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# Non-Contact Vital Sign Monitoring via Ultra-Wideband Radar, Infrared Video, and Remote Photoplethysmography: Viable Options for Space Exploration Missions

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**ABSTRACT**

Current vital sign monitoring of astronauts utilizes cumbersome equipment that requires contact with the patient's body to function properly. These systems require extended time to shave the subject, apply electrodes, and check the signals of the system before operation. It also requires that the astronaut understand the application procedures of the electrodes and data capture process for the system to yield usable data. This paper investigates potential non-contact vital sign monitoring mechanisms that might mitigate some of the current complexities. Non-contact vital sign monitoring includes several advantages over traditional methods because no subject participation is required to properly don the equipment, astronaut comfort is increased, and more accurate vital sign data are captured. This paper reviews the most current literature regarding non-contact vital sign monitoring, including Ultra-Wideband Radar, Non-Contact Photoplethysmography, and Infrared Video as viable options for possible incorporation on future space exploration missions.

## Contents

## 1. INTRODUCTION

During intra- and extravehicular activities, it is necessary to monitor key physiologic biomarkers for astronauts. The current biomonitoring system requires contact with the subject's skin and complex, cumbersome, and time-consuming preparation to properly install the devices. Non-contact health monitoring technology has improved greatly in recent years. It provides several advantages over contact biological monitoring. It requires no skin preparation, causes no skin irritation, and avoids the subtle, inherent inaccuracies caused by monitors being placed in contact with the skin. This report will examine Ultra-Wideband (UWB) Radar, Non-Contact Photoplethysmography (PPG), and Infrared (IR) Video technology as possible methods for future vital signs monitoring.

## 2. ULTRA-WIDEBAND RADAR

### *Background*

Early experimentation with Doppler radar for medical monitoring, while useful for stationary subjects, showed that movement produced by the subjects caused aberrancies in the vital sign data. Additionally, Doppler radar has difficulty penetrating non-metal materials such as wood, soil, and other media. This issue might be mitigated to some degree by using UWB radar technology with the addition of an adaptive filter based on heart rate and respiration parameters (Sharifahmadian & Ahmadian, 2009). UWB radar technology was originally researched for non-cooperative radar imaging for defense usage (Fowler, Entzminger, & Corum, 2002). However, since the 1980s, the technology has been researched to aid in rescue efforts for detection of life forms buried beneath rubble after natural disasters and for many other medical purposes. Research showed that electromagnetic waves at 450 MHz and 1150 MHz could penetrate ground and earthquake rubble to detect buried life forms (Chen, Huang, Zhang, & Norman, 2000). Because different tissues in the body have different dielectric properties, UWB radar allows us to monitor the motions and capture images of internal organs by measuring the displacement of the different tissues. Several emerging medical uses for UWB radar have been recently posited, including diagnosis and treatment of obstructive sleep apnea (Hilton, Bates, & Godfrey, 1999), aortic pressure measurement (Solbery, Balasingham, Hamran, & Fosse, 2009), breast cancer detection (Davis, Veen, Hagness, & Kelcz, 2008), monitoring vital signs of burn victims where dermal monitor attachment is not practical (Higashikaturagi, Nakahata, Matsunami, & Kajiwara, 2008), myocardial ischemia, pulseless electrical activity (Thiel, Kreiseler, & Seifert, 2009), and infant respiratory and cardiac monitoring in an effort to reduce sudden infant death syndrome (SIDS) (Li, Cummings, Lam, Graves, & Wu, 2009).

The Federal Communications Commission (FCC) and International Telecommunications Union-Radio Communications Sector currently define UWB radar as emitted signal bandwidth that exceeds the lesser of 500 MHz or 20% of the center frequency. The FCC currently allows unlicensed use of the UWB radar in the range of 3.1 to 10.6 GHz (Federal Communications Commission, 2002). The advantage of UWB radar over traditional radio transmissions lies in the fact that while radio frequencies vary power level, frequency, and phase to generate a signal, UWB radar transmits via large bandwidth over short pulse periods, typically on the order of a nanosecond, allowing large amounts of information to be sent in a short period of time (less than 60 cm for a 500 MHz wide pulse, less than 23 cm for a 1.3 GHz bandwidth pulse) (Margaret, Anith, Duraisamy, & Muneeswaran, 2009). This type of data transfer yields more objective data than if one were using a single frequency. In addition to being able to transmit a large amount of data in a short period of time, UWB radar radiates and uses a small amount of energy compared to other radio technologies. UWB radar also has high spatial and temporal resolutions and has no compatibility issues with established narrowband systems (Thiel, Kreiseler, & Seifert, 2009). Finally, UWB radar penetrates objects such as rubble, wood, concrete, and ground to obtain accurate measurements of heartbeat and respirations in those media. A recent study was able to determine breathing and cardiac harmonics at a distance of 1 meter while transmitting through 20 cm of brick (Lazaro, Girbau, & Villarino, 2010).

