SPACE GENERATION ADVISORY COUNCIL

MOON VILLAGE ASSOCIATION

MVA Scenario's: Astronaut physiological health monitoring using smart underlayer garment (KYMIRA) for the MVA Analogue Work Group: Human Factors

Astronaut physiological health monitoring using smart under layer garment.

Location:

MVA Moon base location, Moon Base/Habitat Alpha

Narrative:

An elderly Astronaut (50 + yrs) in the team or crew experiences severe shortness of breath and some degree of 'chest pains' with slight discomfort in the left arm. The clinically qualified 'Medical Officer' member of the Astronaut crew observes a grossly abnormal ECG that indicates strongly for a Ventricular Tachycardia (VT) via the Kymira garment output for the astronaut, however they know not to rely on just the ECG results but must assess other aspects of the patient's physiology. 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.

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.

The Moon Village habitat 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 Moon 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 (Moon to Earth orbital satellite communications) via a middleware server to perform necessary message conversion. The middleware server on the Moon base utilises an ultra-high frequency (UHF) antenna (approx 400 megahertz) to communicate with Earth and thus relay the diagnostic data for expert medical interpretation on earth if required.

Mission distance:

~ 1km. – Within the Moon Habitat

Aim:

Medical Officer in Moon Habitat to perform Kymira physiological measurement outputs investigation to determine whether VT is haemodynamically stable or unstable. i.e two main scenarios:

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.

Kymira garment electronic communication with Earth base.
Check this physiological measurement data with an expert specialist clinician on Earth base to confirm the diagnosis and advice on treatment.
Instigate treatment to the Astronaut crew member asap.

Base:

Basic base, 10 astronaut crew total (all wearing Kymira garments) with Medical Officer incorporated into the team, main and backup communication to Earth medical team functional, functional Middleware server is available, DSN network on Earth is functioning and available.

Duration:

Availability of medical advice for the VT within the acceptable 'golden hour' for optimal time to diagnose and treat the Astronaut. – **1 hour**
Instigation of treatment if VT with haemodynamic instability or stable haemodynamics.
Non –Nominal: If treatment delayed beyond the 1 hour window, Astronaut patient is possibly at risk of dying or debilitation.

Equipment:

Kymira garment medical device (Rechargeable battery or mains operated and connected to a solar powered battery charging source)
Communication main between Earth and Moon base/habitat.
Non-nominal 1: If the Kymira garment malfunctions and requires troubleshooting in the form of technical support or advice from earth based supplier to assist (including time taken to help with Moon –Earth round trip delay or minimal lag time phase).
Non-nominal 2: If VT is hemodynamically unstable i.e low BP and the implantable defibrillator malfunctions.

Material and methods

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 this MVA Project, KYMIRA proposes the use of its biomonitoring smart garment as a telemedicine solution, to track and aid in assessing various health parameters of Moon Village base inhabitants during day-to-day tasks and excursions outside of the habitat.

KYMIRA Technology:

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:

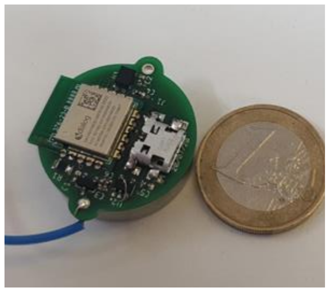
- **Multi-lead electrocardiogram (ECG)**
  - 3-dimensional measurement of heart electrical activity
  - Automated trace labelling and parameter estimation (i.e. PR, QRS, QT intervals, etc). Check for cardiac arrhythmias or other cardiac defects.
- **Targeted electromyogram (EMG)**

- Evaluation of muscle activity and associated nerve cells. Check for muscle degeneration in astronauts and effect of the gravity state on neurophysiology, and rMT levels.

- **Impedance Cardiography (ICG)**
  - Stroke volume, cardiac volume/output. To measure vital haemodynanic information about the heart's ability to deliver blood to the body, the force one's heart exerts with each beat, and the amount of fluid in the chest.
- **Impedance plethysmography (IPG)**
  - Respiration rate
  - Blood volume measurement and changes associated with haemodynamic function. Non-invasive estimations of cardiac output and total peripheral resistance to measure the split second impedance changes within the chest, as the heart beats.
  - Can provide indication of deep vein thrombosis but only when adequate data processing & analysis capability available. IPG has an overall sensitivity of 93% and specificity of 95% for the diagnosis of proximal, occlusive DVT, venous and arterial insufficiency.
  - Indirect assessment of central and peripheral blood flow.
- **Photoplethysmography (PPG)**
  - Optical measurement of volumetric changes in peripheral circulation. Oximetry - analysis of this waveform can help to evaluate various cardiovascular-related diseases such as atherosclerosis and arterial stiffness and detect hypertension.
- **Motion of limb segments via distributed inertial measurement units (IMU)**
  - Inertial forces on limbs, joints and body segments. Ensure astronauts are obtaining the correct amount of exercise?
  - 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**

System Key Features

- **Provides more information to clinicians**, by combining multiple physiological sensors, currently targeting >90% diagnostic yield across the broadest range of cardiac arrhythmias and related conditions.
- **Easy-to-use**, Astronauts Patients would simply get dressed as with any regular garment, without needing to apply gels or adhesives to electrodes to record biosignals.
- **Comfortable to wear**, ensuring adherence over monitoring period.



