From UbiComp to Universe Moving Pervasive Computing Research Into Space Applications

The paper explores how pervasive computing concepts and technologies can be applied to space exploration. The authors discuss several projects they have developed in their Responsive Environments Group at the MIT Media Lab, including: wearables, smart fabrics, sensor networks, cross-reality systems, pervasive/reactive displays, microrobots, responsive space habitat interiors, and self-assembling systems for in-space infrastructure.

Electronic Textiles, Wearable Systems, and Surface Diagnostics: The authors have developed electronic textiles that can be woven into spacecraft structures to detect damage from debris impacts. They have also developed wearable systems that can monitor the health of astronauts in microgravity.

Peristaltic Suit: The authors have developed a wearable compression system called the Peristaltic Suit that can help to prevent the health problems that astronauts experience in microgravity.

SpaceShoe: The authors have developed an intelligent dynamic foot restraint called the SpaceShoe that allows astronauts to walk on ferromagnetic surfaces.

SpaceHuman: The authors have developed a wearable soft-robotic appendage called the SpaceHuman that can help astronauts to grasp objects and move around in microgravity.

AstroAnt: The authors have developed a swarm of miniature robots called AstroAnts that can be used to inspect the outside of spacecraft for damage.

TESSARAE: The authors have developed a system called TESSARAE for self-assembling space habitats. The habitats are composed of individual tiles that can be assembled into a variety of shapes.

The authors argue that pervasive computing technologies have the potential to revolutionize space exploration by making it more efficient, sustainable, and comfortable for astronauts. They believe that these technologies could eventually lead to the development of permanent human settlements in space.

Humanity's increased presence in space is creating opportunities for terrestrial technologies to be adapted for space applications. The work suggests that Pervasive Computing principles will play a significant role in the near-term space future. This work is indicative of an important trend in the space industry, as academic research is rapidly maturing and influencing space-related products and experiences.

Tidmarsh, is a Cranberry farm near Plymouth, that has been transformed into a wetland through extensive restoration. This site has been equipped with a network of low-power environmental sensor nodes; The data collected from this network is available in real time and facilitates various explorations into how to learn from large-scale, long-term sensor installations.

The large, outdoor, multimodal, low-power wireless sensor network (WSN) that they designed for deployment at Tidmarsh Farms, inspired researchers to evolve different kinds of nodes suitable for lunar deployment.

Key features of the LunarWSN include:

1. Sensor Nodes: Each sensor node in the **LunarWSN** is a small, light, and modular unit, designed to be easily customizable. Each node is equipped with solar cells to guarantee powering functionality, regardless of landing orientation. After deployment, these nodes can anchor themselves on the lunar surface, set up a wireless communication network, and begin their sensing operations.
2. Ballistic Deployment: These sensor nodes are designed to be deployed ballistically from a rover or lander to regions of interest, including areas that might be unsafe or impractical for rovers or landers to reach. This capability is crucial for exploring areas that are difficult to access with traditional rovers or landers. After the nodes are deployed to the lunar surface.
3. Localization and Communication: The sensor nodes are equipped with wireless ranging and communication capabilities, allowing each node to be localized using triangulation. This forms an expandable wireless sensor network (LunarWSN) on the lunar surface.
4. Measurement and Analysis: The nodes are equipped with sensors, such as an impedance sensor, to measure the permittivity of the lunar soil, which helps estimate the presence of water. This is vital for acquiring meter-scale resolution knowledge of lunar water distribution and other dynamic phenomena.
5. Resource-Intensive Habitats: The project is aimed at facilitating future lunar missions by leveraging local resources, reducing cost and risk. It particularly focuses on detecting water, which is a crucial resource for drinking and as fuel for rockets and spacecraft.
6. Hardware Redundancy: The design includes hardware redundancy to reduce the chances of failure, ensuring reliable data collection even in the harsh conditions of the lunar environment.

Here we discuss the application of virtual and augmented reality (VR and AR) in space mission operations, the focus is on the development of "Digital Twins" and "Cross-Reality" experiences, which allow users to interact with real environments through virtual representations. This approach has been explored since 2004, resulting in projects like **DoppelLab and DoppelMarsh**. These projects use multimodal sensor data to create virtual analogs of real environments.

Two experiments are highlighted:

The first Experiment involved a digital-twin 3D model of a four-wheeled rover provided by Rover Robotics. This model was deployed in a room, which was mirrored by an artistic rendering of a lunar environment created using the Unity game engine. The user interface and interaction for this experiment were designed to mimic a real-time strategy (RTS) game, allowing the user to control a virtual model of the rover by setting waypoints. The virtual rover will follow the path set by the waypoints, while keeping track of previous traverses through a color scheme reference.

The second experiment focused on a SPOT quadrapod, which is a robot provided by Boston Dynamics. This robot was deployed in an outdoor rocky environment. The SPOT quadrapod was augmented with a LiDAR and a custom multi-purpose 3D-printed payload. This payload acted as a container for various data-collection cameras and devices, including a 360 video camera and higher resolution LiDAR scanners. The collected sensor data could be displayed as a video overlay and integrated into the UNITY visualization environment.

This section discusses the concept of smart buildings in the era of the Internet of Things, specifically focusing on how they can dynamically adapt to the needs of their occupants using data from wearable and in site sensors. Projects like the Mediated Atmospheres systems are highlighted, which demonstrate how indoor environments can respond to an occupant's physiological state by controlling elements like lighting, projected images/video, ambient sound, and even airflow and smell. This approach aims to maintain occupants in a high focus-restoration state.

The concept has gained interest for long-duration space flights, where crew members face psychological challenges due to extreme sensory deprivation and loneliness. These pods can provide a reactive audio/video display or personalized enclosure, adapting in real-time to the occupant's activities and emotional states. This could range from creating an engaging, focus-oriented environment like a library to a more relaxing sensation like a forest stroll.

The responsive system utilizes non intrusive sensing of the occupant's activities, work habits, and reactions to environmental changes, allowing for the creation of personalized response models for multimedia interaction.

A prototype of this experience is the Tidmarsh Living Observatory Portal, a multisensory experience that immerses a user in the natural environment through visuals, smells, and sounds, along with live and recorded data from the site. The experience is tailored for individual users and can last from three minutes to half an hour, avoiding the constraints and disorientation often associated with VR goggles. Yet, as people go into space, they will be transformed by the technology they bring along. This will be defining, and as a research group grounded in Pervasive Computing, researchers have been delighted to open a few views into this quickly moving future and expose new pathways toward Pervasive space implementation.