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Abstract

Oil & Gas offshore platforms are industrial "towns", ranked among the most hazardous working environments. Emergency situations in such environments are unpredictable and characterized by time pressure and rapidly changing conditions. OffshoreMuster brings together the latest technological advancements in real-time personnel tracking and e-mustering, complementing the existing Health and Safety (HSE) procedures, by enabling situation awareness over personnel location and status which is a key factor supporting better decision-making towards zero casualty in emergency situations.

The system's underlying technology, developed after years of dedicated research and development efforts, consists of specialised low-power wireless wearable devices, customised gateways and a secure backbone network infrastructure feeding a modular decision support software system with real-time streams of data for processing and visualisation of information relevant to personnel situation assessment. HSE processes have been transformed into systematic procedures, allowing additional computer-aided decision support features, like the real-time observation of the fire-fighting team response status, the concentration of people in specific areas, instant alerting or the last-known position of a missing person.

Lightweight ubiquitous devices in the form of a bracelet or embedded in the uniform are assigned to People on Board (PoB) and periodically transmit real-time location and status awareness data. A network of dedicated gateways, which are placed at specific locations on the platform or vessel, connected through the infrastructure's ethernet or wireless network, relay the data to a central decision support system. Specialised localisation algorithms and data analytics tools process the data to estimate the personnel positions and PoB status information, interactively visualising in real-time location awareness, incident escalation and alerting, which can significantly reduce response time and speed up a safe evacuation procedure. Computer-aided decision support combined with ultra-low power autonomous IoT technologies systems play a significant role in controlling, managing, and preventing critical incidents in harsh working environments, contributing into minimisation of accidents occurrence in Oil & Gas environments. The presented underling technology has been validated in maritime environments with more than 500 people taking part in real drills (TRL-8). The technology has been tailored to enhance the

safety of personnel working in offshore Oil & Gas assets, currently being under laboratory testing and evaluation while a full-scale industrial deployment is scheduled for the autumn of 2021.
The OffshoreMuster hardware and software components, integrated into a unified solution tailored for the offshore Oil & Gas industry, are presented for the first time. The system has been designed and developed with the support of the European Commission, co-funded by the Fast Track to Innovation Program (Grant Agreement Number 878950).

Introduction

Offshore Oil & Gas infrastructures are ranked among the most hazardous working environments in the world. Besides the strict health and safety regulations, emergency situations and incidents occur regularly. Emergencies in such environments are characterized by time pressure, ambiguity and rapidly changing conditions. Emergency response requires preparation, personnel training and capability to face unforeseen situations where fast reaction is crucial and, in some cases, lifesaving.
The OffshoreMuster system (OSM) complements the existing Oil & Gas Health and Safety (HSE) procedures by enabling computer-aided decision support utilising cutting-edge technologies for real-time personnel location and status awareness, evacuation management, instant Person on Board (PoB) identification and electronic mustering. Proprietary localisation, data analytics and data processing algorithms, feed a modular and easy-to-use decision support system which visualises in real-time personnel location and status, incident escalation information, and instant alerting in emergency situations, all delivered through a unified system. The latter can be a key factor for on-the-spot decision-making that can contribute in saving lives.
The technology behind the system has been developed end-to-end internally and consists of proprietary Hardware and Software modules as well as communication protocols and intelligent algorithms. More specifically, the hardware components consist of low-power wireless wearable devices which can also be discreetly attached to the uniform of personnel, and specialised gateways which are installed on the offshore Oil & Gas infrastructure. The secure data communication modules of the system utilise the infrastructure's ethernet or wireless network relaying real-time data streams to the central decision support system. HSE operators can interactively visualize in real-time location awareness, incident escalation and alerting, which can significantly reduce response times while taking informed decision and speed-up a safe evacuation procedure.
Automation and digitization of Oil & Gas HSE procedures is a relatively new challenge, with the majority of currently available offerings to be geared towards different industry applications such as healthcare and onshore manufacturing environments, or being focused in one aspect of the problem (e.g. mustering operation).
A market survey revealed offerings that simply computerize established paper-based mustering procedures, others that solely concentrate on remote worker health vitals/fatigue monitoring, while some provide basic localization limited in specific areas. OSM uniquely combines all these functionalities and more, such as powerful algorithm-based positioning, incident escalation, alerting and e-mustering under one seamlessly integrated decision support application that offers real-time POB situational awareness and enables Offshore Oil & Gas professionals to act faster in emergency conditions and ultimately save lives. Additionally, a full suite of data analytics and the ability to "play back" real occurred scenarios provide valuable assistance to post-event forensic and root cause analysis, towards a constant improvement of Health & Safety operations.
The paper is organized as follows: First, the solution and the overall system architecture are presented followed by the system's underlying technologies including the hardware components, the communication, the central data processing and visualisation tools. The next section presents the system's evaluation results in order to validate the features and the performance of the system. Finally, the last section concludes the paper.

