Grant Agreement No. 611373

FP7-ICT-2013-10

D2.3 – DiverNet local sensor network integration on diver

Due date of deliverable: 05/2015
Actual submission date: 05/2015

Start date of project: 01 January 2014 Duration: 36 months

Organization name of lead contractor for this deliverable: UNEW

Revision: version 1

Dissemination level		
PU	Public	x
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Contents

1 Outline of the deliverable

This deliverable describes the development of the DiverNet sensor network to capture motion/posture and physiological data from a diver. It covers the sensor devices, data acquisition/processing unit (DiverNet Hub) and the software to analyse and visualise this data.

2 Hardware development

The DiverNet hardware has been designed and constructed by UNEW, working to a specification developed in conjunction with UNIZG and UNIVIE. The system consists of a centralised processing and acquisition unit, referred to as the 'hub', which interfaces to a range of inertial and physiological sensors. The specification of the system is summarised below:

- Simultaneous sampling of up to 20 inertial sensor nodes at a sample rate of 50Hz, (typical operation = 15 nodes).
- Each sensor node consists of:
  - 3 axis gyroscope (L3GD20H) – resolution up to 2000dps, 16bit output
  - 3 axis accelerometer (LSM303D) – 16bit data output (maximum range ±12 gauss)
  - 3 axis magnetometer (LSM303D) – 16 bit data output (maximum range ±16g)
- Tethered surface communication link via RS485 – Throughput of >1MBps over distances of >100m.
- Expandability for integration with alternative physiological sensors via 10 bit and 12 bit ADC interfaces (e.g. breathing belt, heart rate sensors, etc.).
- Additional communication interfaces, USB and RS232, available for connectivity with acoustic modems and local displays (i.e. the diver tablet).
- Central ARM Cortex M3 processor for data acquisition and future integration of on-board data processing algorithms.
- Local removable solid state memory (micro-SD card) and real time clock enabling remote storage and time stamping of data captures (to be supported in future firmware releases).

The central hub utilises an Atmel ARM CORTEX M3 processor as a system on chip solution to sample and process each of the sensor readings. Each of the inertial sensor nodes has an individual I^2C protocol data line and a global clock is provided. The data from the 20 sensor nodes (9 readings each) is then read back as a parallel bus and unpacked (de-interleaved) on board the processor, at an update rate of 50Hz. Inertial sensors wired as 5 groups, one for each limb and one for the torso/head. Additional analog inputs are allocated to interfacing a breathing rate sensor and heart rate sensor.

The initial system, delivered for experiments in 2014 and early 2015, communicates with the surface via RS485 over a tethered connection. This format has been agreed to allow raw readings from all sensors to be gathered and processed in real-time, for the development of the diver gesture and emotion recognition in WP3. The system has been designed to enable the hub to interface to the diver tablet or directly to the diver segment acoustic modem for wireless transfer of sensor data to the underwater and/or surface segment. A block diagram of the system constructed is shown in Fig. 3.1.

