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KYMIRA: ASTRONAUT PHYSIOLOGICAL HEALTH MONITORING USING SMART UNDERLAYER GARMENT.

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Abstract

The SGAC have instigated a Digital Mars Analog Simulation to be developed and implemented. Using KYMIRA's non-invasive, continuous, biomonitoring smart garments as a potential scenario within a Mars Habitat or during excursions. This telemedicine solution can help to activity monitor and track astronaut health trends over the duration of the mission as well as accelerate clinical decision making when rapid decline or an acute event takes place. The smart garment is worn under EVA suits, similar to compression clothing. Garment sensors enable non-invasive, continuous and simultaneous physiological measurements. The smart garment is worn under loose fitting outfits or EVA suits, similar in principle to compression clothing. Garment sensors enable non-invasive, continuous simultaneous measurement. A key aspect of KYMIRA's proposed technology is the use of multiple physiological biomarker recordings to enable accurate medical assessment. When doctors, such as Cardiologists and Emergency Medicine physicians, make treatment decisions for patients with ECG abnormalities they do not only rely on the ECG results but must assess other aspects of the patient's physiology. An illustrative example of this is with Ventricular Tachycardia (VT), which is one of the most dangerous heart rhythm abnormalities that can be recorded by a cardiac monitor. When VT is associated with haemodynamic instability (i.e. a considerable drop in blood pressure), patients must be offered an implantable defibrillator to rapidly terminate the rhythm when it occurs. On the contrary, when VT is tolerated haemodynamically (i.e. with preservation of blood pressure), medications or ablation procedures to eliminate the cause are the best treatment. These two different kinds of VT simply cannot be distinguished using an ECG alone. In fact, any heart rhythm abnormality that results in haemodynamic instability requires a different treatment when compared to the exact same abnormality with preserved haemodynamic function. Even the most expert human analysts cannot reliably determine more precise diagnoses over broad categorisations.
Being able to measure multiple parameters drastically improves accuracy and speed of diagnosis which would be crucial, given the environment, light-delay, and lack of full medical assessment facilities and staff available.
Besides diagnosing serious and acute deteriorating health conditions, this same system would be used to objectively measure long-term physiological trends in Astronauts and help evaluate corrective measures. For example, individual muscle conditioning as well as an adherence to appropriate exercise and training regimes, tailored for a specific astronaut's needs could be better enabled via this smart garment system.
Keywords: Biomonitoring, smart garments

Acronyms/Abbreviations

Ventricular Tachycardia (VT).
Extra Vehicular
Space Generations Advisory Council (SGAC)

1. Introduction

The SGAC have instigated a Digital Mars Analog Simulation to be developed and implemented. Using KYMIRA's non-invasive, continuous, biomonitoring smart garments as a potential scenario within a Mars Habitat or during excursions. This telemedicine solution can help to activity monitor and track astronaut health trends over the duration of the mission as well as accelerate clinical decision making when rapid decline or an acute event takes place.
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The Mars based Medical Officer is unsure of the diagnosis and wishes to seek advice and concur with medical colleagues on Earth base.

Results of this data are electronically transmitted via connectivity from the Mars base where a Medical Officer member of the crew can view the results on a Laptop and also to a terrestrial Earth based 'Medical Team' using a VPN and global satellite comms (mars to earth orbital satellite communications) via a middleware server to perform necessary message conversion. The middleware server on the Mars base utilises an ultra-high frequency (UHF) antenna (approx 400 megahertz) to communicate with Earth through NASA's orbiters around Mars and thus relay the diagnostic data for expert medical interpretation on earth if required.

2. Material and methods

Kymira garment medical device. (Rechargeable battery or mains operated and connected to a solar powered battery charging source).

Non-nominal: If the Kymira garment malfunctions and requires troubleshooting in the form of technical support or advice from Kymira supplier to assist.

Experiment logistics:
Mass = 5kg
Volume = 300mm x 250mm x 350mm
Total garments = 4, with 2 to be used at any given time.
Crew required = Two members of Analogue Simulation crew to be involved throughout (Analogue Simulation team) = one man and one woman.
Duration = Minimum, 4 days of measurement, ideally 3 hours or more each measurement.
Setup = suiting up and ensuring connectivity, power supply etc. is correct. Should take no longer than 30 minutes, less once used to it.
Work required = can be worn for any work done but ideally 6-12 hours of the garments being worn in EVA's.
Onsite takedown = Kymira garments can just be placed in the box as originally packaged with all components.

