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ARTIFICIAL INTELLIGENCE AND DIGITAL TWIN-POWERED SMART LUNAR GATEWAY AND PLANETARY EXPLORATION MISSIONS

Abstract

In recent years, there has been significant interest from the National Aeronautics and Space Administration (NASA), European Space Agency (ESA), Canadian Space Agency (CSA), Indian Space Research Organization (ISRO), and other space agencies, space companies, and research organizations worldwide for exploration for Moon, Mars and beyond involving unmanned and manned missions. There have been several missions proposed and some of them (Artemis I, an unmanned mission for Lunar exploration) have been flown as well. All these missions involve significant challenges ranging from the assembly of large spacecraft such as the Lunar Gateway, conducting breakthrough scientific experiments onboard, communicating scientific results with the Earth ground station, and keeping spacecraft fully operational for longer duration (such as 20 or 30 years). In order to solve these challenges and achieve significant cost savings and sustainability of these missions, these challenges must be performed autonomously with a return on best scientific results compared to traditional predominant manual-driven operations used for International Space Station and other planetary missions. Artificial intelligence can play a major role in achieving these goals. In this paper, an artificial intelligence (AI) and digital twin (DT)-based solution, called 2PCube will be presented for Lunar Gateway. This solution involves an innovative autonomous multi-agent framework with a hybrid method wherein the data-driven method is combined with the model-based method. Reinforcement learning is considered along with convolutional neural networks (CNN) layers, long short-term memory (LSTM), and conventional neuron layers for autonomous fault detection, isolation, and prognosis of spacecraft subsystems. The selection of hyperparameters of the hybrid model is automated and optimized via genetic algorithm, particle swarm optimization, and differential evolution. Autonomous assembly operations including modular design concepts will be proposed for faster assembly followed by autonomous scientific experiments for finding breakthrough results. Next, onboard data communication with the Earth ground station will be considered for autonomous management of communication bandwidth and data. Furthermore, predictive maintenance of all subsystems (fault detection, isolation, prognosis, and recovery) of Lunar Gateway with a focus on its attitude and orbit control system will be examined to achieve sustainability and a longer period of its operation. Finally, the proposed methodology will be discussed for future Mars and other planetary exploration missions.