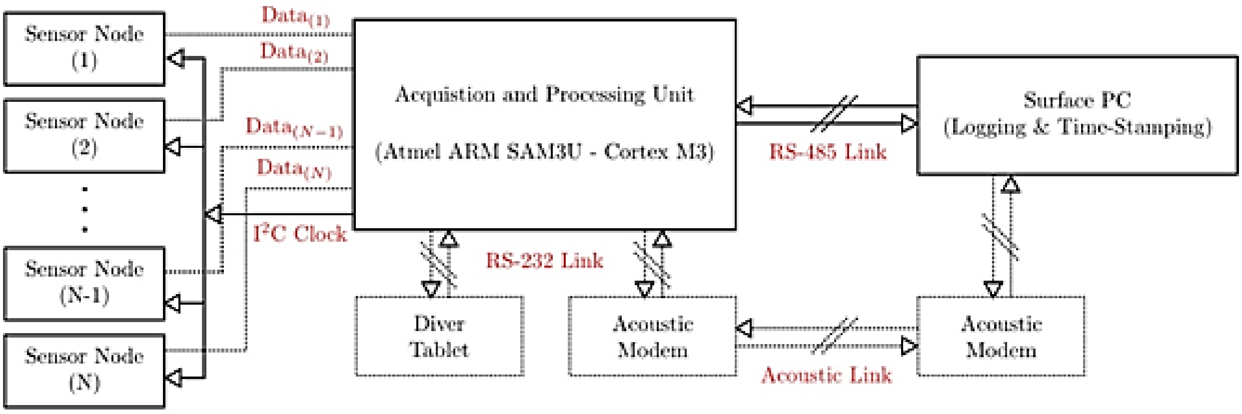

Fig. 3.1. DiverNet System Block Diagram

Fig. 3.2 shows one of the printed circuit boards (PCB) assembled for delivery to UNIZG. Firmware has been completed to implement the data acquisition and transfer and this has been successfully validated in experiments by UNIZG and UNIVIE. Mechanical enclosures have been completed, machined from 5083 grade aluminium and utilising micro Subconn connectors (underwater mating) for the connection of the sensor groups and surface tether. The physical mounting of the inertial sensors allows flexible positioning around the body to identify the most effective locations for motion/gesture capture and to allow for varying body dimensions. A first experimental system was delivered in April 2014 to UNIZG and some refinements were made throughout 2014 including the addition of physiological sensors as will be reported in later sections. Figure 3.3 shows the experimental system installed on a diver and then in action during a dive.

