A Sensor Fusion Wearable Health-Monitoring System with Haptic Feedback

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Summary

Wearable Health-Monitoring Systems (WHMS)

Wearable Health-Monitoring Systems (WHMS):

- the design and development of these systems (WHMS) has received lots of attention;
- low-cost systems;
- Multi-sensor fusion is one of the most suitable technologies to use.

Multi-sensor fusion and Haptics:

- a system that features a multi-sensor fusion approach and also provides an integrated haptic feedback for the user has not yet been deeply investigated.

A Possible Application Scenario: Offshore Operations

Safety of offshore installations is a crucial issue:

- Increasingly demanding marine operations are at the heart of the maritime industrial cluster.
- These advanced operations are associated with a high level of uncertainty on board of an offshore installation because such an installation usually operates in a dynamic environment in which technical, human and organisational malfunctions may cause accidents.

Motivation Factors

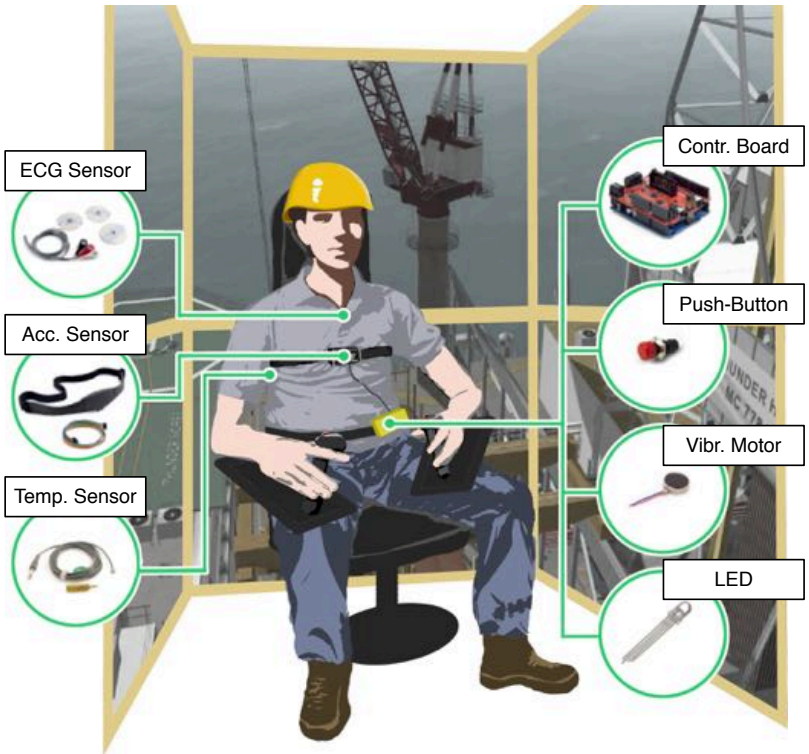
- This kind of working environment is associated with a considerable amount of stress for the workers.
- Physical stressors include noise, vibration, poor lighting and ventilation, confined living and working space, adverse offshore weather conditions, long working hours and and shift work[1].
- Psychosocial stressors cover job characteristics (work load, variety, clarity, control), perceived risk (fire, explosion, travelling by helicopter or ships, etc.), job insecurity, work-family balance, and the lack of certain types and sources of social support.

Mandatory health and safety monitoring:

- Mandatory health and safety monitoring of all crew members was put in place by the offshore health and safety law in order to minimise human error and potential resulting hazards. It is also mandatory to keep records pertinent to such monitoring.
- There is an urgent need to develop more efficient methods and tools that will allow for a greater accuracy and therefore more reliable modelling and simulation of risk assessment.

[1] WQ Chen, I TS Yu, and TW Wong. "Impact of occupational stress and other psychosocial factors on musculoskeletal pain among Chinese offshore oil installation workers". In: *Occupational and environmental medicine* 62.4 (2005), pp. 251–256.

