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Development of Extraterrestrial Food Production Systems: An Application of Mechatronics and the Internet of Things

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Significant resources are being directed towards the development of bio-regenerative food systems by NASA and others to support long-duration space flights and to decrease the mass and volume of pre-packaged supplies (Perchonok et al, 2012). The space mission is supported by research in controlled-environment agriculture (CEA) based on indoor sealed environments that make extensive use of light emitting diodes (LEDs) for illumination, renewable energy systems, recycled water, together with automatic control of temperature, humidity and CO_2 levels with natural and artificial growth media and synthetic biology (Benke and Tomkins, 2017; O'Leary and Benke, 2018).

Potential applications of CEA include food production in remote and inhospitable environments such as deserts, spacecraft and submarines and on other planets where endurance is constrained by human factors rather than the range provided by propulsion systems. The task is difficult and not to be underestimated, but it is not impossible. Bioengineering and OR can provide a baseline and methodology to support research originating from terrestrial CEA systems, such as so-called Vertical Farms, which are now appearing in smart cities and highly connected urban clusters around the world (Benke and Tomkins, 2017).

Design and development of CEA systems requires software and hardware support from many disciplines, including mechanical engineering, electronics, biosystems engineering and information and communications technology (ICT). The combination of these disciplines has been termed mechatronics, which reflects its origins in hybrid systems based on integration of electronics with mechanics. In the specialised field of extraterrestrial CEA, to assure fail-safe operation, additional disciplines contribute to the mix, including space medicine and aerospace engineering. Associated with the field of mechatronics is the emerging field of Internet of Things (IoT), which involves network connectivity of sensors, software and actuators that support data processing and the operation of robots and adaptive systems. The IoT has many applications, including smart homes, smart cities, manufacturing industry and food production systems (Tzounis et al, 2017).

There are many problems and research challenges presented by mechatronic and IoT systems, some of which can be well addressed by OR using computer simulation with support from artificial intelligence (AI) at the systems level (O'Leary and Benke 2018). The challenges include latency issues for communication with Earth together with the need for fail-safe reliability engineering. A recent study reviewed progress in applying OR methods to IoT systems and noted that OR methods are now being applied to some of the major IoT research challenges, particularly Big Data, in the context of data management and predictive analytics (Ryan and Watson 2017). In agriculture, the application of Big Data offers support to farming operations, facilitation of real-time operational decisions and the redesign of legacy business processes (Wolfert et al, 2017).

A research framework is proposed for CEA on Earth as a platform to investigate extraterrestrial food production for long-duration space flights and future missions to Mars. Reasons for space travel and colonisation are identified together with problems faced for food production. Advantages and disadvantages of CEA are discussed. The important role of IoT is highlighted and problems in information acquisition and transmission are described in the context of recent experimental work. The role of simulation is demonstrated as a cost-effective assessment tool.

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