OffshoreMuster: A holistic solution for Health & Safety procedure automation

OffshoreMuster introduces a holistic solution for the offshore Oil & Gas HSE operations, offering computer-aided decision support for emergency situations. Real-time Person on Board (PoB) and incident-response-teams' (firefighters, safety crew, etc.) situational awareness, incident escalation management, head-counting and efficient electronic mustering as well as evacuation management, are combined for the first time through a unified system consisting of proprietary hardware components, communication protocols, and a top system software modules (**Figure 1Error! Reference source not found.**). The System hardware consists of low-power wireless wearable devices that periodically transmit RSSI signals, and customised gateways that receive, parse and relay the signal through a secure backbone network utilising the infrastructure's ethernet or wireless network. Streams of data securely feed a centralised decision support system that receives the data, applies innovative localisation, machine learning and Artificial Intelligence (AI) algorithms which produce meaningful decision support information that can be visualised through various Graphical User Interfaces (GUI). In addition, instant head-counting and fast electronic mustering are provided via a handheld device and a customised mobile app connected in-real time with the central Decision Support System (DSS).

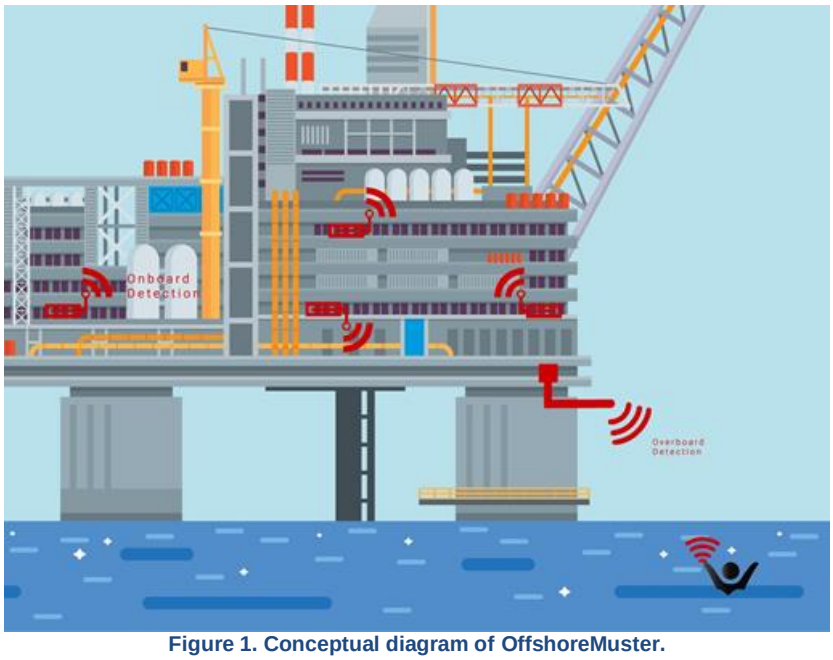

Figure 1. Conceptual diagram of OffshoreMuster.