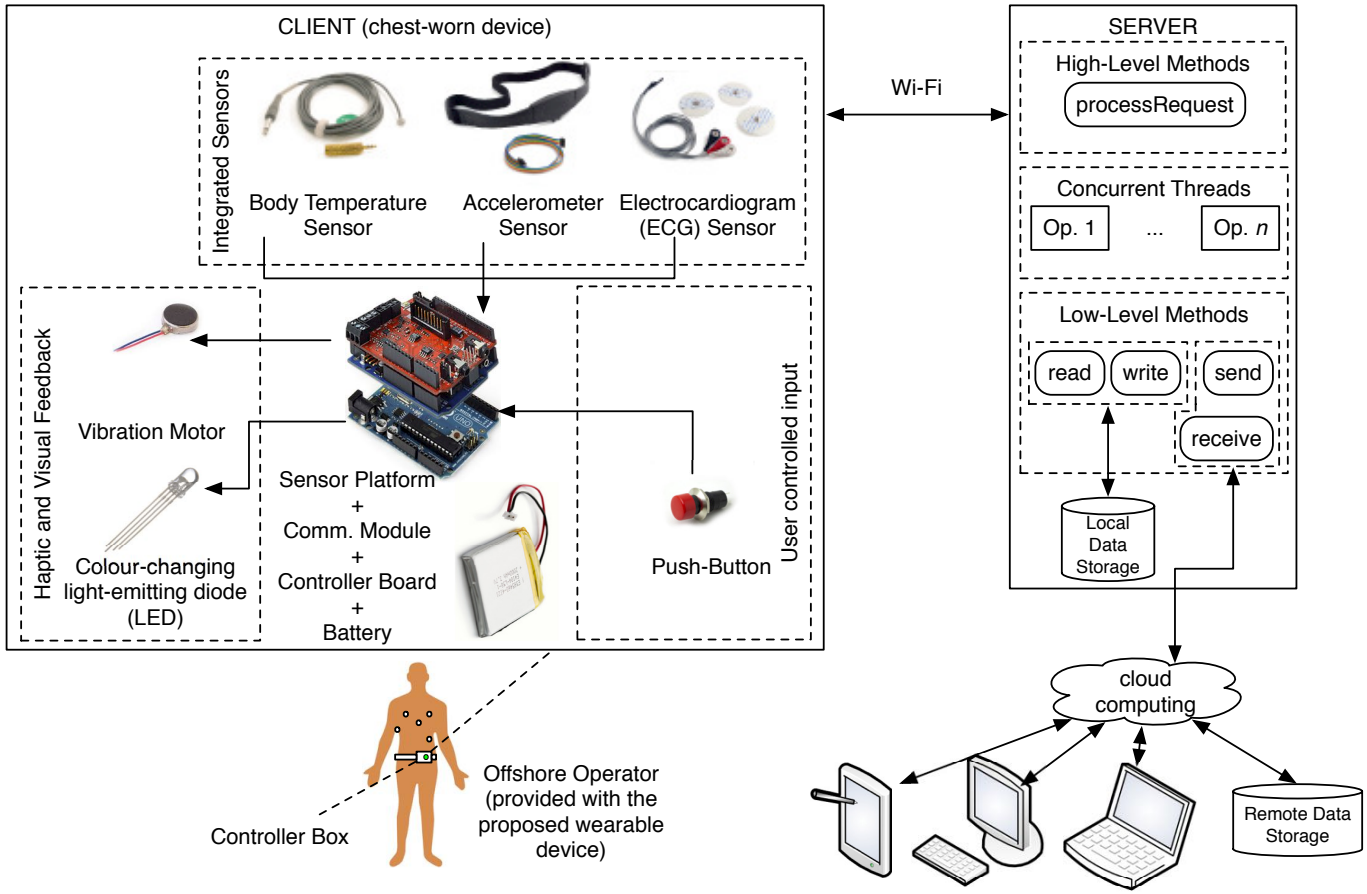
A Wearable Health-Monitoring System for Offshore Operators



A wearable health sensor monitoring system based on a multi-sensor fusion approach:

- Biometric and medical monitoring applications can be performed by using this multi-sensor device. The embedded vibration motor makes it possible to actuate distinctive haptic feedback patterns.
- The Light-emitting diode (LED) provides the operator with an additional intuitive visual feedback. The provided push-button can be used by the operator to report a potential emergency state.
- Data can be sent to a cloud computing system in order to perform permanent storage or visualised in real time by sending the information directly to a laptop or smart phone.

System Architecture



- A client-server pattern is adopted.
- The overall system design is the result of the application of specific virtual prototyping methods and simulations tools to aid us in making optimal architectural choices, testing procedures and validation techniques.

