Software-Instrumentation Platform to Improve Situational Awareness for Emergency Responders (Safe Rescue)

Call identifier: ITEA 3 Call 2 Smart Mobility

D.3.3: State of Art Document

Due Date of Deliverable: 28 April 2018
Completion Date of Deliverable: 24 September 2018

Start date of project: 1 January 2018 Duration: 39 months

Lead partner for deliverable: GOHM Electronics

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

Document History

Issue Date	Version	Changes Made / Reason for this Issue
01.02.2018	V0.1	SotA structure added
05.03.2018	V0.2	Localization SotA added
28.04.2018	V0.3	Communication SotA added
24.09.2018	V0.4	Vital Sign Sensing SotA added

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1 State of the Art

1.1 Communication SotA

Projects like Safe Rescue considered as a Wireless Sensor Networks (WSNs) that typically consist of an embedded sensor nodes which have limited power and process capability, cloud infrastructure that collects, analyse and persists data and gateways which are the bridge between cloud infrastructure and sensor nodes. Sensor nodes measure the physical environment (temperature, humidity, vital signs etc.) And sends these data to gateway. Gateway, on the other hand collects the data from various sensor nodes and then sends the data to cloud infrastructure. Therefore, it is obvious that there are two communication subnet within Wireless Sensor Networks. First subnet connects sensor nodes to one or more gateway nodes and the second subnet that connects gateways and backend cloud infrastructure.

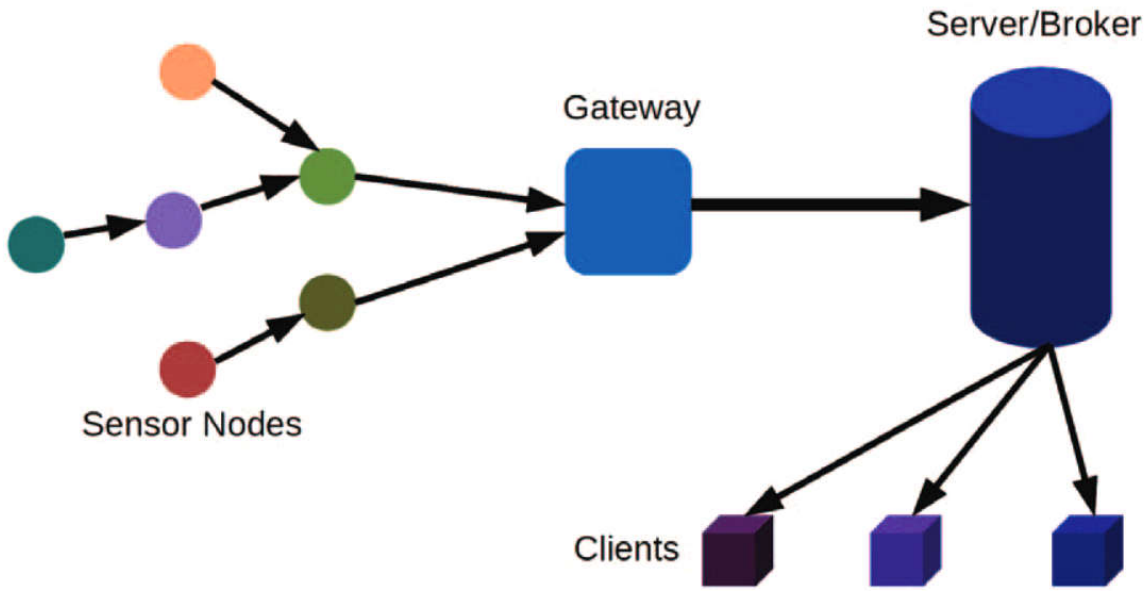

Figure 1. Wireless Sensor Networks

1.1.1 Sensor Node - Gateway Communication

On sensor node - gateway communication, there are several concerns to be fulfilled such as consuming ultra low power, maximizing communication distance, minimizing packet error rate, effective usage of frequency band, providing low latency and stable communication with minimizing interference. In state-of-the-art there are many communication technologies which trying to figure out these issues. These technologies are compared and most appropriate technologies are chosen to be used on sensor node - gateway communication.