Fig. 3.2. DiverNet 'Hub' PCB : Dimensions 107mm x 40mm

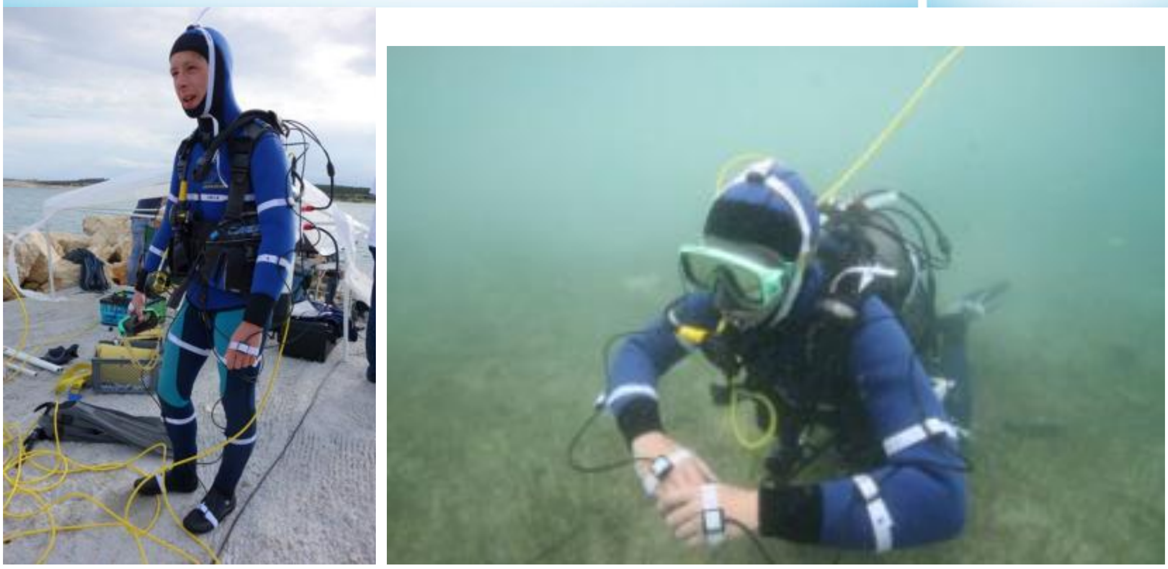

Fig. 3.3. DiverNet sensor system deployed on a diver

3 Additional physiological sensors

The DiverNet system has been expanded to include a simple commercially available breathing belt pictured in fig 4.1. This consists of a piezoelectric bimorph linked to an elastic strap which fits around the chest and translates the expansion/contraction of the chest cavity into a small signal which corresponds to acceleration. A signal conditioning circuit has been designed and constructed (amplifier and filter) to improve the signal-noise ratio from this sensor and the output of this circuit fed into a spare ADC channel on the DiverNet hub. Initial testing gives encouraging results as shown in Fig. 4.2, allowing the rate, depth and regularity of breathing patterns to be extracted for analysis by UNIVIE.

The device is not designed for underwater operation and although this has been successfully applied in freshwater pools, a waterproof variant has been constructed by UNEW using the same piezo sensing element with suitable encapsulation. This device will be used in upcoming experiments carried out by UNIVIE during 2015.

An additional sensor added for upcoming experiments will be a wireless heart rate sensor as shown in fig 4.3. This is a simple chest mounted ECG sensor which transmits a 5kHz EM signal for each heart beat. Due to the low frequency inductive signalling, this can be detected up to 1m away in sea water and so is suitable for transmission to the DiverNet hub. A receiver circuit has been designed by UNEW and this will be incorporated into the system for experiments in 2015.

Fig 4.1. Breathing belt device

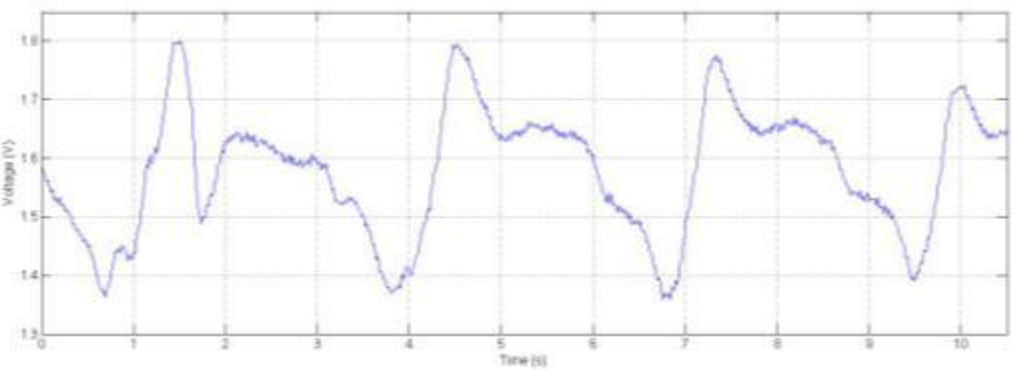

Fig 4.2. Output of breathing belt sensor connected to DiverNet (24 breaths/minute)

Fig 4.3. Wireless heart rate sensor

4 Software and visualisation

UNIZG-FER have developed the software for communication with the DiverNet and for visualization in the ROS environment. Raw DiverNet data is received on the surface via the RS485 link. The data is unpacked and processed by a ROS node. Processing includes transformation of raw acceleration, magnetic and gyro measurements to roll, pitch, yaw attitude. The attitude is additionally filtered by a complementary filter. Attitude measurements in combination with known measuring positions on the human body can be used to measure attitude and positions of the extremities. Data visualization is achieved using the ROS 3D visualization tools, see Fig. 5.1.
The human-like model is specified in a Unified Robot Description Format (URDF). The URDF is a XML like format that helps in 3D modelling object with joint and movable parts, i.e. robots. The model specifies 15 characteristic points/joints as defined by UNIVIE to help measure body posture and extremity position. A sample video of the visualization is available online here.

