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New technology innovations with potential for space applications

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Abstract

Human exploration and development of space is being pursued by spacefaring nations to explore, use, and enable the development of space and expand the human experience there. The goals include: increasing human knowledge of nature's processes using the space environment; exploring and settling the solar system; achieving routine space travel; and enriching life on Earth through living and working in space. A crucial aspect of future space missions is the development of infrastructure to optimize safety, productivity, and costs. A major component of mission execution is operations management. NASA's International Space Station is providing extensive experience in both infrastructure and operations. In view of this, a vigorously organized approach is needed to implement successful space-, planet-, and ground-based research and operations that entails wise and efficient use of technical and human resources.

Many revolutionary technologies being pursued by researchers and technologists may be vital in making space missions safe, reliable, cost-effective, and productive. These include: ionic polymer–metal composite technology; solid-state lasers; time-domain sensors and communication systems; high-temperature superconductivity; nanotechnology; variable specific impulse magneto plasma rocket; fuzzy logic; wavelet technology; and neural networks. An overview of some of these will be presented, along with their application to space missions.

1. Introduction

On January 14, 2004, President George W. Bush announced a new vision for NASA to implement a sustained and affordable human and robotic program to explore the solar system and beyond; extend human presence across the solar system—starting with a human return to the moon by the year 2020 in preparation for human exploration of Mars and other destinations—develop the innovative technologies, knowledge, and infrastructures needed to explore and to support decisions about the destinations for human exploration; and promote international and commercial participation in exploration to further US scientific, security, and economic interests. "This cause of exploration and discovery is not an option we choose, " said President Bush, "it is a desire written in the human heart."

2. The exploration scenario and operations environment

NASA's vision is to improve life on Earth, extend life into space, and find life in the universe. The International Space Station (ISS), missions to the moon for long-duration stays, and a human mission to Mars are elements of this [1,2]. Three prominent goals of NASA are to (1) conduct scientific research to understand the processes and phenomena that underlie the formation of the universe and the life it supports; (2) explore the universe to expand human knowledge and presence; and (3) pursue along with other government, industry,

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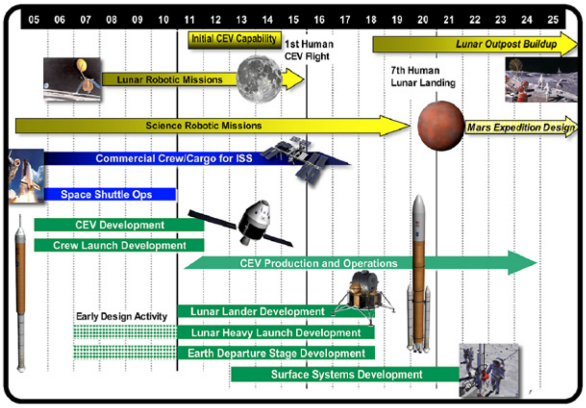

Fig. 1. NASA exploration roadmap.

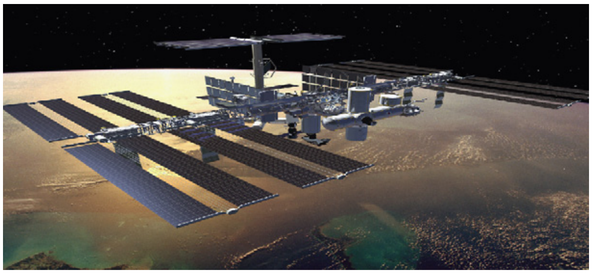

Fig. 2. Fig. 2. ISS developing future capability.

and academic communities applications of aeronautics, space science, and technology for the preservation and improvement of life on Earth [1,2].

NASA has formed the Constellation Program to maintain US presence in low Earth orbit, return to the moon to establish an outpost, and explore Mars and beyond. Fig. 1 details the missions that make up the NASA exploration roadmap.