The OSM architecture enables the system components to be integrated into a unified system, ensuring robustness providing at the same time the necessary modularity and adaptiveness to fit any specific offshore Oil & Gas HSE operations' process. The overall system breakthrough is that it combines many sub-systems into a holistic solution with the ability to perform different HSE distributed tasks continuously, ensuring systematic event handling, resilience in failures and unobstructive operation. The use of cutting-edge technologies ensures fast and secure data transmission and processing as well as the ability to visualise information and useful insights in an intuitive GUI. The high-level system architecture is presented in Figure 2, and it involves the main hardware components, the lower-level data processing tools and software algorithms, the middleware software services and the interfaces and connectors to the top system graphical user interfaces.

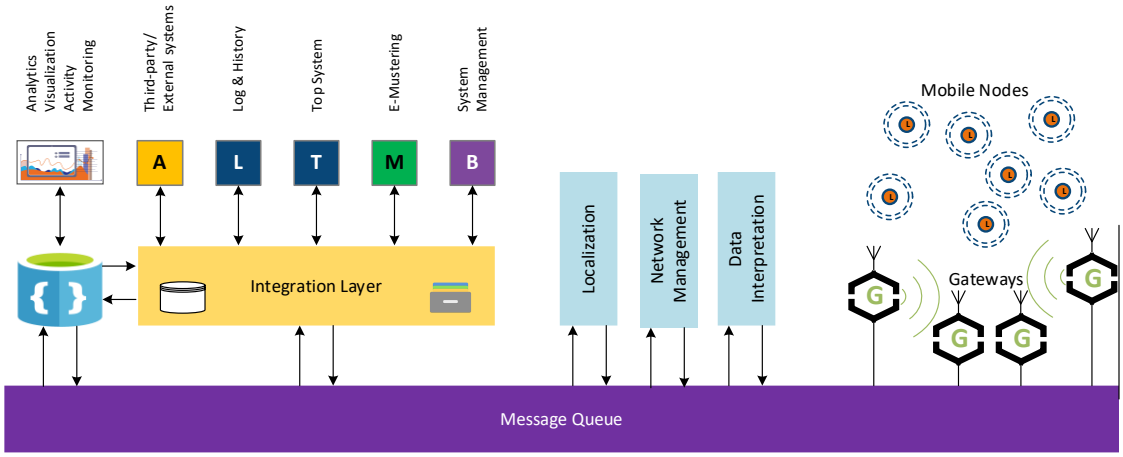

Figure 2. High-level architecture

The proprietary underlying Technologies

Field devices

OffshoreMuster underlying technology consists of low-power wireless devices (OSM mobile nodes), customizable gateways (OSM gateways) and a secure backbone network infrastructure feeding with real-time data a modular central decision support system (OSM DSS).

OSM Gateways | OSM wireless mobile nodes | OSM C&C System

Figure 3: Main OffshoreMuster System Hardware Components

Lightweight devices (OSM mobile nodes) assigned to PoB are continuously providing location and status awareness information. OSM mobile nodes are equipped with an ultra-low power (icycom [1]) System on a Chip (SoC) technology along with an accelerometer for movement monitoring, RFID for PoB identification and headcount, panic/alert button for issuing silent or customizable alarms, water detection sensor for triggering man-overboard alerts and battery management components for device health status information. Data from mobile nodes combined with specialized localisation algorithms and data analytics tools can provide a holistic view of the situation on the offshore infrastructure.

OSM gateways are statically installed over the infrastructure and are acting as anchors to the infrastructure's ethernet-based LAN network collecting and relaying localisation and situation awareness data from OSM mobile nodes into the OSM DSS system. OSM GWs are equipped with Texas Instrument SoC technology (for RF-communication with OSM mobile nodes), combined with a powerful System in a Package (SiP) (from Octavo Systems [2]) processor responsible for the reliable communication with the OSM DSS over a robust Publish/Subscribe communication protocol. Efficient interoperability of the two technologies has been achieved along with addition of several interfaces for potential integration with 3rd party systems. Moreover, OSM gateways are equipped with RFID/NFC and Bluetooth/WiFi connectivity, PoE-enable power supply and an internal battery which can provide power (for >18h) to the gateway in case of emergency.