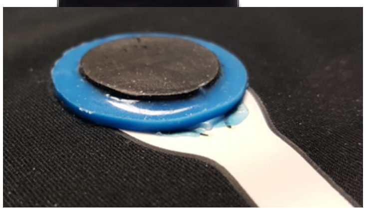


Fig .1
Kymira physiological measurement garment and sensors.

- KYMIRA's proprietary and patented biocompatible garment electrodes and seamless electronic integration techniques ensures patient comfort and 'invisible' integration within clothing.
- **Reusable,** garments are robust and washable, as with any regular item of clothing, for a suitable mission duration.
- **Lightweight** garments, with a single miniature electronic unit for battery and antenna.
- **Low power**, enabling day-long recording with a provision for Bluetooth wireless communications as and when needed to habitat hubs (BLE 5.1 allows for line of sight transmissions). Battery will eventually require charging, however, habitat light-harvesting with indoor-PV cells will contribute to energy provision, as could outdoor-PV cells for energy heavy missions, which can be applied to the outer layer of an EVA suit. Also, magnetic coupling can provide a source for continuous charging of the battery without removing the garment.
- **Thermoregulation** provided by KYMIRA's passive Infra-red emitting clothing.

SCENARIO concept:

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 Moon 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 nighttime biometrics recording.

Non-Nominal Scenario a):

Battery failure via PV cell malfunctions whilst on EVA and no physiological measurement readings taken for the astronaut.

Non-Nominal Scenario b):

A communications break down between the Moon Habitat and Earth base due to Middleware server failure, UHF antennae failure or satellite comms issue leading to a delay in relaying diagnostic results/data to Earth base and vice versa.

This leads to a delay in final diagnosis of the astronaut and can ultimately lead to Astronaut debilitation or even death.

Nominal Scenario for Kymira device electronic communications: IT connectivity and electronic communications

The ability to download physiological measurement results is developed to ensure rapid decision making at the Moon Habitat via communication and transmission of diagnostic data to clinical experts on Terrestrial Earth base.

The Middleware Server- converts the message received to a readable HL7 format (see diagram above for process).

The HL7 results are then relayed to the relevant Earth based server, to be visible under the 'Astronaut unique identifier' (CAD/Event number) on the Terrestrial Earth base system accessible on a PC workstation or laptop. Results can be accessed directly by clinicians on Earth base via use of a secure, password protected 'web portal' provided. The clinicians can then 'cross match' the CAD based Astronaut ID with the CAD number displayed in the Earth based system to positively ID the Astronaut and match with the results displayed in the system.

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 'MVA Moon 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.

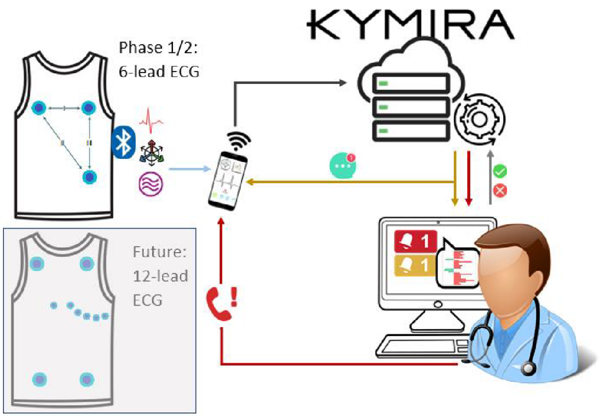


Fig. 2 Kymira System Architecture

<u>Generic Datalink Architecture for MVA</u>

A controller (DMS) or middleware server on the Moon base or Habitat utilises a UHF antenna (approx 400 MHz) to communicate with Earth.