1.1.1.1 Narrow Band

Narrowband communication uses narrower bandwidth of frequencies in data transmission. This brings some advantages over wideband communication. In personal tracker - gateway communication this type of technology is used to transmit packets. Some of the advantages of narrow band communication can be listed as:

- Narrowband signals usually have better range than wideband signals using narrower filters.
- NB signals can achieve better ranges with the same power. Thus, it is also provides low power communication.
- NB uses less bandwidth, so other nodes can also transmit their data at the same time without interference. This is very efficient way to use frequency band.

Sensor nodes in field such as personal trackers, wearable vests should reach long distances to transmit data with minimal packet losses. Also, personal trackers should be designed with ultra low power consumption. These requirements makes UWB necessary for sensor nodes.

1.1.1.2 Ultra Wideband

Ultra wideband communication technology uses short pulses to transmit information. The pulse generates a very wide instantaneous bandwidth signal according to the time-scaling properties of the Fourier transform relationship between time t and frequency f. [9] UWB signals can be transmitted from 450MHz to 10GHz with the range of few meters. When the distance is getting increased, packet losses will be increased. The short UWB pulses are ideal for indoor localization applications because of their resistance against multipath effects and supreme time resolution.

UWB communication technology is used in personal tracker- gateway communication to localize personnels. Personal tracker detects location of person in indoor and outdoor. In outdoor localization, GNSS systems are used to detect high accurate location. But in indoor GNSS satellites are not available. Therefore, other technics should be used in indoor localization such as ToF, AoA, TDoA. As a result, to detect high resolution location of person in indoor, there is a need for measuring flight time of signal. UWB technology can provide this high time resolution using its short pulse signal features. Thus, UWB is chosen for personal tracker- gateway communication.

1.1.1.3 Bluetooth Low Energy

Bluetooth is a wireless technology standard which is used transmitting and receiving data over short distances. It uses 2.4 GHz frequency band. Bluetooth Low Energy (BLE) is also wireless personal area network technology and aimed to be used in healthcare, fitness, security etc. Applications. Comparing with the standard Bluetooth protocol, its power consumption and cost are considerably reduced while maintaining similar communication range.

Bluetooth also provides much stable and easy implementation to talk any devices which uses bluetooth. Thus, BLE is much appropriate way to collect and send sensor information in close ranges because of easy implementation and low power features of bluetooth technology. BLE

is used in sensor nodes (Health Wristband, Personal Tracker, Wearable Vest) communication for close range sensor data collection. This provides very standardized and stable way for communication.

1.1.2 Gateway- Cloud Communication

The data generated by sensor nodes are delivered to the cloud infrastructure through the gateway. Considering the number of gateways and sensor nodes, bandwidth and energy efficiency of the communication between gateways and cloud becomes important. As a result, Message Queue Telemetry Transport (MqTT) and Constrained Application Protocol (CoAP) have been proposed to solve these problems of WSNs.

MQTT runs on top of TCP, however CoAP runs on UDP. There is also MQTT-SN, MQTT for Sensor Network which runs on UDP and operates slightly better than CoAP[10]. However, CoAP is much more popular than MQTT-SN and there is almost no library exists for MQTT-SN. CoAP is an application level protocol and can be divided into two sub categories, request-response and publish-subscribe models. CoAP is based on Representational State Transfer (REST) architecture and supports request-response model like HTTP. Since HTTP is not suitable due to the power, processing and bandwidth consumptions for embedded devices, CoAP can be considered as re-design of subset of HTTP functions. The second category of CoAP communication is publish-subscribe model like MQTT supports. CoAP supports this publish-subscribe architecture using extended GET method. Subscribers, subscribes the URI and when publisher publishes data for this URI, all the subscribers are notified about the published data. CoAP relies on UDP transport layer to get rid of unnecessary TCP headers. Although UDP is inherently not reliable, CoAP provides its own reliability mechanism. This mechanism brings two message types to the protocol, which are “confirmable messages” and “non-confirmable messages”. As names stands, confirmable messages request an acknowledgement while non-confirmable messages doesn’t.