### *Applications*

UWB radar would allow monitoring of heart rate and respirations passively, remotely, and without crew requirements for set up or proper donning. Due to the unique nature of UWB radar, it could be possible to monitor a subject with the same equipment whether they were inside or outside the spacecraft while wearing clothing or protective equipment.

A typical human heart causes chest displacements of 0.08 mm while respiration ranges from 0.1 mm to several millimeters depending upon the subject (Singh & Rmachandran, 1991). During heavy respiration, the third and fourth UWB radar harmonics of the breathing frequencies (typically between 0.2 and 0.7 Hz) can sometimes interfere with the harmonics of the heartbeat (0.8 and 3 Hz). This issue can be overcome with a simple canceller filter based on a moving target indicator or clutter cancellation system, which would effectively reduce the high-output respiratory signal to continually monitor the heart rate signal (Lazaro, Girbau, & Villarino, 2010) (Chen, Huang, Zhang, & Norman, 2000).

Current technology allows detection and monitoring of heart rate and respirations at a distance of up to 3 meters from the sensor (McEwan, 1998). However, most research has been conducted at the 1- to 2-meter range. While this distance makes single-node monitoring impractical for multi-crew large spacecraft, research with multiple input, multiple output (MIMO) techniques and multiple receivers makes coverage of large areas practical. Additionally, a combination of MIMO and single input, multiple output (SIMO) receivers were able to isolate input from multiple subjects successfully (Zhou, Liu, Host-Madsen, Boric-Lubecke, & Lubecke, 2006) (Boric-Lubecke, Lubecke, Host-Madsen, Samardzija, & Cheung, 2005). Therefore, it would be conceivable to produce a MIMO/SIMO multi-receiver system that would be able to monitor heart rate and respirations of multiple crew members passively and without sensor contact while in or near the spacecraft.

Early research with UWB radar proved complex because of the difficulty in capturing reliable vital data due to the random body motion of the subjects. Incidentally, the research done with MIMO/SIMO multi-receiver systems has been able to cancel out the random noise caused by physiological motion and random movements by using more than one receiver (Li & Lin, Complex signal demodulation and random body movement cacellation techniques for non-contact vital sign detection, 2008). Another benefit of UWB radar is that it is not influenced by changes in magnetic fields (Thiel, Kreiseler, & Seifert, 2009).

Finally, UWB radar has a low radio power pulse (less than -41.3dB in indoor environments) and produces no ionizing radiation (Federal Communications Commission, 2002). Therefore, this technology could likely provide continuous non-contact remote biomonitoring with no health risk.

### *Shortcomings*

While UWB radar has several advantages over current vital sign monitoring, there is currently no way to monitor subject for arrhythmias and blood pressure via UWB. Current technology allows for electrocardiogram (ECG) monitoring via 3-lead Einthoven layout. However, UWB radar technology is not currently advanced in its ability to recognize arrhythmias. If utilized at this point, UWB radar would likely need to be supplemented with other technologies for a complete non-contact remote vital sign monitoring system.

Another drawback of the current UWB radar technology is that it is more difficult to obtain vital sign data from people with high body fat. While studies of slim people have produced usable data, detection of data from overweight people is more challenging (Leib, Menzel, Schleicher, & Schumacher, 2010). It is possible to determine the heart rate of a person with more adipose tissue, though the very small motion measured on heart tissue is attenuated by the surrounding body fat and makes the signal more difficult to interpret. While obesity is not typically an issue with the astronaut population, female breast tissue would likely attenuate the signal in a similar fashion.

## 3. REMOTE PHOTOPLETHYSMOGRAPHY

### *Background and Applications*

PPG was pioneered by Hertzman's studies of microcirculation in limb extremities in the 1930s (Hertzman, 1937). Now, pulse oximetry via PPG monitoring has become a standard of care in health care settings (Aoyagi, 2003). Current PPG generally utilizes light sources that must contact the tissues being studied, and only provides data for a few square centimeters of the contacted tissue. While this technology supplies important vital information, there are several conditions where dermal contact is undesired, such as damaged skin (burns, lacerations) or poor patient hygiene (Cennini, Jeremie, Kaan, & Van Leest, 2010).

Recent advances in PPG have shown the ability to monitor blood pressure via micro dermal circulation with non-contact PPG and IR light-emitting diode (LED) illumination from a simple photodiode from distances of 20 cm to 1 meter (Shi, Hu, Echiadis, Azorin-Peris, Zheng, & Zhu, 2009). Motion artifact is the greatest issue to overcome when attempting to monitor blood pressure via non-contact sensor. Motion distorts the light signals read by the PPG sensors and gives invalid readings. Cennini et al. showed that it is possible to measure heart rate from a distance of 1 meter in real time with use of a multispectral illumination device with an adaptive filter (Cennini, Jeremie, Kaan, & Van Leest, 2010). The multispectral illumination device consisted of blue and IR lights. Hemoglobin strongly absorbs the blue light spectrum while, at the same time, the IR light was used to determine motion artifact. The resulting signal was band-pass filtered at 0.75 to 3.5 Hz (typical heart rate range), and filtered via multiplicative coefficient filter utilizing Least Meant Square to minimize the error.