Client (Chest-Worn Device)

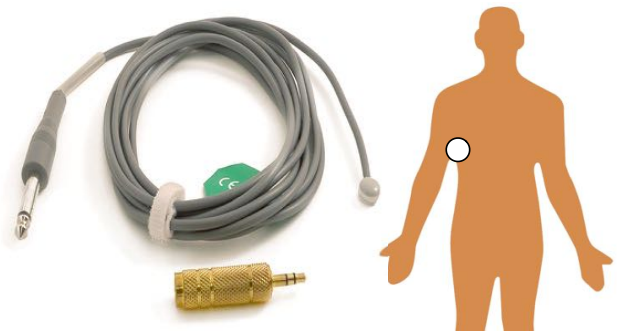
- A polymer lithium ion battery is adopted in order to provide power to the proposed controller box.
- An *Arduino Uno* board based on the *ATmega328* micro-controller is used as a client.*Arduino* is an open-source electronics prototyping platform based on flexible, easy-to-use hardware and software.
- To give communication capabilities to the proposed wearable device, an *Arduino WiFi Shield* is stacked on top of the adopted controller board. In detail, the *Arduino WiFi Shield* allows the client to communicate with the server by using the 802.11 wireless specification (WiFi).
- To gather the operator's biometric data, an *e-Health Sensor Shield* is stacked on top of the adopted communication module. The *e-Health Sensor Shield* allows *Arduino* boards to easily gather information from different sensors. An open-source software library is provided with the *e-Health Sensor Shield*, allowing for easy access to the sensor data.

Sensors

- An ECG sensor kit is adopted. This sensor input can be used as a diagnostic tool to assess the electrical and muscular functions of the operator's heart. This sensor has proven to be useful in the diagnosis of several cardiac pathologies ranging from myocardial ischemia and infarction to syncope and palpitations.

- An accelerometer sensor is adopted. This sensor is used to monitor five different patient positions (standing/sitting, supine, prone, left and right). Analysing movements during on-board operations helps in determining work quality and irregular pattern behaviours. The accelerometer sensor also help to detect fainting or falling of the operator while working.

Sensors



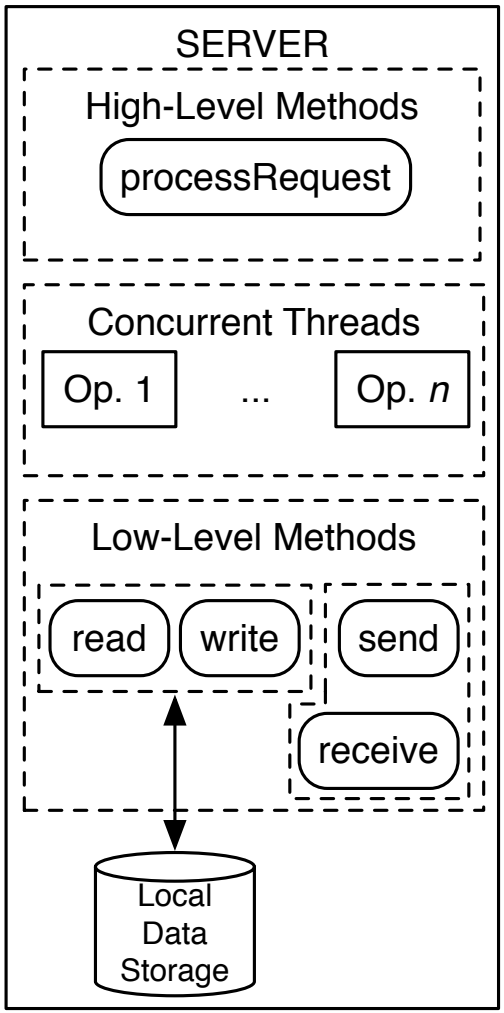
- A temperature sensor is provided. Body temperature is an important health state indicator and accurate measurements can provide medical insight into the wearer's response to different situations. The reason is that a number of diseases are accompanied by characteristic changes in body temperature. Likewise, the course of certain diseases can be monitored by measuring body temperature, and the efficiency of a treatment can be evaluated by the physician.

Intuitive Haptic and Visual Feedback

- A vibration motor is embedded on the back side of the controller box and it allows for actuating distinctive haptic feedback patterns according to the operator's health state. This feature is fundamental for improving the user's risk perception.
- When the operator's health state is normal, the motor does not produce any vibrations. On the contrary, two different vibration patterns are actuated to symbolise a potentially abnormal condition (low frequency vibrations) or a rather dangerous state of health (high frequency vibrations).