MQTT protocol is also application level protocol. Protocol uses a topic based (CoAP uses URI) publish-subscribe architecture where multiple clients can establish a connection to broker to subscribe specific topics. Therefore, clients can receive the published messages to these topics. MQTT also supports hierarchical topics to allow subscribers to observe hole hierarchy using wildcards in topics.

Unlike CoAP, MQTT relies on TCP, like HTTP, however reduces the overhead unlike HTTP. MQTT also provides communication reliability using three QOS (quality of services). QOS-0 stands for at most once. This is the best effort mode for network. The published message is not stored and not acknowledged. The message could be lost or duplicated. However, it is the fastest mode of message transferring. QOS-1 stands at least once. Messages might be delivered multiple times if failure occurs before the acknowledgement received by the sender. Also, messages are stored locally at the publishers until they receive acknowledge. In case of acknowledge doesn’t received, re-transmission done by publisher. The last QOS is QOS-2 and stands for exactly once. It guarantees that there is no duplication of published messages. Basically it extends QOS-1 by storing messages also at receivers in order to prevent duplicates. Best part of QOS is it can be changed dynamically for each messages. QOS-0 is corresponds to non-confirmable messages in CoAP and QOS-1 corresponds confirmable messages. However, there is no similar corresponder for QOS-2 in CoAP.

CoAP is able to cache responses in order to reuse for further requests. Caching is done by including additional parameters about validity and freshness in the responses. Caching may be useful to reduce response time and network bandwidth consumption. Despite, MQTT does not provide caching mechanism like CoAP. However, MQTT brings retained messages and last will and testament that are not exists in CoAP.
Retained message is a normal MQTT message. However, broker stores the last retained message for that topic. Then, each client that subscribes to a topic pattern that matches the topic of the retained message received the retained message immediately after subscription. Retain messages help newly-subscribed clients get a status update immediately and eliminates the wait for the publishing clients to send the next update. Therefore, there are no idle states for newly-subscribers about the status.
Last will and testament (LWT) also a great future that MQTT brings. Since the protocol aimed to be used on IoT devices and embedded systems, it is assumed that the network reliability may poor from time to time. Also, it is important to know connectivity statuses of a devices in the network. In MQTT, special packet (DISCONNECT message) is used to inform broker that device is not connected anymore. However, it is not possible to send DISCONNECT packet every time (half-open tcp connection, battery failure etc). Therefore, a client can declare a last will and testament packet while connecting to broker. LWT messages are like normal MQTT messages with own topic and payload. The broker stores the LWT messages and publishes to the its topic under some circumstances which are if the client doesn't sends a DISCONNECT packet before closing network connection or broker fails to communicate with the client within keep-alive period.
Retained Messages and LWT is powerful when they combined to store the state of a client on specific topic. For example, connection status of a devices could be managed using this two type of messages. Clients sends an retained messages for its "status" topic with a payload of "online" and last will and testament message for same "status" topic with a payload of "offline" while connecting to broker. After that, each newly-subscriber receives the status of client (online or offline) immediately after subscription.
Considering the features discussed above, it is better to use MQTT for a project like Safe Rescue. QOS-2 provides a reliability that a message will be delivered exactly once, Retained and Last Will Testament messages provide to reduce idle time for concurrent disconnection and connections of devices, hierarchical topic names provides better architecture and isolation. Each wearable device in the Safe Rescue system (Personal Tracker, Wristband, Emergency Vest) will connect to the network using nearby gateways. Also, cloud infrastructure will communicate with the wearable devices using gateways. Besides, other cloud components like Localization Engine, Decision Support System will be isolated from each other using topics. Therefore, each cloud application component will receive only relevant data.