Communication

The lightweight wireless devices interact with the gateways using Ultra-Low-Power (ULP) Radio-Frequency (RF) communication at 868 MHz. Data and device status information are encapsulated in periodic beacons and relayed by the gateways towards the OSM DSS system over a backbone network. The power at which the gateways receive the beacons is used by the central localization algorithm to compute the OSM mobile nodes locations, given the known OSM GWs coordinates. The ULP wireless medium access protocol used is based on WiseMAC [3], which is provvent to have very good robustness, resilience and reactivity while at the same time being very low power. Its High-Availability (HA) variant [4] was specifically designed for the deployment of a large number of mobile nodes in applications requiring low latency, while keeping the power consumption of battery-operated devices very low. WiseMAC-HA exploits the difference in resources and requirements of the two communicating device types in OSM (gateways and mobiles), using a different scheme for the uplink and the downlink traffic. Thus, this allows to duty-cycle the radio of the mobile nodes as well as reduce the transmission duration of their messages.

For OSM, the mobile nodes operate at 50kbit/s and the transmission power is set at 10dBm. The message payload is a few bytes long and encoded in binary format (following a proprietary type-value format) while the data travels in the wireless network. A cross-network routing layer header has been defined to transmit application layer-related information end-to-end (over the wireless and the backbone networks). All devices are identified by a unique ID given by hardware. The mobile devices have no individual network address, which greatly facilitates flexibility for meeting end-user needs in system deployments.

Publish/Subscribe messaging, event streaming and data collection

The OSM devices and the middleware components use the Publish/Subscribe model to exchange data over a message queue system, according to the architecture depicted in Figure 2. Messages are organized in topics following a semantically driven tree hierarchy. Data consumers express interest in topics (subscriptions), while data producers publish their labelled data under a topic. At middleware and higher levels, all data is encoded in JSON format. A dedicated and optimized data interpretation component performs conversions to/from the binary encoding in the wireless network, validating the data sources and expanding any sensor data contained in the beacons into the corresponding high-level topics. The Apache Kafka [5] framework has been selected as the OSM message queue broker, providing a robust, scalable, replicable and secure event-streaming infrastructure as explained in the following section (Software - Middleware).

Data processing and visualization

Software - Middleware

The middleware software components of the system adopt Apache Kafka as the main messaging-queuing mechanism, and microservices as the data exchange service engine. Apache Kafka integrates the lower layer of the OSM devices (mobile nodes and gateways) with the upper layer of the system (middleware) at a robust message/event driven integration pattern. Microservices, on the other hand, provide the customisable coupling of the various components and their integration through well-defined interfaces. The interconnection of these software technologies is supported by Docker [6] technology which transforms the system to a Platform-as-a-Service (PaaS) product. The OS-level virtualisation is used to deliver software in packages called ‘containers’. The OSM containers are isolated from each other and bundle their own software, libraries and configuration files; they can communicate with each other through well-defined channels. All containers are run by a single operating system kernel which requires fewer resources compared to similar virtual machines implementations. More than twenty (20) containers are deployed for the OSM system, being responsible for collecting data from the OSM GWs, storing data in SQL an noSQL storages, performing data processing tasks (i.e., data interpretation, RSSI aggregation, location report analysis, etc.), delivering container monitoring and orchestration (Portainer [7]) and delivering interfacing messages to the GUIs.