These include space shuttle and ISS operations, Crew Exploration Vehicle production and operation, lunar and Mars robotic missions, Lunar Outpost buildup, and Mars expedition design. NASA's space platforms include Earth- and moon-orbiting platforms, space stations, and deep space platforms. To these platforms intended for operations, logistics, and communications are to be added satellites for scientific or observational systems. Technology drivers for these platforms include: advanced structures and materials, avionics systems, human support, communications, sensors, environmental interactions, propulsion and control, and power and thermal management. The NASA science programs are in support of Earth science, planetary science, heliophysics, and astrophysics. These programs also need unique sensor, data acquisition and processing, and mission support technologies.

The ISS provides a permanently manned, multipurpose facility in low Earth orbit, with a life expectancy of more than 20 years (Fig. 2). It will provide great opportunity for basic and applied science in microgravity with continued addition of capabilities resulting in a six-person crew planned for 2009. The ISS will also provide valuable design and verification for future space systems and technology.

The Constellation architecture is being formulated to meet the stated exploration objectives. The Lunar Outpost location is to be chosen to optimize the envisioned objectives, which include: using the moon and Mars locations and environments to conduct scientific investigations, learning to survive on another planet, and dealing with the health and logistics issues of extended stays. In choosing the Lunar Outpost location, consideration should be given to having an area with the least possibility of falling space meteorites and cosmic/solar burst particle radiation. In addition, the area should be of scientific interest and have a suitable landing site, an area useful for oxygen production and other in situ resources utilization (ISRU) capabilities, sunlight availability, line-of-sight communication with the Earth, and nearby permanently shadowed areas for potential in situ water production.

The environments for the Earth, moon, and Mars vary significantly and call for specific technology solutions. Lunar surface temperatures can range from −299 to 250 °F [3]. The temperature cycle on Mars can range from −225 to 64 °F, based on Mars Pathfinder data and NASA calculations. These values are typical and more recent and accurate data are available from NASA.

One of the environmental factors on the moon is lunar dust. The risks for prolonged explore to lunar dust will include mechanical failures in spacesuits and airlocks, lung disease, and decreased efficiency of the solar energy panels. Mars dust will have similar consequences. The ionizing radiation is one of the most significant hazards for both hardware and humans in space. This hazard will demand attention for both lunar and Mars missions [4].

Solar light environment will continue to have a pronounced influence on many aspects of the Lunar Outpost and a human mission to Mars. The lack of atmosphere on the moon and presence of Mars atmosphere will present different scenarios for solar energy use and will demand differing approaches. Another environmental factor to be faced on Mars is the occasional presence of regional dust storms resulting in altering both temperature and lighting conditions. In addition, as with the moon, water harvesting will need unique technology to make it a cost-effective proposition.

The gravity environment will modulate human survival on the moon and Mars. For the moon, this adaptation will be to about one-sixth and for Mars to about two-fifths. The effects of gravity on humans and living organisms continue to be studied. Results to date show profound effects on several functions of the human body [5–7].

The distance to the moon and Mars results in round-trip communication delays of a few seconds to more than 40 min and provides technology challenges to alleviate the consequences of these delays. For this reason, reliability and autonomy must be incorporated in mission-critical system designs.

3. Projected space technology needs

The President's Commission on Implementation of United States Space Exploration Policy formed after President Bush's January 2004 announcement issued a report in June 2004 [1]. Finding 4 from this report states: "the Commission finds that successful development of identified enabling technologies will be critical to attainment of exploration objectives within reasonable schedules and affordable costs." The report lists 17 enabling technologies, and the Commission recommends that NASA conduct initial assessments of these technologies and develop and integrate them in its exploration architecture.

Following this report, NASA conducted an extensive study titled "NASA's Exploration Systems Architecture Study" to identify the systems and architecture needed to realize the exploration goals [4]. Section 9 of this report, entitled "Technology Assessment," provides a summary of the technologies needed and recommends that NASA undertake a vigorous approach to developing a process to prioritize the funding of new technology development. The NASA Exploration Systems Mission Directorate (ESMD) uses two technology focused programs—the Exploration Technology Development Program (ETDP) and the Human Research Program—to carry this out.