1.2 Localization SotA

This chapter lists, describes, examines and compares several available technologies that could be potentially used as a basis for the Localization Sub-System. The idea is to investigate existing platforms to get an idea of the state-of-the-art and to compare these candidate technologies and select the most suitable one to be used as a basis for the Localization Engine.

1.2.1 Candidates

Each indoor localization technologies and algorithm has their own advantages and disadvantages. Widely used Indoor Localization Techniques and Indoor Localization Algorithms selected as candidate for Safe Rescue project.

Candidate Indoor Localization Techniques;

- Triangulation
- Fingerprinting
- Trilateration

Candidate Indoor Localization Algorithms;

- RSS (Received Signal Strength)
- ToF (Time of Flight)
- AoA (Angle of Arrival)
- TDoA (Time Difference of Arrival)

1.2.2 Requirements of the Localization Sub-System

In order to analyze and compare available platforms the Safe Rescue project team defined a structured list of requirements. These requirements were derived from the future usage scenarios that are described in Chapter I.
Existing technologies compared under the following metrics;

- **Accuracy**

Precision of the calculated location one of the most critical metric in Safe Rescue System. Selected localization technique should calculate the location as precise as possible to prevent misleading of Rescue Team Members

- **Adaptiveness**

Environmental impact changes might influence the performance of localization system. A technique that can adjust to natural changes can give better accuracy rather than a techniques that can't adjust. For example, multi-path problem should be considered and the system should have immune to multi-path problem to increase accuracy and reliability.

- **Cost**

The term cost in positioning system has many aspects or factors on consideration. Important factors include money, time and energy. Money factor is related to new hardware purchase. Time factor is related to effort for enhancement (increasing coverage, relocation of installed devices, replacement of installed devices etc.). Energy on the other hand is another critical factor in Indoor Positioning System due to the limit of mobility. Mobile devices should consume as less as possible power to extend life time.

- **Coverage Range**

Each localization technique has different coverage area. The better localization system are the one that cover better range.

1.2.3 Technology Overview

1.2.3.1 Triangulation

Triangulation uses the geometric characteristic of triangles to achieve or estimate the location of person or object. To find the location of a person or object, at least two reference point is required. The reference points which the exact positions are known receive the signal from mobile tracker device which demonstrated on Figure 2. The location of mobile device's calculated with the angle of received signal by at least two reference point.

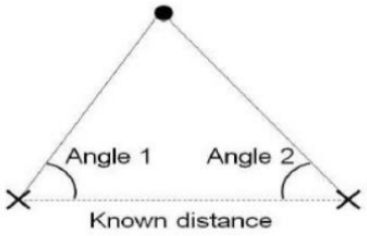

Figure 2. **Triangulation**

1.2.3.2 Fingerprinting

Fingerprinting is another widely used techniques for indoor localization. Fingerprinting uses the Received Signal Strength (RSS) of multiple anchor points which locations are known. However, to be able to estimate the location of, first training should be done. Basically, fingerprint database should be built in installation phase.

1.2.3.3 Trilateration

Trilateration term refer to a position determined from distance measurements. It is also called range measurement technique. To calculate/estimate location of an object, at least three fixed points are necessary. Demonstration of a system could be seen on Figure 3. L_1, L_2 and L_3 are fixed points and P is the point that location is unknown. Using the distances d_1, d_2 and d_3, the coordinates of point P can calculated.

