneously though many connections entering one bridge though the G2 expert system. EVA would use voice commands similar to Siri and Alexa, and includes four main components: a speech recognition unit (SRU), a natural language processing unit (NLP), a bridge, and a voice interaction module (VIM). NASA plans to use NPAS and EVA to improve missions and command by making it adaptable to any environment.

B. Autonomous Navigation and Interstellar Space

As of January 2021, NASA is funding Pathfinder for Autonomous Navigation that aims to advance low-cost and highly-capable architecture for autonomous CubeSat rendezvous and docking. CubeSat's mission is to distribute sensor networks, satellite repair missions, and on-orbit assembly of large structures. Recent methods of autonomous navigation include recognizing the doppler shift and relativity. Relativistic spacecraft in Interstellar space utilizes different reference frames, distances to stars, and astrometric and spectrometric calculations to estimate position and velocity. Today, there are many challenges facing travel through deep space, and navigation is only one part of it. The costs outweigh the potential benefits with no major breakthroughs in communication, propulsion, and required speed considering the massive distance. Current technology uses onboard radio transponders for navigation, which makes the development of autonomous algorithms so appealing using Newtonian mechanics. Still, the time delay compromises accuracy to an uncorrectable extent with distance, and the uncertainties surrounding the interstellar medium (ISM) are too vast to account for in any algorithm today. According to a study done by Draine, high-energy particles change the velocity of the spacecraft, experiencing Lorentz force curving its trajectory. The strength and orientation of the field are unknown which highlights autonomous navigation as the only attainable method. Traditionally, velocity and position are estimated relative to the sun or earth; shortcomings arise when estimates are made from prior knowledge and current observations. Einstein's theory of relativity plays a role in calculating distances between objects in space as additional data in regards to navigation. Four-dimensional spacetime diagrams are useful in calculating infinitesimal distance, and one relativistic autonomous navigation algorithm developed at Cornell, independently measures distances to stars with sufficient accuracy, which is the key to autonomy in the ISM.

III. Applications of Technology

In space, autonomous systems can extend to almost every discipline regarding satellites, photography, adaptive controls, and transportation. Additionally, autonomy would minimize the risk associated with exploring unknown environments and terrains in space. The risk for human safety would ultimately diminish as circumstantial risk is replaced with autonomy, and there is no longer a need for human interference. Some of the applications of autonomous systems in space discussed can be used outside of an astrological context. For instance agriculture researchers have implemented autonomous tractors in various countries; some are still developing autonomous capacities in picking produce and other physically laborious tasks. Caltech launched the Next Generation of Autonomous Flying Ambulances to eliminate pilot cost, terrain based and vertical takeoff-and-landing (VTOL) obstacles, accident risk, time lost from traffic, and buildings that inhibit perpendicular routing for speed. This would also improve urban mobility and rural accessibility with far range capabilities, and widen the evolution of rapid medical service. Autonomy would cut time and cost challenges for building satellites, taking photographs, transportation, adaptive controls, reduce accident risk, avoid traffic and building interference, and avoid ground based obstacles. The benefits outline the elimination of the cost of pilots as well as the inability to land in rough terrain or near busy highways like some of the issues helicopters face now. The model encompasses disassemblable wings for low-footprint landing on roads, hover features for as long as eight minutes, backwards mobility, optimally canted motors for its mission profile, and design features to address VTOL challenges. The future seems unlimited in the ways autonomous systems can apply; once a technology is manipulated to adapt, it can be inserted into almost every sector of life.

IV. Ethical and Legal Implications

The procedural and patent law surrounding autonomous systems, particularly in space, is relatively new, and expectedly in ongoing debate. The global impact of such technologies begs to ask how international privacy laws and shared research between nations should be handled, and ultimately comes down to individual agencies and external precedent. While the minimization of risk of human life seems objectively progressive, the obsoletion of work that can be done by unskilled, uneducated, or handicapped individuals can potentially rewrite the structure of the workforce and damage acceptance of such individuals in entry-level jobs even with positive intention in pursuit of efficiency. This affects the disabled and mentally ill communities as competition for efficiency and cost reduction may outweigh skill. An attempt to automate some aspects of life can also lead down a slippery slope, and question where to draw the line. In the medical field, researchers debate how much a computer can and should generate responses and decisions to a given situation. There is arguably more complexity to the human mind than a progression of algorithms that factor in a level of humanity that can be viewed positively or negatively depending on each circumstance.

V. Conclusion

Considering the possibilities of usage in the future, some of the negative side effects may be avoided if comercial adaptation of the technology is regulated. Alternative avenues in the aerospace industry are being explored at varying levels. The U.S. Army conducted research on the autonomous flight and guidance control system for the Black Hawk Helicopter. Most ardently the research explored avoidance guidance in the Risk Minimizing Obstacle Field Navigation algorithm, Safe Landing Area Determination landing site selection, and situational awareness for impared visual environments. As with any new technological development, ethical implications are always to be considered. The Principle of Double Effect allows good actions with good intentions, although wrong outcomes may follow, given that the good sought and the wrong accepted have balanced proportions. Translated, the good of the technology produced coupled with the good intentions behind the design can be accepted. This is so, only as long as the positive progress and plan for new jobs outweigh the substantial decline of jobs that will become obsolete with the installation of autonomous systems.

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