Pervasive Computing in Space

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Imagine "astronauts working in a lunar habitat with Internet of Things devices." In response to such a simple prompt, within seconds a generative AI rendered the image above, which enamored this issue's guest editors with its fanciful, seemingly humorous depiction of what appears to be a pair of space-suited engineers engaged in something like a hackathon while sitting in the lunar dust with coffee cups nearby. Beyond being a fun way to kick off this Special Issue on Pervasive Computing in Space, this image underscores how quickly world-changing technology is now being unleashed. Just within the last year or so, AI has moved beyond mastering niche applications and into popular use with increasingly sophisticated chatbots and image-generating environments that win art contests alongside humans. Regardless of the intensifying discussion this sparks about machine creativity and intelligence, AI has now become a quickly moving landscape. We do not know how far this ride will go and where the next roadblocks, always close-at-hand in previous years, will manifest.

Digital Object Identifier 10.1109/MPRV.2023.3263366
Date of current version 14 June 2023.

Space technologies have likewise brought us to a new renaissance, where the limitations of decades past show signs of relaxing. It has become abundantly clear that we are living at the dawn of a new Space Age. The dreams of life in space that humanity has pursued since the 1960s have been born anew, tempered by new technological capability. Multiple governments have recently joined the ranks of the space-faring nations, together with a multitude of new players at the table as the industry develops a stronger role. Launch capability is expanding enormously, while bold ideas of things to do in space loom closer and become more feasible. The next few years, for example, will usher in commercial orbital habitats along with the next phase of human exploration of the moon enabled by a plethora of lunar rovers, landers, and orbiters—all sponsored by a cornucopia of governments and industries following their own visions of a profitable and expansive future. Looking further out, we are on the threshold of an amazing portfolio of missions to the outer planets and asteroids that, together with new space-based observatories and science missions, will vastly expand human knowledge and perhaps find evidence of extraterrestrial life (or the lack of it). Humanity is renewing its push into space, and as we reach further, we will become increasingly changed by the technology we bring along and the answers we uncover.

The first Space Age essentially defined cutting-edge technology, as ideas like VLSI and wearable physiological monitoring, for example, trickled down from NASA missions into commercial reality. Now, much of the transfer flows the other way, as technology developed for terrestrial applications finds a path into the next generation of space missions—and the concepts, engineering, and design of pervasive computing systems and the Internet of Things (IoT) will be main passengers on that conveyor. It is very much a symbiotic relationship, however; the harsh and still-unconventional realities of space will shape research in all aspects of what our community does into fascinating extremes. Accordingly, we have assembled a set of articles in this Special Issue that evolves concepts explored under pervasive computing into space applications.

Over the last years, researchers focusing on health and wellness applications in pervasive computing have been exploring the identification of vocal features that aid in detection of depression and other mental ailments. As very long duration space missions can exasperate stress and tension between a crew and challenge overall mental wellbeing, in [A1], Paromita et al. apply techniques that have been used for such affective speech processing to detect positive and negative microbehaviors between team members in simulated space missions.

One of the main enabling factors behind pervasive computing has been the ubiquity of agile and dependable communication links at all scales. In [A2], Gordon et al. explore the role of optical communication for a variety of lunar missions and operations. While laser communication between terrestrial satellites and even across long-haul distances for planetary missions has been explored and, in some cases, implemented and demonstrated, this article summarizes its lunar potential and suggests various use cases.

In [A3], Ekblaw et al. chronicle how a research group long steeped in pervasive computing has recently pivoted into space research. Several of their projects, ranging from e-textile linings for spacecraft to the world's smallest planetary rover, are traced from their origins in the pervasive community into actual microgravity and space deployment.

For over a decade, researchers in the greater pervasive community have explored ultra-low-power, chip-scale smart wireless sensor packages—these have evolved from Kris Pister's "Smart Dust," to the University of Michigan's "MicroMote," to Shyam Gollakota's electronic "dandelion seed," for example. Space applications for these platforms abound at a radical, but rapidly approaching, frontier. We hence close this issue with an invited Spotlight piece by Manchester and Loeb [A4] that traces the miniaturization of space probes from today's microsats down to orders-of-magnitude smaller evolving "chipsats." Beyond overviewing the technology, this article takes us on a whirlwind ride through possible applications that range from distributed probes of planetary atmospheres to their use on laser-propelled interstellar missions.

As terrestrial technology advances, the concepts of how, what, and why we go into space will also evolve—witness how most of the wonderful space-opera stories that many of us grew up with decades ago seem so dated now (albeit, they are still wonderful stories). We live at a special juncture where new technologies and realities, many of which are gestating within the pervasive community, are rapidly shaping how we will live on Earth and how we will enter into space. It is now our responsibility to shape the space operas for the next generation with new technologies that can lead to lunar habitation and beyond. To say the least, it will be an exciting ride!

APPENDIX: RELATED ARTICLES

[A1] P. Paromita, A. Khader, S. Begerowski, S. T. Bell, and T. Chaspari, "Linguistic and vocal markers of microbehaviors between team members during analog space exploration missions," *IEEE Pervasive Comput.*, vol. 22, no. 2, pp. 7–18, Apr.–Jun. 2023.

[A2] N. G. Gordon, D. Marsili, I. Nikas, and N. Boschetti, "Lasers on the moon: Recommendations for pioneering lunar communication infrastructure," *IEEE Pervasive Comput.*, vol. 22, no. 2, pp. 19–25, Apr.–Jun. 2023.
[A3] A. Ekblaw et al., "From UbiComp to universe—Moving pervasive computing research into space applications," *IEEE Pervasive Comput.*, vol. 22, no. 2, pp. 27–42, Apr.–Jun. 2023.
[A4] Z. Manchester and A. Loeb, "Space: The ultimate computational edge," *IEEE Pervasive Comput.*, vol. 22, no. 2, pp. 43–48, Apr.–Jun. 2023.

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