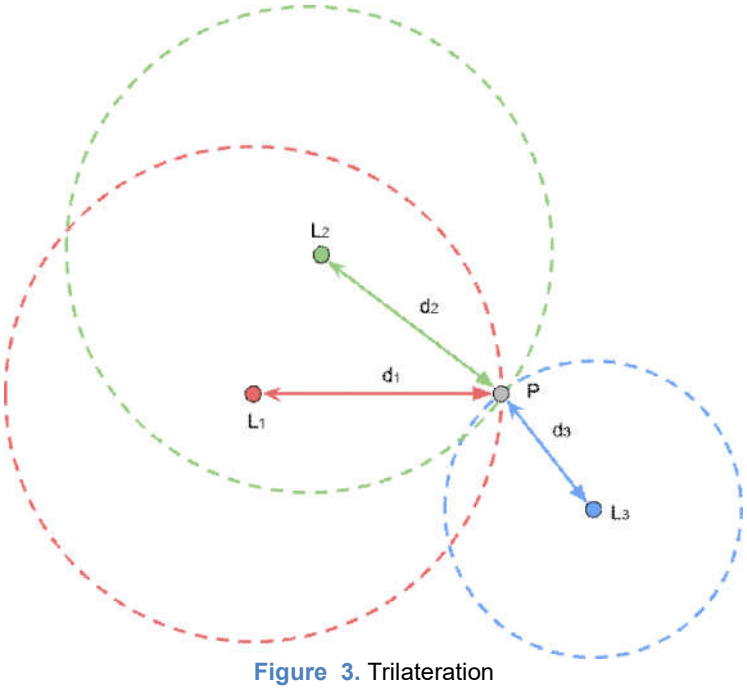

Figure 3. Trilateration

1.2.4 Algorithm Overview

1.2.4.1 Received Signal Strength (RSS)

RSS is a simple algorithm to deploy and develop, also does not require specialized hardware at anchor gateways. RSS estimates the distance of unknown node to reference node from some sets of measuring units using the attenuation of emitted signal strength. Bluetooth or WiFi could be used. However, existence of obstacles indoors may cause the different attenuation coefficient for RF signals. Therefore, the establishment of accurate indoor propagation model is very challenging.

1.2.4.2 Time of Flight (ToF)

Time of Flight is the most accurate technique compared to others. ToF and Trilateration has very powerful combination and low error rate. There is no need for synchronization between anchor points. Nevertheless, to calculate ToF, multiple communication should be done for each Anchor points to eliminate the clock differences. Besides, the ToF information calculated at the mobile tracking device not anchor points. These time information also should be sent to Server or anchor points explicitly. Therefore, ToF algorithm requires too much communication and power. The more communication means more traffic and package loss and less device support.

1.2.4.3 Angle of Arrival (AoA)

Angle of Arrival algorithm tries to calculate the intersection of several direction lines which originating from a mobile device or anchor gateways. To calculate mobile device coordinates, at least 2 angles should be measured by directional antenna or array of antenna and converted

into direction lines. Nevertheless, AoA requires complex and expensive equipments and affected by multipath problem.

1.2.4.4 Time Difference of Arrival (TDoA)

Time Difference of Arrival method uses the time difference of a signal that received by anchors. To calculate/estimate location of a person, at least 3 anchor points should receive the same signal that transmitted by mobile device. And also, anchors should be time synchronized. Thus, the location can be calculated using trilateration of time differences. Unlike ToF algorithm, TDoA requires only one packet transmission from mobile device and the time calculations done in anchors or server. Therefore, mobile device can save power. In addition, number of supported device (mobile device that will be located) in TDoA algorithm is the maximum compared to other algorithms.

1.2.4.5 Summary

Table 1 shows the important characteristics of indoor localization systems and related technologies.