As part of the DMAS Project, KYMIRA proposes the use of its biomonitoring smart garment as a telemedicine solution, to track and aid in assessing various health parameters of Mars-base inhabitants during day-to-day tasks and excursions outside of the habitat. The smart garment is worn under loose fitting outfits or EVA suits, similar in principle to compression clothing. Garment sensors enable non-invasive, continuous and simultaneous measurement of:

- Multi-lead electrocardiogram (ECG)
  3-dimensional measurement of heart electrical activity
  Automated trace labelling and parameter estimation (i.e. PR, QRS, QT intervals, etc).
- Targeted electromyogram (EMG)
  Evaluation of muscle activity and associated nerve cells
- Impedance Cardiography (ICG)
  Stroke volume, cardiac volume/output.
- Impedance plethysmography (IPG)
  Respiration rate
  Blood volume measurement and changes associated with haemodynamic function.
  Detection of deep vein thrombosis, venous and arterial insufficiency.
  indirect assessment of central and peripheral blood flow.
- Photoplethysmography (PPG)
  Optical measurement of volumetric changes in peripheral circulation
- Motion of limb segments via distributed inertial measurement units (IMU)
  inertial forces on limbs, joints and body segments
  estimation of total energy expenditure, joint angles, fatigue, dynamic acceleration, etc.
- Geo-tracking within habitat

Enabled with multiple habitat hubs for triangulation
- Core body temperature

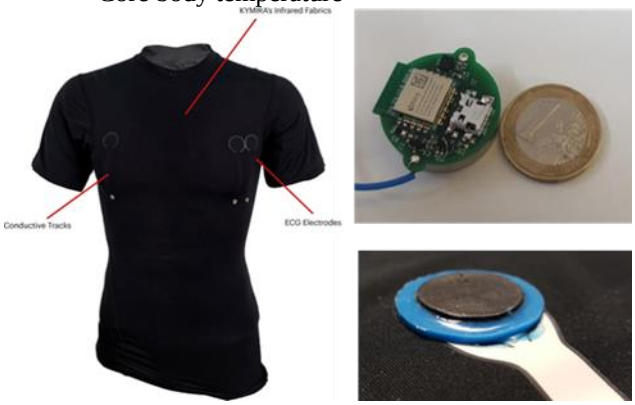

Fig .1 Kymira physiological measurement garment and sensors.

3. Theory

Location:

MOON OR MARS BASED ASTRONAUT ANALOGUE SIMULATION HABITAT.

Possible Scenario Narrative:

Astronaut in astronaut analogue team experiences severe shortness of breath, 'chest pains' with slight discomfort in the arm.
The 'Medical Officer' member of the Astronaut crew observes grossly abnormal ECG -indicates a Ventricular Tachycardia (VT) via the Kymira garment output for the astronaut.

1) VT with severe drop in BP (Heamodynamically unstable).
   Treatment: implantable defibrillator to rapidly terminate the rhythm.

2) VT with normal BP (Heamodynamically stable).
   Treatment: medications or ablation procedures to eliminate the cause.

This illustrative example of Ventricular Tachycardia (VT), is one of the most dangerous heart rhythm abnormalities that can be recorded by a cardiac monitor. When VT is associated with haemodynamic instability (i.e. a considerable drop in blood pressure), patients must be offered an implantable defibrillator to rapidly terminate the rhythm when it occurs. On the contrary, when VT is tolerated haemodynamically (i.e. with preservation of blood pressure), medications or ablation procedures to eliminate the cause are the best treatment. These two different kinds of VT simply cannot be distinguished using an ECG alone. In fact, any heart rhythm abnormality that results in haemodynamic instability requires a different treatment when compared to the exact same abnormality with preserved haemodynamic function. Even the most expert human analysts cannot reliably determine more precise diagnoses over broad categorisations.