The middleware system components interact with the service layer via well-defined interfaces that follow the RESTful paradigm for interoperability with third-party systems. The system's middleware module consists of a set of Java-based microservices defining the Integration Layer (Figure 2) which is responsible for the data storage handling. Data storage meticulously incorporates both SQL and NoSQL storages to deliver optimum performance and resource utilization based on the data characteristics and the application requirements. In OSM, raw data that enclose RSSI reports is received from every node (paired with a unique person identifier). These data are fused, processed and feed algorithms that will produce the location and status reports. The output information is strongly related to the time of the generation of data (timestamp). Elastic Search facilitates the retrieval and aggregation of time series data programmatically, while data analysis and data storage are optimized. The data include information from the gateways and mobile nodes along with authentication related data (user credentials). Therefore, all system-level requirements such as consistency, ACID [7] transactions, stability and reliability are fulfilled. Towards this direction, storage of the relational data is handled by PostgreSQL [8], which is the dominant, SQL-compliant and open-source relation database management system.

The system's visual interfaces are three: a) the system management web interface, b) the operators decision support Graphical User Interface and c) the e-mustering mobile app.

The system management web interface allows administrative operators to fulfill daily (i.e., manifestation) as well as periodic (i.e., devices replacement, structural changes) tasks, system configuration and maintenance. Some examples of the services that the system delivers are: real-time system 'health status' monitoring, device configuration and scheduled firmware updates, general arrangement (GA) insertion, manifest and personnel shift management configuration.

The OSM decision support Graphical User Interface (GUI) was developed utilising vector graphic animation technologies. The flat interface provides a unique, intuitive UI/UX experience to the end-user, as it offers a gamification-oriented and realistic depiction of all the necessary decision support information in one unified interface. The GUI is able to handle large volumes of transactions and deliver visual output for many features including: real-time PoB localization, non-authorized area presence detection and alerting, real-time incident escalation for emergency situations (anonymous person identification at any given time, last known position in case of a missing person, real time movement tracking, etc.), instant head-count at any assembly point and fast e-mustering progress reports (reports and graphs) and man-overboard instant alerts.

Figure 4: OSM GUI

Moreover, e-mustering handheld devices along with a dedicated OSM e-mustering mobile application are utilized in order to automate and optimize the mustering process by efficiently scanning a unique identifier

from each OSM mobile node. All mobile nodes are equipped with a passive RFID tag which is efficiently parsed by an RFID reader included in the mustering handheld devices. In addition, e-mustering handheld devices are equipped with a number of communication interfaces including GPRS/EDGE/UMTS and WiFi which enable communication with the OSM DSS either through the backbone communication network, or through a WiFi internet connection. Through these links, the handheld devices are capable of communicating with the platform's manifest and synchronize with the OSM database on-the-fly receiving and providing valuable information regarding the mustering process status.

Figure 5: e-mustering application

System Innovation & Results

Localisation Algorithms

A core function of the OffshoreMuster System is on-platform person localisation, which operates both indoors and outdoors. Based on Receive Signal Strength Indicator (RSSI), OSM uses the receive power measurements reported by the gateways on mobile device RF transmissions in their vicinity, to compute the mobile device positions in terms of deck level and x-y coordinates (with respect to a reference point). The gateways are thus used as anchors, with their fixed coordinates registered in the system at deployment time. Although RSSI- based methods are known for their rather poor accuracy due to multi-path and fading effects (especially in the harsh propagation environments), they provide a convenient and cheap localisation solution in a wireless network at no additional cost (signal power values are available at message reception), with an expected accuracy which meets the OSM requirements (a few meters).

There are two main steps in the OSM localisation process: the RSSI data collection, which collects, sorts and aggregates the data coming from the gateways, and the localization algorithm that computes the mobile node position when fed with aggregated information for a mobile device. To keep up with scalability and low-latency requirements, parallelism has been introduced in the computations at different levels (data sorting, algorithm invocation), resulting in a data flow over a few middleware modules communicating over Kafka.