System	Technique	Algorithm	Accuracy	Calculated At	Adaptiveness	Cost	Covering Range
BLE	Trilateration	RSS	1-5 m	Mobile Dev	Low	Low	Low
Wi-Fi	Trilateration Triangulation	RSS AoA	3-30 m 1-10 m	Mobile Dev Infrastructure	Low Medium	Low High	High High
UWB	Triangulation Trilateration	RSSI ToF AoA TDoA	1-5m 1cm-1m 1cm-1m 1cm-1m	Infrastructure Mobile Dev Infrastructure Infrastructure	Low High High High	High Medium High High	Medium Medium Medium Medium

Table 1 :**Indoor Localization *Comparison***

Bluetooth operates in the 2.4 GHz ISM band and compared to wlan, it has shorter range (typically 10-15 m), and has lower data rate (1 Mbps). On the other hand, bluetooth tags are small sized and cheaper transreceivers. Also they are power efficient (BLE). However, the Personnel Trackers (PT) and Emergency Vests should collect unique ids of placed bluetooth tags and send them to the Localization Engine by itself. This process will elevate the energy cost of a system. Besides, multi-path problem will arise in bluetooth fingerprinting.

Unlike Bluetooth, Wi-Fi has wider range from 50m to 100m. Using Wi-Fi in indoor positioning and navigation system depends on knowing a list of wireless routers that are available in an area in which the system operated in. Running RSS algorithm is the most popular indoor positioning method for WLAN. It is easy and can run on off-the-shelf WLAN hardware. Other algorithms like AoA/TDoA is less common due to the complexity of time delay and angular measurements.

Ultra Wideband is a communication technology and has great differences with traditional communication technologies. It does not require the use of traditional communication system in the carrier, but by sending and receiving nanosecond or less of the extremely narrow

nanosecond pulses to transmit data. Therefore, UWB technology could be used for precise indoor positioning systems. Also, UWB has immune to multi-path problem. On the other hand, UWB hardware is expensive in contrast to other technologies.

Accuracy is the most important requirements without doubt for Safe Rescue Localization Sub-System because the goal of the project is to minimize lost in case of disaster in complex and huge facilities. If the accuracy is not precise enough, for example if estimated coordinates of a victim locates victim in next room or above floor, the rescue chance of the victim may drops dramatically. Recent works shows that, UWB has the 100% accuracy within 0-1 meter range, on the other hand, BLE %75 accuracy, Wi-Fi has %35 accuracy within same range. Considering that, UWB has the best accuracy compared to other systems.

Since UWB is a great solution for indoor localization systems, there are many alternative algorithms that can be used with UWB technology. Since RSS algorithm has the worst accuracy, it is not applicable for crucial systems. On the other hand, ToF has good accuracy. However, due to the required communication to calculate location of a person it is not suitable for big infrastructures. Thus, AoA and TDoA are the remaining two algorithm that can be used in Localization Sub-System. The two algorithm has almost same advantages and disadvantages except the development effort. AoA requires more effort on hardware design and AoA are affected by multipath problem and signal reflection from wall or other objects. To sum up, UWB and TDoA is the most suitable technique for Indoor Localization in infrastructures and big facilities.

1.3 Vital Sign Sensing SotA

In Safe Rescue project vital sign sensing implies measurement of heart rate (HR) via photoplethysmography (PPG) technique. PPG is an optical technique which is used for detection of volumetric changes in peripheral blood circulation. PPG uses LEDs and photodetectors to detect blood flow rates by capturing the reflected light intensity from skin. However, reflected light may be affected by skin pigmentation, pressure disturbances and motion artifacts. To improve obtained HR signal, signal processing techniques may be applied [12].

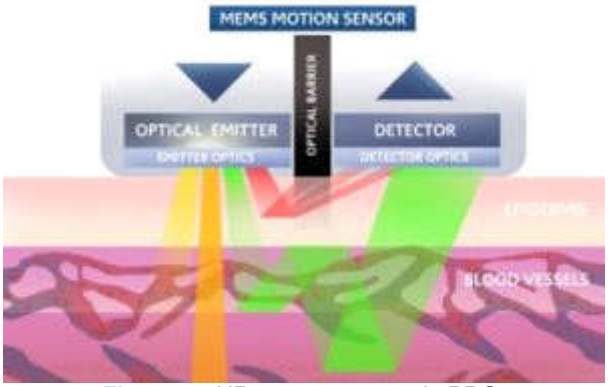

Figure 4. HR measurement via PPG.