Currently under the NASA ETDP, high-priority technologies being pursued are: ablative thermal protection system, automated rendezvous and docking, autonomous landing and hazard avoidance technology, propulsion and cryogenics advanced development, human robotic systems, ISRU, supportability, high-performance and radiation-hardened electronics, advanced fission-based power systems, energy storage, dust project, thermal control system development, exploration life support, advanced environmental monitoring and control, fire protection, detection, and suppression, extravehicular activity (EVA), automation for operations, intelligent software design, and integrated systems health management project.

The technology investment areas given in NASA's Exploration Systems Architecture Study are structures and materials, protection, propulsion, power, thermal controls, avionics and software, environmental control and life support, crew support and accommodations, mechanisms, ISRU, analysis and integration, and operations [4].

Crew health care needs for long-duration missions should include highly accurate and reliable monitoring and diagnosis systems, and countermeasure technologies resulting in maintaining healthy crews for long periods on the planetary surface. Imaging and diagnostic systems, preferably in vitro, need to be developed with attractive mass, size, power, and ease of operation. Technology developments are needed in the areas of space radiation protection including: biological countermeasures, medical care devices, clinical capabilities, reduced-gravity countermeasures, behavioral health management, crew cohesion training and performance, human performance measurement, environmental control, and food storage and processing. Intelligent and autonomous medical informatics systems are needed to track and document the medical history of crew members. Countermeasure technologies include: exercise, timed drug release, targeted drug therapy, triggered drug release, and operating hardware. Medical operations will develop contrast agents to target specific sites for surgery, bio-mimetic or engineered compounds to help wound healing, and miniatured electron microscopes for biopsies.

Key concerns that distinguish NASA technology requirements include: size per unit of mass, strength and performance per unit of mass, power generation and energy storage per unit of mass, and information processing and intelligence per unit of mass. Indeed, mass and size are the major determinants of mission costs. Coupled with this, space missions demand a very high degree of reliability and autonomy.

The main drivers for space technology development are increased productivity, higher safety, and reduced cost. The productivity needs include human–machine symbiosis, sensors, nanocomputing, nanoelectronics, data mining, fuel cells, and energy storage. Safety includes radiation protection, life support, countermeasures, and managing the health systems. As was stated earlier, costs are highly correlated with mass and size. Technologies are needed to provide multifunctional performance with minimum mass and size. In addition, power and thermal management technologies can also reduce mission costs.

The recent stated technology challenges and priorities for the science missions according to Headquarters are as follows: new remote-sensing technologies to better see, detect, and measure the Earth, the sun, the solar system, and the universe; large, lower-cost, lightweight mirrors and space-deployable structures for the next generation of large telescopes and antennas; novel platforms, including power and propulsion technologies, that can take instruments to new vantage points; intelligent distributed systems that enable advanced communications, efficient data processing and transfer, and autonomous operations of land- and space-based assets; and information synthesis to derive useful knowledge from extremely large data sets through visualization, advanced simulations, analysis, and seamlessly linked models.

Operations, as the term applies to the nation's civil space program, constitute a broad spectrum of activities and associated facilities that enable the conduct of a program or mission to achieve desired goals or objectives. Operations areas typically include automation and robotics, training systems, in-space operations, ground operations, and associated information acquisition and processing infrastructure. Often space- and ground-based operations have to accommodate new requirements or modifications to the previous mission requirements. In this context, technology needs can also be identified to serve changing requirements of long-duration missions, space assembly and servicing, international space activities, and the interaction of flight systems.

4. New technologies with potential space applications

Research and development efforts throughout the commercial, academic, and government sectors have resulted in revolutionary technologies that have potential for space applications. One example is the magnetic resonance imaging (MRI) system. Studies have shown that the structure/volume and functions of muscle, bone, and connective tissues for astronauts exposed to microgravity are affected [5–7]. The cardiovascular system, neuromuscular functions, and metabolic activity are also affected [7]. NASA has used MRI data to study the anatomical changes of selected astronauts both before and after their flights.