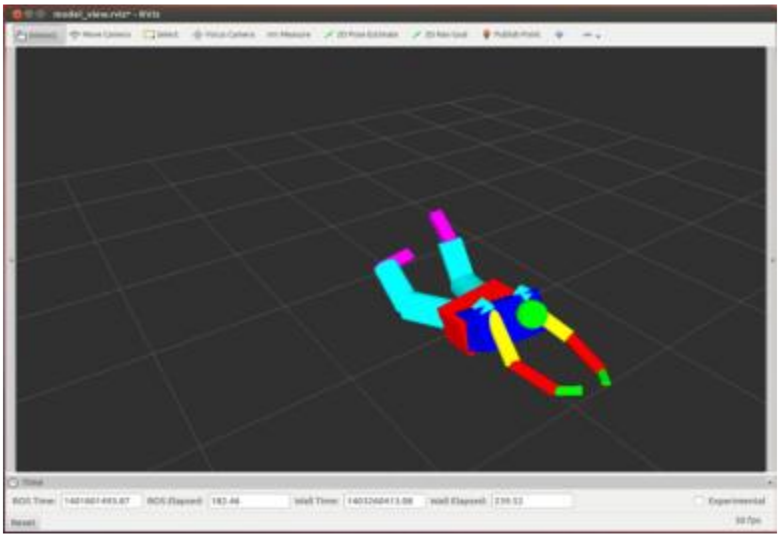

Fig. 5.1. 3D reconstruction of the diver posture in ROS RViz

Since the initial version described above, which visualizes the diver with a virtual stick-man figure, a new virtual model of the diver has been made. It is also specified in the URDF format, but uses realistic body parts models described in Collada files which were provided by University of Jacobs. The new model is displayed in Fig. 5.2.
Another model has been created using the Bivision hierarchy (BVH) textual file format. In comparison to the 3D visualization in ROS based on URDF, this model is much simpler, but provides all the information on joint states and body posture and is playable in many commercial players for motion capture models. A simple skeleton-only visualization of this model is shown in Fig. 5.3. All collected data is easily transformed between the two models.
A filter for the sensors is still under development. Current version, which operates at individual sensor level, has further been improved with dynamic filter parameter selection, leading to better visualization quality.

Fig. 5.2. Visualization of the diver in ROS RViz with the new diver model.

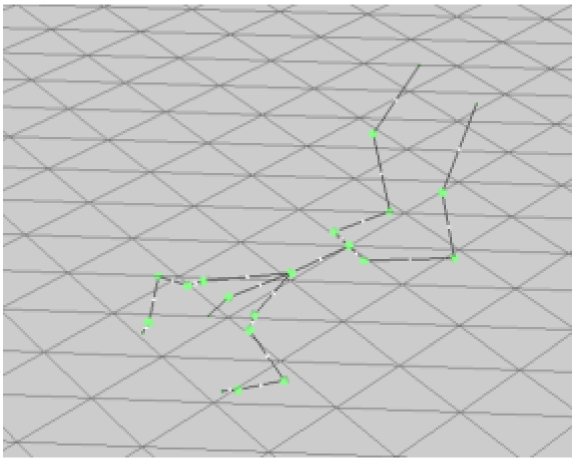

Fig. 5.3. Simple visualization of the BVH diver model.

For the purpose of sensor fusion and orientation estimation a gradient descent based quaternion filter developed in [http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=5975346] is used. The filter uses magnetic field measurements to remove the drift in gyroscope and gives an estimate of orientation for each of the DiverNet sensors. It provides similar performance to Kalman filter based solutions, but has lower computational complexity.

To deal with offsets caused by imperfect sensor placement on the body an initial calibration step has been added. After the diver takes one of the predefined poses, rotation quaternion between the ideal pose and the measured pose is calculated for each sensor and used to correct the orientation. The result of such procedure is shown in Fig. 5.4, where on the left is the visualized diver model before calibration and on the right after calibration.