A normalized least-mean-squares algorithm presented by Fallet et al. [13] attenuates motion artifacts and recreates multiple PPG signals from various mixtures of damaged PPG waves together with accelerometer data. Nowak et al. [14] used non-negative matrix factorization

or spectral subtraction for signal augmentation and motion artifacts removal alongside with particle filtering or online Viterbi decoding. The MICROST framework was proposed by Zhu et al. [15] which consist of heuristic tracking, first-frame processing and acceleration classification. A wristband-type PPG heart rate sensor was developed by Ishikawa et al. [16] which is able to reduce motion artifacts in daily activity and detect heart rate variability (HRV). By using noise reduced pulse signals based on auto-correlation and peak detection methods, instantaneous HR detection with high noise resistance were achieved by Fukushima et al. [17]. Lee et al. [18] used complementary split-ring resonators to develop frequency-multiplexed sensor array. FitBeat [19], a wrist-wearable device that allows precise HR monitoring during intensive exercises, integrates motion and contact sensing alongside with simple spectral analysis algorithms to restrain miscellaneous error sources. A sensor module design focused on anomalies due to optical properties of skin was proposed by Mohapatra et al. [12,20].
Measured Blood Volume Pulse [21] can be used to detect HR. Besides, HR can be measured by using multi-channel WPPG sensor signals and acceleration signals [22]. Used for monitoring and calculating HR, analyzing activity level and tracking fitness performance, infrared technology is another system used in wearable sensors [23]. Moreover, by using tellurium dioxide triangular microwires an ultrasensitive pulse driven sensor was made to obtain pulse measurements [12,24].
Vital sign sensing also implies blood oxygen saturation measurement. Ratio of oxyhemoglobin concentration and the sum of oxy- and deoxy-hemoglobin concentrations in the blood is called oxygen saturation [25]. Only peripheral oxygen saturation (SpO_2) is taken into consideration because of its non-invasive nature suitable for the measurements on the wrist [26]. To obtain SpO_2 data two LEDs, operating at different wavelengths (usually red (650 nm) and infrared (950 nm)) alternately shine light on the sensing area. The intensity of reflected light from the tissue and skin concludes concentration of oxyhemoglobin and the volume of the blood. Optical signal is collected by a photodetector. Binding of oxygen with hemoglobin defines its absorptivity. The known molar absorptivity of oxy- and deoxy-hemoglobin at each wavelength alongside with the ratio of the photodetector signal upon excitation at each wavelength give the oxygen saturation [25]. Moreover, SpO_2 measurements can be derived by PPG sensing [27]. The general concerns that prevent the accuracy of acquired measurements are the motion artefacts and ambient light interference. To overcome these problems sensor can be placed closely to the skin as well as enabled to flex and move with the skin. Novel oximetry sensing devices can be integrated with organic and textile optoelectronics [12,25].

1.4 Artificial Intelligence Decision Support SotA

There are various algorithms using to solve different kind of problems. AI algorithms can be roughly divided into thinking and acting humanly or rationally. Also, rule-based and learning algorithms could be added as another two main category. AI based high-level decision makers algorithms can be seen in Figure 5.