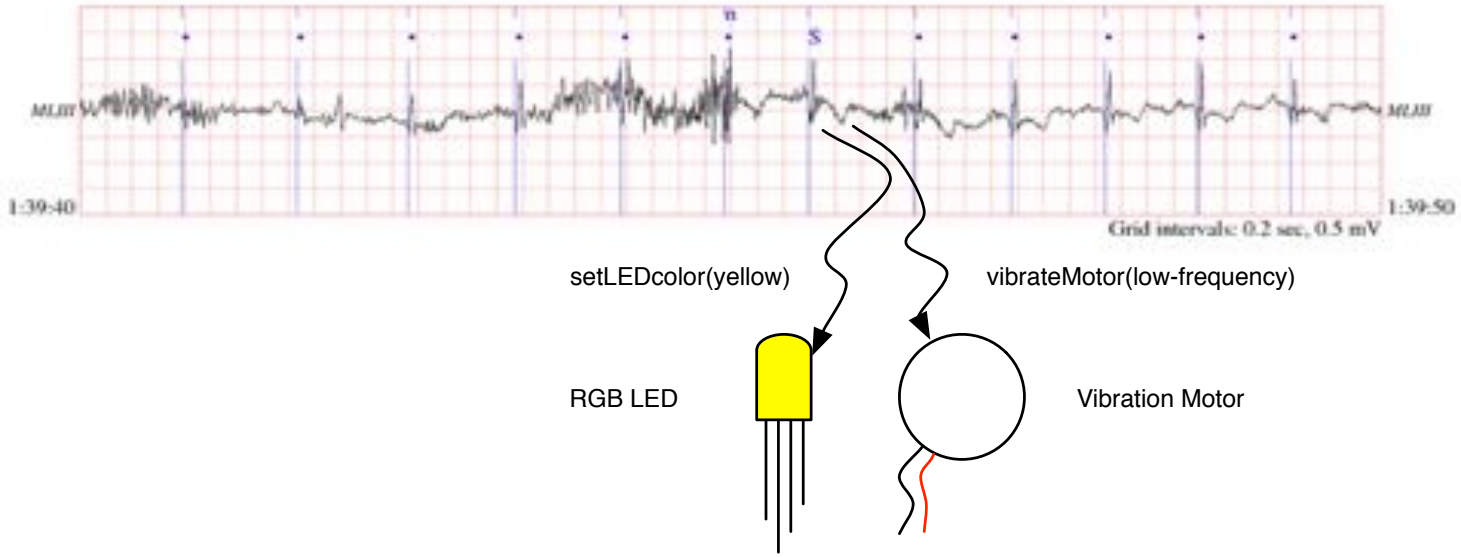
- A colour-changing LED is embedded on the visible side of the controller box. This LED provides the user with an additional intuitive visual feedback of the current health state. In particular, three different colours are used: green to indicate a normal health state, yellow to symbolise a potentially abnormal condition and red to point out a dangerous health state.

Multi-Threading and Multi-Level Hierarchical Server



- The *High-Level methods* layer includes the *processRequest* control function, which handles each client request.
- The *Concurrent Threads* level is the layer where each client request is treated as a concurrent process. The health state of each operator is monitored by a separate thread. Each monitoring thread sends the current information status back to the corresponding client so that the vibration motor and the LED can be actuated.
- The *Low-Level methods* layer includes the functions that are used to write data to a local database (*write*), to read previously acquired data from a local database (*read*), to send the acquired data to the cloud (*send*), and to receive previously acquired data from the cloud (*receive*).

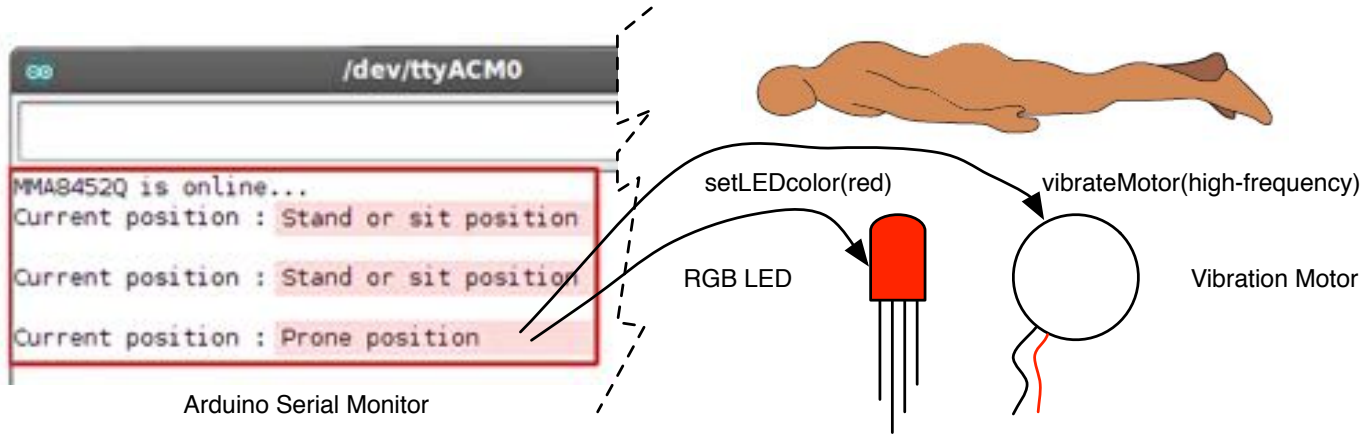
ECG Simulation Results



Concerning ECG monitoring, we used data from the *Physiobank* archive[2]. The possibility of detecting supraventricular premature or ectopic beats (atrial or nodal) is considered.
"Ectopic beats occur when another region of the atria depolarises before the sinoatrial node and thus triggers a premature heartbeat". A simply way to detect this event consists in comparing the current beat time interval with the average time interval of the previous beats.