No in-flight MRI data are available, although the need for such data and the use of MRI in space has been proposed. Conventional MRI systems require liquid helium refrigerant, bulky cryostats, and excessive power, and are heavy. These systems therefore become prohibitive in terms of cost. High-temperature superconductors (HTSs) can make a space-borne MRI system feasible because this system can work at higher temperatures. With proper design and thermal control, these systems can be made cryogen free. HTS magnets can operate at 150 K with some compounds and can be cooled by relatively inexpensive, reliable, and compact coolers. Other technologies showing promise include ionic polymer–metal composite (IPMC) technology; solid-state lasers; time-domain sensors and communication systems; nanotechnology; variable specific impulse magnetoplasma rocket (VASMIR); fuzzy logic; wavelet technology; and neural networks.

4.1. High-temperature superconductivity

Superconductivity, the loss of electrical resistance, was discovered by Heike Kamerlingh Onnes in 1911 by showing that mercury becomes superconducting at 4.2 K. In 1986, Karl Alex Muller and Georg Bednorz developed a new compound consisting of barium, lanthanum, and copper. This compound was relatively easy to prepare and has a superconducting temperature of approximately 30 K [8]. In February 1987, Paul C.W. Chu and Mao-Ken Wu and their team members developed an yttrium, barium, and copper compound that super conducted at about 90 K, which is above the temperature of liquid nitrogen [8]. Subsequently, higher-temperature superconductors with critical temperature above 125 K were discovered and under pressure higher superconducting temperatures were achieved. By 1996, temperatures above 164 K were recorded [8].

The application of superconductors to space missions draws impetus from technology needs as well as the low temperatures that space offers. Space applications for HTS were studied by Krishen and Ignatiev with a comprehensive review provided in 1988 [9]. Specifically, technology development areas studied included: (1) high current power transmission, (2) microwave components, devices, and antennas, (3) microwave, optical, and infrared sensors, (4) signal processors, (5) sub-millimeter wave components and systems, (6) ultra-stable space clocks, (7) electromagnetic launch systems, and (8) accelerometers and position sensors for flight operations. Considerable progress has been made in developing some of the HTS-based technology for these applications. In particular, HTS has been used in sensing systems for the transmission of signals from collectors to detectors.

The use of HTS in space communications has been studied, and communication systems have been designed [10]. Experiments establishing the performance of these systems have been proposed. Other proposed applications include momentum wheels for satellite attitude control, magnetocardiography (MCG) system for noninvasive monitoring of cardiac activity, and magnets for energy storage. The momentum wheel is based on superconductor magnet bearing with substantial energy saving [11]. The MCG system is designed to monitor biomagnetic fields emitted by the heart during the cardiac cycle [12]. It is based on HTS superconducting quantum injection diodes. The MCG can measure cardiac signals a few inches away from the chest. The application of magnets to MRI was mentioned earlier. Other applications will include energy storage on the lunar surface and VASMIR. The VASMIR system will be discussed later in this paper.

4.2. *Ionic polymer–metal composites*

IPMCs are evolving with desirable mechanical and sensing properties [13–16]. Shahinpoor and Kim [14] have developed simpler compositing and electroding processes resulting in cost savings in the manufacture of IPMCs. Many IPMCs are composed of perfluorinated ion exchange membrane (IEM). The IEM is composited with gold or platinum or carbon conductor, or a conductive polymer.

When subjected to a low applied field on the order of 10 kV/m across a metalized or conductive surface, IPMCs show large bending motion. Furthermore, these materials can retain a modified shape with particular levels of input voltage. Research to date has shown a force greater than 40 times the weight of an IPMC and large bending displacements can be realized with very low input voltages [13]. For example, a 14-mm displacement in a cantilever beam of 20 mm × 5 mm × 0.2 mm with 1.5 V and 146 mA current is observed [13].