Software infrastructure for data capture via small Bluetooth module.
MS Azure-based data infrastructure with signal feature extraction, event-based classification and logging.
Data collected from garment/astronaut transmitted via smartphone or home hub to secure Mars habitat middleware server (HSCN-compliant).
Data correlation & signal feature extraction to identify/classify anomalies. Contextualised event classification (plus data) shared with astronauts (medical officer) in 'MDRS habitat' or 'Earth terrestrial monitoring base' through browser-based system.

Minor incidences logged for next check-up. Events classified as 'serious' initiate alerts to the astronaut & medical officer in the astronaut team, establishing direct contact.

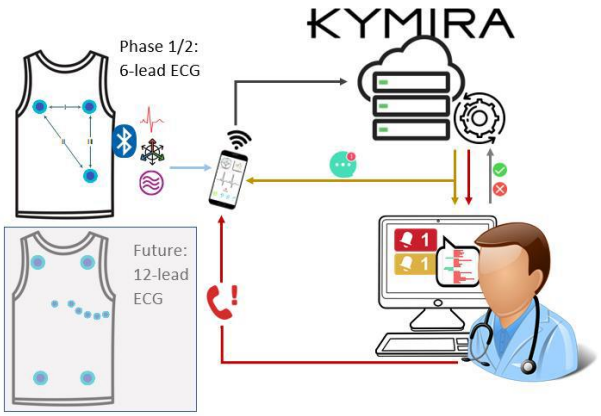

Fig. 2 Kymira System Architecture

Data Link Architecture proposal:

A controller (DMS) or middleware server on Mars base utilises a UHF antenna (approx 400 mhz) to communicate with Earth through NASA's mars orbiters.
The Kymira, POCT, INSITU Bioanalyser, LMC and MILA can all link to this controller or middleware server on Mars base to transmit data to it.
The Mars base and orbiter antennas within close range of each other & communicate more easily compared to the long-range telecommunications with Earth provided by low-gain and high-gain antennas.
Takes approx. 5 - 20 minutes for radio signal to travel the distance between Mars and Earth, depending on planet positions.
Using orbiters to relay messages is beneficial as they are much closer to the Mars base than the Deep Space Network (DSN) antennas on Earth.
The Mars habitat UHF antennae achieves high data rates of up to 2 megabits/sec on relatively short-distance relay link to orbiters overhead.
The orbiters then can use their much larger antennas & transmitters to relay that data on the long-distance link back to one of 3 x DSN antennae on Earth.

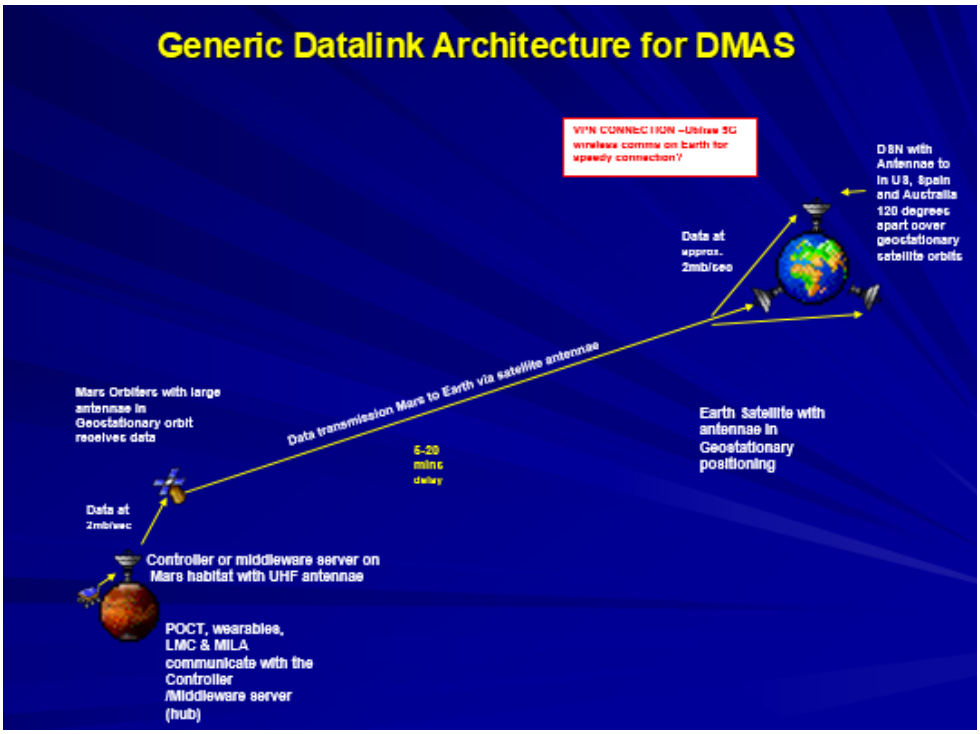

Fig .3 Generic data-link architecture proposal.