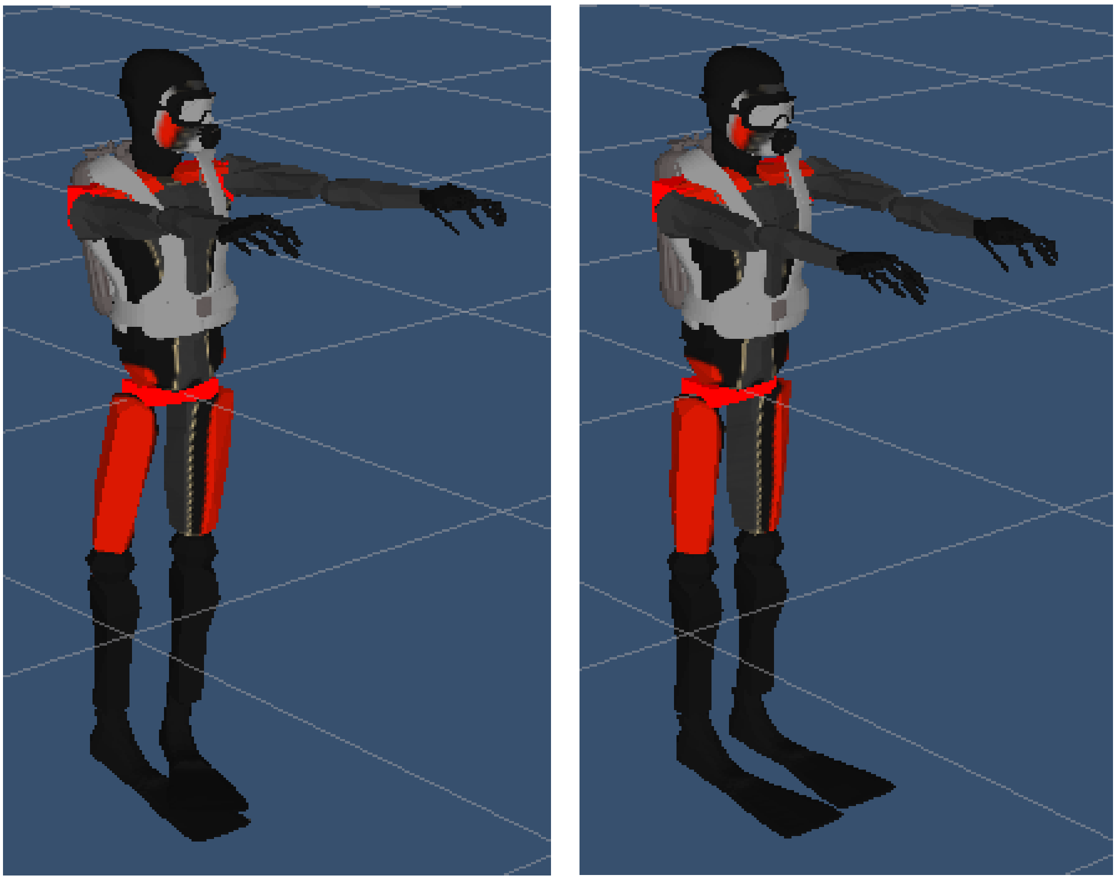

Fig. 5.4. Diver model before (left) and after (right) calibration with predefined pose

5 Conclusions and future work

The DiverNet network of inertial sensors has been designed, constructed and tested by UNEW and successfully deployed on numerous divers to date with many hours of data collected from up to 20 inertial sensor nodes . The hardware platform is proving reliable and has been expanded to include input from a piezo-electric breathing sensor which has been adapted for subsea use. A wireless heart rate sensor will also be integrated into the unit for future experiments. Algorithms to calculate and display the diver posture from the inertial data have been developed by UNIZG with very promising results, leading to an IEEE conference paper on the hardware design and processing being published. Posture data is now being analysed by UNIVIE to determine how gestures and other information on the diver state may be extracted and how many sensors are actually required to extract this information.

Experiments will continue throughout 2015 when the DiverNet system will be deployed wirelessly, first with on board data logging and then with sensor data transferred to the diver's tablet for local processing, to extract gesture/state information and transfer this information to the other segments via acoustic transmission.