Fig. 3 shows a quarter lifted by an IPMC [16] by the application of a step voltage of 2.8 V ($E = 1.4\,\mathrm{V/mm}$). The time interval between the frames is approximately 1 s. This displacement of IPMCs can be made bidirectional by reversing the polarity of the electric field. When subjected to an imposed bending stress, IPMCs develop a measurable voltage across chemically/physically placed electrodes. For example, the bending of a cantilever IPMC strip produces 10’s of millivolts [17]. This attribute makes it a sensor with attractive properties compared to shape memory alloys and electrostatic ceramic actuator sensors.

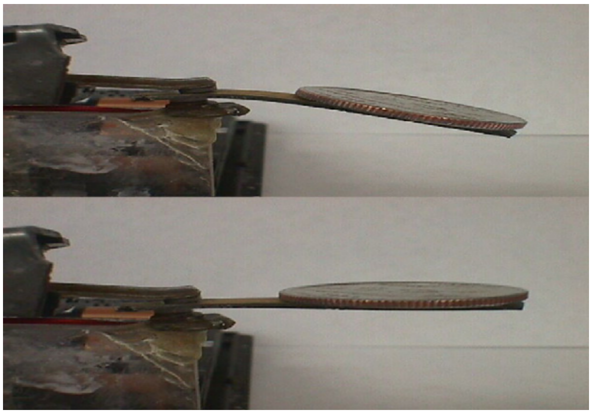

Fig. 3. A quarter is lifted with IPMC (with permission from Kim [16]).

IPMC technology can be envisioned for use in space robotic, human support, and vibration monitoring and control. These applications will be briefly discussed.

4.2.1. *Robotic applications*

A variety of end effectors are possible with IPMC technology in space environments. The agility and quick response of these end effectors will promote their use in micro- and partial-gravity environments. The technology can also be used to provide mobility using legs and wheels. On the moon surface, vehicle-borne mechanisms can be used due to lack of atmosphere. In the Mars environment, the use of insects and flies such as a Mars worm, Mars fly to navigate over, on, and below the planetary surface can be envisioned.

4.2.2. *Human support*

The development of a tight suit incorporating IPMC actuators/muscles that allow contact with human muscles is needed to realize the benefits for crew members.

In one of the applications, the actuation is provided to move human extremities against the IPMC muscle movement. The resistance against motion provides a countermeasure for muscle atrophy in a space environment. The suit muscles will be actuated through selective electric pulse sequences both spatially and temporally. In this way, a combination of human muscles will get exercised for a specified time. This type of body conditioning is effective and efficient in that an astronaut can be working using hands and arms while getting exercise in other parts of the body as well.

The second application can augment the strength of astronauts to enhance their performance and response time in space environments. A similar suit to that used as a countermeasure or exercising system can be used in this mode to regulate and provide strength to astronauts, especially during EVAs. The strength and precise motion provided through these systems can give better precision for task execution. The same tight suit can be used as a passive sensing system to monitor the posture and motion of astronauts during designated periods to categorize human factors effectiveness of each astronaut/suit.

4.2.3. Vibration monitoring and control

Monitoring of structural vibration of satellites such as the ISS can be accomplished by mounting IPMC devices at strategic places on the structure and gathering vibration data continuously, either through a hardwired scheme or a wireless optical/infrared communications system. These data can be used to develop three-dimensional vibration models and to calculate effects on the trajectory, instrument pointing, and gravity environment. Corrections to the data and pointing instruments can then be made based on these data. IPMC devices can be placed at vibration isolation points to generate opposite actuation to that of the rack/instrument vibration. In this way, vibrations can be alleviated or reduced to provide vibration-free environments.

4.3. Carbon nanotechnology

The unique chemistry of carbon nanotubes (Fig. 4) provides material with strongest fiber possible, electrical conductivity of copper, thermal conductivity of diamond, large-aspect ratios, large surface areas, and the scale and precision of DNA [18]. Reduced mass and volume and multi-functionality makes materials and devices based on this technology most desirable for space applications.