[2] Ary L Goldberger et al. "Physiobank, physiotoolkit, and physionet components of a new research resource for complex physiologic signals". In: *Circulation* 101.23 (2000), e215–e220.

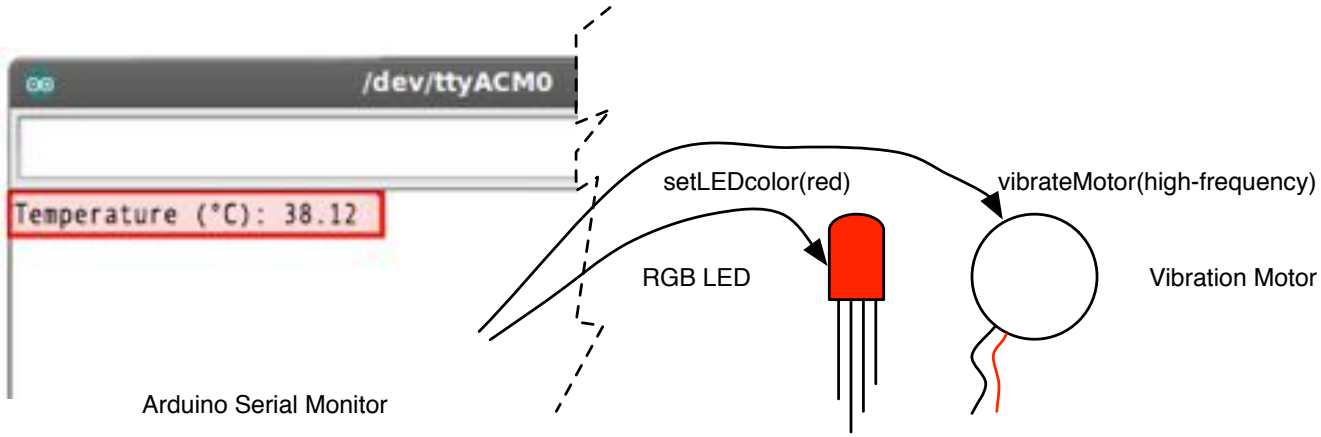
Accelerometer Simulation Results



The possibility of detecting five different operator positions is considered. By using the software library provided with the *e-Health Sensor Shield*, the proposed system is able to distinguish between the following positions: standing/sitting, supine, prone, left and right.

A particularly dangerous situation that can happen is fainting, which may cause the operator to fall while working. When this happens, the corresponding server-side monitoring thread sends a status update to the client so that the vibration motor can vibrate with high frequency and the colour of the LED can be changed to red.

Temperature Simulation Results



The possibility of detecting states of fever and hyperpyrexia for the operator has been considered. Particularly, axillary body temperature measurements are taken at 10-minutes intervals.
The case of hyperthermia is considered as an example. This is quite dangerous for the operator, therefore the system considers this case as a critical state and makes the motor the vibrate with high frequency, while the colour of the LED is changed to red.

Conclusion and Future Work

A Wearable Health-Monitoring System for Offshore Operators:

- It is possible to use the collected biometric information in real-time for monitoring the health state of the crew members, or subsequently analyse the data to facilitate a medical diagnosis.
- The information can be sent wirelessly to a cloud computing system for permanent cloud-based data storage or it can be visualised in real time if sent to a laptop or a smart phone.
- In this preliminary work, virtual prototyping methods were fundamental in the development of the proposed system architecture.

Future work:

- The use of experimental data will make it possible to certify and asses system performance in a real application scenario.
- Advanced techniques for data mining may be adopted.
- The proposed framework may be integrated with a positioning system for offshore operations that we recently developed[3].

[3] Filippo Sanfilippo and Kristin Ytterstad Pettersen. "XBee Positioning System with Embedded Haptic Feedback for Dangerous Offshore Operations: a Preliminary Study". In: *submitted to the Proc. of the OCEANS'15 MTS/IEEE Conference, Genova, Italy*. 2015.

Thank you for your attention

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