To increase both robustness and accuracy, two localization algorithms have been integrated in the OSM system: a) a simple Proximity-based solution, which suits well in harsh propagation environments, thanks to its independence of a power-distance model and to its low requirement on the number of RSSI measurements needed to compute a position; and b) a Particle Filtering algorithm (a Sequential Bayesian technique using a Monte-Carlo approach) [9], which can provide higher accuracy. Apart from the ability to conduct a comparative study at system development time, the availability of the two algorithms at runtime allows to get optimal results for each mobile position estimation, depending on the collected aggregated data.

A test deployment in an indoor building environment utilized in order to validate the data collection

process and evaluate the performance of the two localisation algorithms. The testbed comprised of 13 gateways and 10 mobile devices (initially placed at fixed positions for result evaluation purposes), ran for a six months and statistics were conducted on data sets collected over 24-hour periods, as shown in the example of Figure 6. The localization accuracy achieved is 4.77m for the Particle Filtering algorithm for 95% of the time and 6.46m for the Proximity algorithm for 95% of the time (including statistics for all mobiles during the same period). The localization algorithm accuracy can be further decreased (if necessary) with the deployment of more gateways and algorithmic fine-tunings. Full-scale industrial pilot deployment is scheduled for autumn 2021 in which OffshoreMuster system's performance will be validated in a fully operational offshore asset. Localisation accuracy, system response, alerting, e-mustering, reliability and system effectiveness in emergency situations will be evaluated with scenarios based on existing HSE procedures.

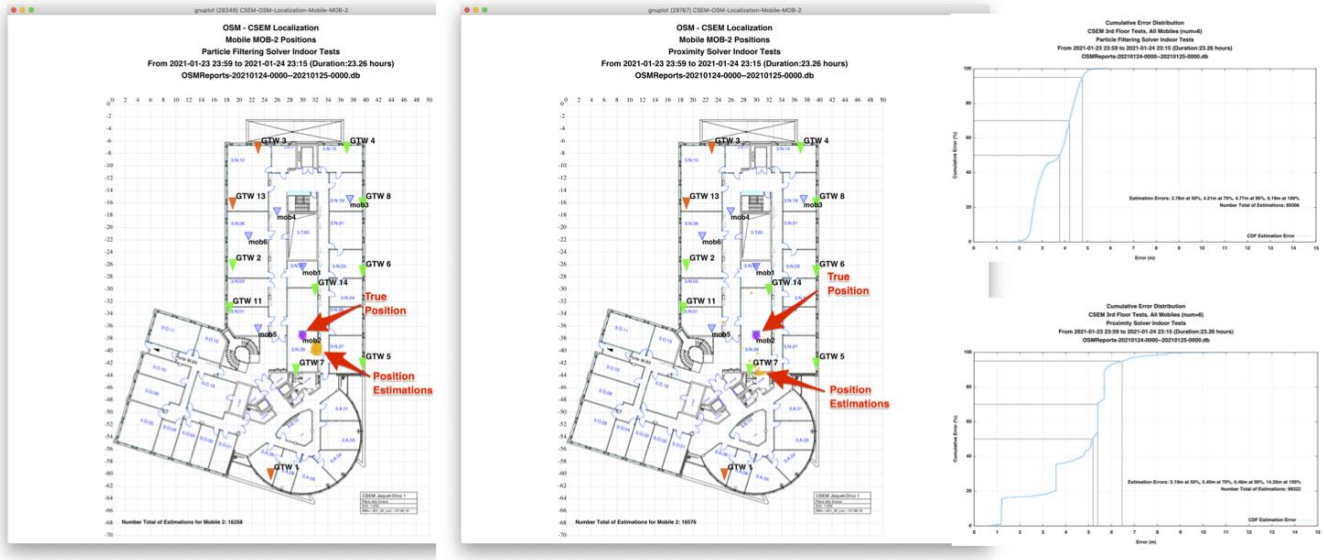

Figure 6 OSM Localisation results

Analytics

Leveraged by the modular architecture of the OSM microservices, one of the key components that add value to the plethora of computer-aided decision support features and bring the added value to the end users is the analytics. OSM realizes data analytics in two layers.