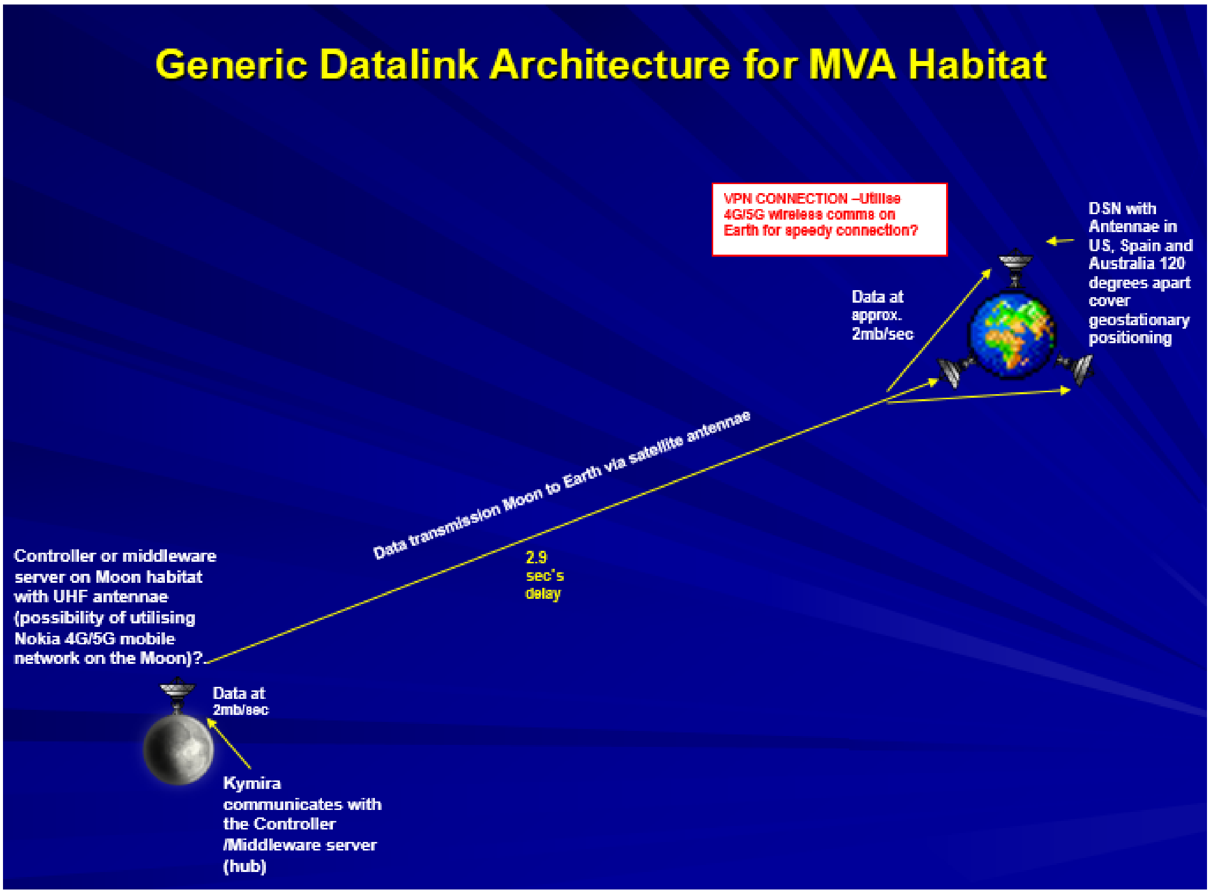
The Kymira garment can link via possible 4G/5G Mobile Network (Nokia?) to this controller or middleware server on the Moon base or habitat to transmit data to it.

The Moon base antennae establishes a long range telecommunications link (possibly 4G/5G – Nokia?) with Earth provided by low-gain and high-gain antennas.

Takes approx. 2.9 seconds for radio signal to travel the distance between the Moon and Earth.

Deep Space Network (DSN) antennas on Earth are able to receive the data signal directly with antennae located in US, Spain and Australia 120 degrees apart in geostationary positioning.

The Moon habitat UHF antennae achieves high data rates of up to 2 megabits/sec on relatively short-distance relay link.



Non-Nominal Scenario's for electronic communications:

The following can cause a breakdown in connectivity & communications:

1) The 'Middleware server' or 'controller' on the moon base can fail (interface requires restarting or other),
2) UHF antennae failure (needs fixing)
3) 4G/5G wireless comms issue leading to delay in relaying diagnostic results/data to Earth base and vice versa.
4) Satellite overpasses may cause unpredictable random delay via momentary interference in electronic data communication.

DATA MESSAGES QUEUE UP ON INTERFACE AND RESUME UPON RE-CONNECTION OTHERWISE ASTRONAUT NEEDS TO TROUBLESHOOT ANY OF THE ABOVE ISSUES SHOULD THEY ARISE.

All of these failures can lead to delay to the 'golden 1 hour' requirement for diagnosis of Astronaut serious or adverse medical condition and instigation of the required treatment.

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.

Conclusion

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.

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.

References:

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