The numerous applications of single- and multiple-wall nanotubes to space systems are currently being explored across NASA and many research institutions. Applications include power/energy storage, advanced life support, crew health maintenance, electromagnetic/radiation shielding, sensors and instrumentation, thermal management, and structural integrity. Applications for materials include primary structures and inflatables. The use of single-walled carbon nanotubes (SWCNTs) in polymer and ceramic matrices results in improved strength and thermal performance.

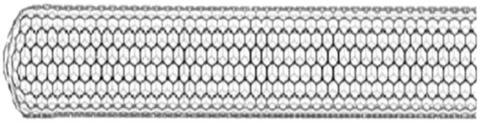

Fig. 4. Carbon nanotube.

A brief synopsis of some of the work being carried out by the NASA Johnson Space Center (JSC) Nanotube Team is given here. Long-duration space flight requires a regenerable system for air revitalization. In this application, SWCNT can be used to replace zeolites and amine-coated polymer beads. Carbon nanotubes offer advantages in terms of reduced mass and volume, larger surface area, and better thermal conductivity. In one of the applications, SWCNTs are chemically bonded (functionalized) with amines to make CO_2 scrubber material [19]. Amines require lower energy for regeneration than the molecular sieves presently in use [19]. The SWCNTs provide a higher surface area, resulting in both volume and weight savings. Carbon nanotubes with greater surface area and nanoporosity provide superior materials for electrolyte ion support for supercapacitor power and energy storage. In addition to increased capacity for storage, these devices offer better electrical and thermal conductivity. The use of carbon nanotubes fuel cells provides increased reliability through reduced activation polarization, high capacity through high surface area, and higher power density from more efficient use of platinum catalysts.

Current research efforts at NASA JSC involve the use of microwave energy to heat nanotubes in polymer and ceramic matrices for localized heating, curing, and bonding. This technique is being explored for the repair of the shuttle thermal protection system. The use of SWCNTs in phenolic-impregnated carbon ablator thermal protection material is also being explored. The use of nanotubes in thermal protection materials can result in increased strength and enhanced thermal and radiation protection. The use of SWCNTs in polymer matrices and its application to thin transparent coating is showing promise for low material density and high electrical conductivity for electromagnetic shielding. The use of solar-radiation-sensitive functionalized SWCNTs to measure radiation dose rates and total radiation dose is advantageous as the higher nanotube surface area increases the sensitivity of the measurements.

4.4. VASIMR

VASIMR is a high-power plasma rocket that is capable of continuous exhaust modulation at constant power [20]. This electrode-less heated thruster operates over a wide range of thrust and specific impulse combinations to obtain maximum propulsive flight efficiency [20].

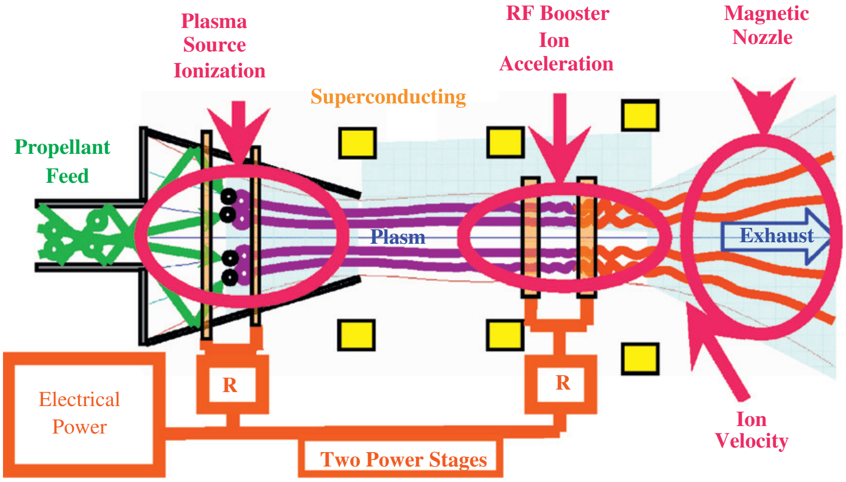

Fig. 5. VASMIR diagram.