A primary screening of raw data providing a 1st layer of the analytics utilizes the ELK [10] stack comprised of the *Elastic Search* and *Kibana*. ELK is a powerful tool that facilitates the storing and monitoring of large volumes of data while providing deeper insights through its high customizable dashboards and cross – platform analytics engine. *Elastic Search* is the core component that enables storing, searching, and analyzing huge volumes of data quickly, while at the same time it offers queries responses in near real-time. ELK uses a structure based on documents instead of tables and schemas and can achieve fast search responses and data aggregations facilitated by its inversed index implementation instead of searching the stored documents directly. On the other hand, *Kibana* provides an intuitive way to create visualisations, performs data analysis on the fly and ad-hoc data exploration. Indicative *Kibana* visualisations of daily persons' activity (using data from OSM system) highlighting the most active persons and their range of movement are depicted in **Figure 7**. In addition, *Elastic Search* can be integrated with other 3rd party systems besides *Kibana* through the extensive REST APIs available for storing and searching data.

As a second layer for OSM Analytics components, more sophisticated techniques are employed to perform pattern recognition and event detection. In that context, the Tensorflow [11] framework (*Tensorflow Serving* feature [10]) is utilised, which is a flexible, end-to-end open-source machine learning platform that focuses on training and inference of deep neural networks for high-performance production environments. *TensorFlow Serving* provides out of the box integration with *TensorFlow* models and can

be easily extended to serve other types of models. This is of paramount importance for the sustainability of OSM's Analytics components with the deployment of new algorithms and experiments.
OSM system collects localisation and situation awareness data from PoB which is then processed by the OSM analytics component, aiming to identify patterns on the PoB movements, habits/routine and presence. This information could be proven very valuable for correlating the occupancy of the Oil & Gas platform with events that may occur during its operation as well as for further optimization of the existing HSE procedures.

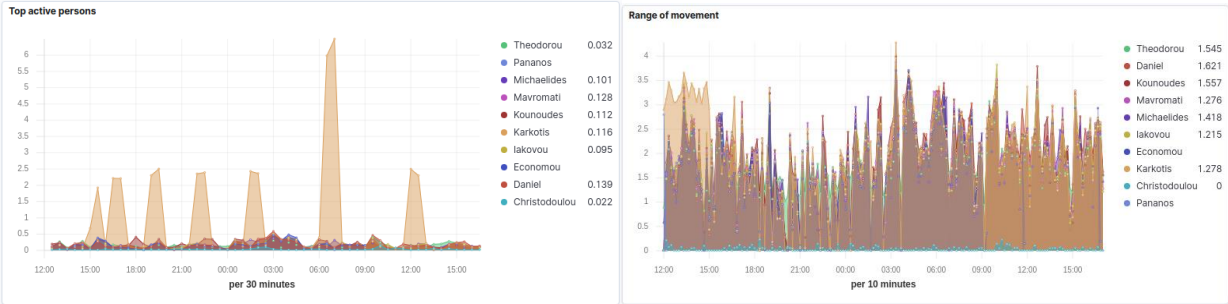

Figure 7: OffshoreMuster Analytics

Conclusions

Emergency situations in offshore Oil & Gas sector can be catastrophic and typically are characterized by the extreme time pressure and the rapidly changing conditions. Cutting-edge technologies can bring situation awareness information such as personnel location and status, e-mustering information and customizable alerts for complementing the existing HSE procedures. OffshoreMuster's underlying technology, consisting of wearable devices, gateways, e-mustering handheld devices and a modular decision support system have been developed after years of dedicated research and development efforts and have been validated in maritime environments. The paper presents the OffshoreMuster hardware and software components, integrated into a unified all-in-one solution tailored for the offshore Oil & Gas industry. It worth noting that system evaluation at a full-scale offshore Oil & Gas industrial deployment is scheduled for autumn 2021 envisioning OffshoreMuster to become a useful asset for better decision-making towards zero casualties in emergency situations.

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