The classical method for monitoring UWB radar involves pulse excitation. These high-peaked power signals are usually expressed as swept or steep sine waves of random noise, or pseudo-random noise sequences (Sachs & Peyerl, 2001). Since this target signal is not a usable impulse response function, a fast Fourier transform was utilized to determine the heart rate frequency in real time. Any future development of non-contact PPG will likely utilize a similar dual wavelength approach.

Some also have begun to couple the non-contact PPG technology with high-speed digital video cameras to produce heart rate information in a waveform, three-dimensional format (Zheng, Sinjung, Azorin-Peris, Chouliaris, & Summers, 2008). By collecting the information in a waveform, others have been able to obtain Lead II ECG-like data by interpreting signals from PPG monitoring devices utilizing a Windows Graphical User Interface in real time (Gomez & Yabar, 2010). The addition of the high-speed camera allows for non-contact monitoring of a larger field of view than traditionally monitored by current PPG technology. Additionally, Zheng et al. recently demonstrated that a multi-wavelength camera-based PPG system has been shown to monitor blood perfusion at different tissue depths. The camera utilized a ring illumination source and dual-wavelength resonant LEDs at 660 and 880 nm rather than simple LEDs (Zheng, Sinjung, Azorin-Peris, Chouliaris, & Summers, 2008). The reflected photons were gathered using a Complementary Metal-Oxide Semiconductor camera capturing 21 frames per second at each wavelength. While the standard pulse oximeter is able to monitor the perfusion of a few square centimeters, this research was able to track pulsation signals from the entire volar surface of the hand simultaneously in real time.

### *Shortcomings*

In the case of adults, pulse oximetry is most commonly monitored via extremity cuff devices such as the finger cuffs. This would be undesirable for astronauts due to the inherent loss of manual dexterity. New research has shown that PPG incorporated into the communications cap, suit, and toe monitors of research space suits did not impede astronaut dexterity (Fei, et al., 2010). However, the incorporated PPG system would still require contact with the subject’s skin.

Finally, PPG is not currently reliable under certain physiological conditions such as low-volume states, shock, or abnormal temperature conditions. The minimal research that has been performed concerning PPG and shock showed that the photoplethysmography waveforms were unusable for vital data during posttraumatic hemorrhagic shock (Natalini, Rosano, Franceschetti, Facchetti, & Bernardini, 2006).

## 4. VIDEO

While UWB radar and PPG offer some utility in the future of non-contact vital sign monitoring, new research in pulse detection via standard video and blind source separation is also promising. Poh et al. recently completed research with standard, commercial, off-the-shelf web cameras and were able to determine the heart rates of multiple persons simultaneously in normal ambient lighting (Poh, McDuff, & Picard, 2010).

One of the problems hindering UWB radar and PPG technology is the noise associated with motion artifact. Poh et al. used blind source separation (aka blind signal separation) to filter their video feeds by independent component analysis. This is a rapidly proliferating method to reduce this noise motion artifact that could also be applied to UWB and PPG technology. Blind source separation works by separating all received signals into independent signal categories without aid of historical signals. In other words, it separates all newly received signals based on their properties regardless of the historical input pattern. This allows like data to be grouped together, consequently marginalizing data that are lower throughput. This effectively filters the noise artifact from the target signal (Comon, 1994). This technology has been used effectively in ECG signal analysis (Chawla, Verma, & Kumar, 2008), electroencephalogram (Jung, et al., 2000), and fetal/maternal heart ECG signal disambiguation (Cardoso, 1998).

Poh et al. used the video camera to visualize the volumetric changes in each subject’s face with each pulse by monitoring the changes in ambient light. The red, green, blue colored sensors were able to determine the plethysmographic data in each of these color spectra and determine the different light-absorbing qualities of the hemoglobin as well the ambient light noise signals and movement.

This method of non-contact pulse video monitoring was able to determine heart rate ± 2.29 bpm while subjects were sitting still. The system was slightly affected by the motion of subjects when they were allowed to tilt their heads, nod their heads, look up and down, lean forward and backward, and make facial expressions, talk, and laugh (± 4.59 bpm) (Poh, McDuff, & Picard, 2010). Considering that this research was conducted with a commercial webcam, it would be conceivable that higher-quality cameras would yield superior pulse data.

## 5. CONCLUSION

While non-contact UWB radar, PPG, and video imagery are not yet to the capability required for vital sign monitoring in the clinical setting or on space flight, they offer viable options for future research. Perhaps, individually or in combination, some of these novel technologies could be utilized to improve upon the current cumbersome and time-consuming methods of vital sign monitoring for space travel.


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