As shown in Fig. 5, the VASIMR system encompasses three linked magnetic cells. The "plasma source" cell involves the main injection of neutral gas (argon or lighter gases) to be turned into plasma and the ionization subsystem. The "RF booster" cell acts as an amplifier to further accelerate the plasma ions to the desired energy using electromagnetic waves and ion cyclotron resonance. The "magnetic nozzle" cell converts the energy of plasma into directed motion and ultimately useful thrust [21]. The continuous optimal tuning of thrust and specific impulse produces a linear rocket equation [22]. This feature can result in constant acceleration and a substantial saving of time for an exploration mission to Mars. VASIMR systems will also enable efficient boosting of the satellites in Earth, moon, and Mars orbits.

The generation of strong magnetic fields in space for VASIMR can be enabled by the use of high-temperature superconductors. Tai-Yang Research Corp., through the NASA JSC Small Business Innovation Research Program, has developed 24-cm HTS coils for installation into the ground-based VASIMR experiment. In addition, the contract provided two additional 16-cm coils to support thermal tests. Thermal tests on these coils have been successful.

4.5. Solid-state laser-based chemical sensors

Laser absorption spectroscopy is showing great promise for space applications as a result of the development of innovative solid-state laser and sensing technologies [23]. The advantages of mid-infrared spectroscopy based on laser difference frequency generation include high speed, high precision, operation at room temperatures, and access to wavelengths suitable for remote sensing modality with high sensitivity.

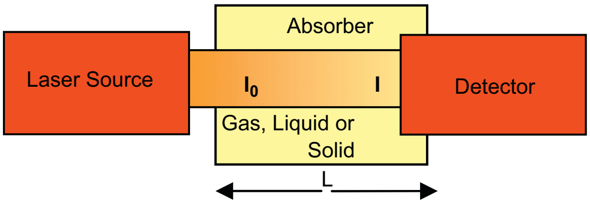

Fig. 6. Spectroscopy technique [24].

The technique uses the Beer–Lambert Law of linear absorption (Fig. 6). The absorption at a wavelength is a function of the product of molecular line intensity and the normalized spectral line shape function. Long optical absorption path lengths are needed for high sensitivity. These path lengths can be achieved using cavity enhanced multipass absorption cell or open-path monitoring with retro-reflectors, or with evanescent field monitoring with fibers and waveguides. High-resolution spectroscopy with line widths of less than 30 MHz has been realized with this technique [24].

Atmospheric trace gases such as carbon monoxide, nitric oxide, nitrous oxide, formaldehyde, methane, and sulfur oxide can be measured with concentrations of 100–9000 parts per billion [23,25,26]. The external cavity widely tunable thermoelectrically cooled design developed by Wysocki et al. [26] employs a cavity mode tracking system. This system is capable of mode hop-free spectroscopic operation for high-resolution multiple species of trace-gas detection applications.

This technology offers potential benefits in terms of reduced cost, reduced power consumption, reduced size, and increased reliability with improved tuning range.

4.6. Ultra-wide band communication and navigation

Ultra-wide band (UWB) communications and navigation systems are realized by transmitting and receiving ultra-short electromagnetic pulses. As shown in Fig. 7, a UWB system has a bandwidth greater than 0.20 of the center frequency or occupies 500 MHz or more of the spectrum [27]. For narrow band (NB) systems, the bandwidth is typically 1% of the center frequency.

Short-pulse-width signals have very large signal bandwidth. For example, as shown in Fig. 8, a pulse of approximately 0.5 ns provides a bandwidth of 1–2 GHz [27]. The short pulses can be transmitted as a single pulse or in groups. The information can be encoded in pulse position, amplitude, and phase. The techniques that have been explored most are the time-modulated UWB (TM-UWB) and the direct sequence phase coded UWB (DSC-UWB).