Daily Protocols - Basic Procedure for Astronaut to follow:

1) On waking, astronauts change out of sleep smart outfits to day-time smart garments. They place overnight comms units in appropriate charging hub and replace with fully charged day comms units.
2) Throughout the day, perform normal activities uninhibited by garments, which record activity, stress and fatigue levels, as well as monitor for any acute health anomalies or negative trends which might require corrective actions.
3) Biodata from astronauts within the Mars Habitat are automatically and wirelessly transmitted off the garment at set points throughout the day (e.g. every 2/3 hours) for analysis by AI-enabled Habitat hub/Medical Officer/Earth Operations.
4) Any corrective actions are logged and communicated to the Astronauts/medical officer either during set briefing times, or via their personal terminals as notifications/messages/video recordings from earth.
5) Corrective actions are undertaken, with biodata fed back as per the usual set transmissions, through which adherence can be monitored and positive changes confirmed.
6) During external excursions, garments are worn under EVA suits, and maintain a constant live link to Habitat supplying biometrics of astronaut. This provides live AI-enabled insights to the Habitat team, supporting quick decision making.
7) At the end of the day, day-time smart garments are swapped for sleeping smart outfits. Day comms units are placed in charging dock to charge overnight but could be continuously charged via Magnetic Coupling to location, and overnight comms units, now fully charged, are attached to sleep outfits for night time biometrics recording.

4. Results and Discussion

KYMIRA utilises multiple physiological biomarker recordings to enable accurate medical assessment.

1. Astronaut Physicians or Medical Officer makes treatment decisions for patients with ECG abnormalities as well as other aspects of the patient's physiology.

2. Multiple physiological parameters measured improving accuracy & speed of crucial Astronaut/Patient diagnosis including serious and acute deteriorating health conditions.

3. Kymira objectively measured long-term physiological trends in Astronauts and patients.

4. State of Astronaut Individual muscle conditioning & adherence to appropriate exercise/training regimes monitored closely.

5. Provided information to medical officer via multiple physiological sensors, currently targeting >90% diagnostic yield across the broadest range of cardiac arrhythmias and related conditions.

The following was discovered upon utilisation of Kymira to date:

- Easy-to-use, Astronauts/patients simply get dressed as with any regular garment, without needing to apply gels or adhesives to electrodes to record bio-signals.
- Comfortable to wear, ensuring adherence over monitoring period. KYMIRA's proprietary and patented biocompatible garment electrodes and seamless electronic integration techniques ensures patient comfort and 'invisible' integration within clothing.
- Reusable, robust and washable, as with any regular item of clothing.
- Lightweight with single miniature electronic unit for battery and antenna.
- Low power consumption, enabling day-long recording with a provision for Bluetooth wireless communications to habitat hubs (BLE 5.1).
- Battery requires charging - habitat light-harvesting with indoor PV cells contribute to energy provision with outdoor PV cells for energy heavy missions, which can also be applied to the outer layer of an EVA suit.
- Magnetic coupling can provide source for continuous charging of the battery without removing garment.
- Thermoregulation provided by KYMIRA's passive Infra-red emitting clothing.

6. Conclusions

A key aspect of KYMIRA's proposed technology is the use of multiple physiological biomarker recordings to enable accurate medical assessment. When doctors, such as Cardiologists and Emergency Medicine physicians, make treatment decisions for patients with ECG abnormalities they do not only rely on the ECG results but must assess other aspects of the patient's physiology. Being able to measure multiple parameters drastically improves accuracy and speed of diagnosis which would be crucial, given the environment, light-delay, and lack of full medical assessment facilities and staff available.
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