Short pulses are transmitted at high rates in the TM-UWB system. These pulses are spaced in time at random or pseudo-random time intervals [28]. Data modulation is implemented by dithering the timing of the pulse transmission or by signal polarity. Time coding of the pulses allows channelization while the time dithering and signal polarity provide the modulation [28]. A high-duty-cycle phase-coded sequence of short pulses is transmitted at gigahertz rates in DSC-UWB systems. A pseudo-noise sequence provides modulation, spectrum spreading, and channelization [29]. Multiple pulses are coded to represent a single bit of information.

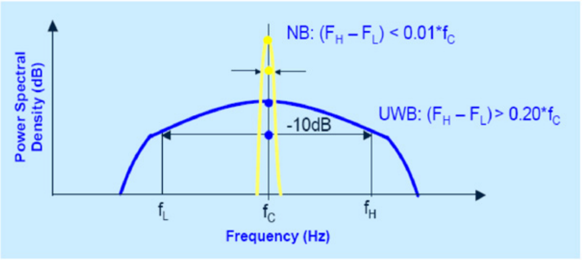

Fig. 7. UWB vs. NB systems.

In communication systems, the advantages of UWB systems include robustness to multipath fading, low transmitted power and power density, low probability of interception, multichannel operation, and high-spectrum efficiency. The TM-UWB systems can operate in a radar mode for detection, ranging, and motion sensing of robots or personnel. This application would provide important operational data on the lunar surface. The technique can also be used for precision mapping of terrain and collision avoidance. Another suggested application includes radio frequency identification allowing the precise location and tracking of assets on the Lunar Outpost [29,30].

5. Conclusions

The complexity of future long-duration human missions to the moon and Mars and the critical need for safety, reliability, and cost-effectiveness dictate the use of innovative technologies and techniques. As discussed in this paper, the lunar and Mars environments provide very hard challenges for systems and humans to be functional and productive. In view of this, vigorous efforts to incorporate new technologies in future space missions must be undertaken.

Much of the research and development in the US is being conducted at academic institutions and research

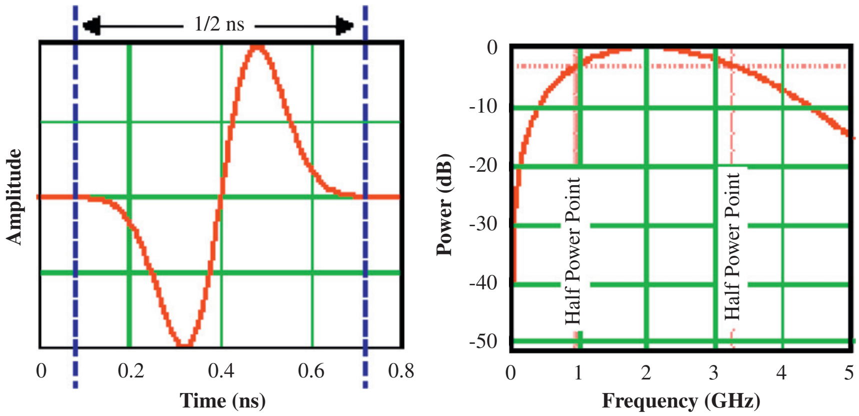

Fig. 8. Pulse in time and frequency domain.

laboratories, and in the private sector for their own goals and objectives. The ensuing developments may or may not be adoptable to space missions for several reasons. Some of these could be the constraints of mass, size, power consumption, and reliability for space systems. In some instances, the space environment could make their use cost-prohibitive. However, some of these technologies could be modified to make their use a priority in space systems. In this paper, the promise and feasibility of using high-temperature superconductivity technology, ionic polymer–metal composites, carbon nanotechnology, VASMIR, and solid-state laser-based chemical sensors, and UWB communication and navigation is discussed. Other technologies showing considerable promise are wavelet technology, fuzzy logic, and neural networks. Promising research and technology development is ongoing in these technology areas. For example, wavelet-based data compression and processing is showing revolutionary promise for video and certain types of signals. New methods and hardware using compression sensing with digital image and video cameras can substantially reduce sampling rates with very little effect on image quality [31]. In another application, three-dimensional wavelet image processing has shown improvements in the resolution of volume data with most effective image compression [32].

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