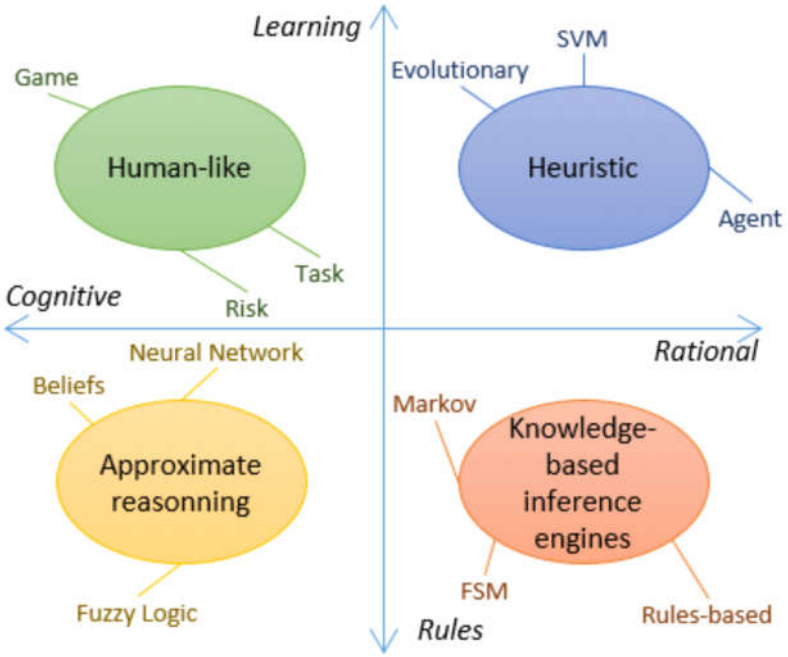

Figure 5. Decision Makers Algorithms

1.4.1 Knowledge-based Algorithms

Under some conditions, some actions should be taken. Knowledge-based algorithms are perfect solution for these kind of problems. One of the most known knowledge-based algorithm is rule-based reasoning algorithms. Basically, it works as "*if* observations, *then* actions". Knowledge base, of course must be fed and changed when acquiring new knowledge.

Another knowledge-base algorithm is Finite State Machines (FSM) which is an abstract machine that can be in exactly one of a finite number of states at any given time. Finite State Machines can change its state in response to the inputs (like environmental changes). However, the maintenance of the knowledge base is difficult for FSM.

1.4.2 Heuristic Algorithms

Heuristic technique, designed for solving problem more quickly when classic methods are too slow. They have low computational time and complexity and they are able to handle complex problems. On the other hand, it is not guaranteed that they give the global optimal and accurate solution. Agent representation is one of the most convenient interpretation of

heuristic methods. An agent is an intelligent autonomous entity. It adopts to the environment's observation, then models a rational and social behaviour.
Support Vector Machines (SVM) are a set of related methods for supervised learning, applicable to both classification and regression problems. A SVM classifiers constructs a hyperplane or set of hyperplanes in a high dimensional space.

1.4.3 Approximate Reasoning

Approximate reasoning methods are based on boolean compromises. However, approximate algorithms rely on many-valued logic, in other words fuzzy logic. By approximate reasoning which is neither very exact nor very inexact. In other words, it is the process by which a possible imprecise conclusion is deduced from a collection of imprecise premises. These conclusions are truth values with an approximation dimension, which is different of what we called approximate values for heuristic algorithms. Since the values are within a large range, they manage complex problems. Advantage of approximate reasoning in decision is the vagueness aspect, i.e. the flexibility and allowance to the designed rules and by extension to the uncertain data. However, traceability is difficult and this is the main disadvantage of fuzzy logic.

1.4.4 Human-like Decision Making Algorithms

Human-like decision makings systems are designed to reproduce perception of human cognitive aspects. To handle different kind and complex situations, human-like decision making systems are designed as intelligent, potentially learner and cognitive procedure. The most used human-like decision makers are risk function models.
Management of emergencies which are natural or man-made requires enough information and technical experienced rescue team. Required information could be provided by combining environmental sensors (raw) and processing of this raw sensor information. Therefore, a great amount of information is available that should be used to improve the management of the emergency, which generally means making the best decision at the right moment.

Supporting the decision-makers with knowledge-based systems (KBS) is a good choice as they are able to integrate both theoretical and common sense knowledge directly taken from the expert decision-makers. KBS provide explanations of recommendations; which is important in an emergency. Responsible personnel cannot adopt a decision without fully understand it.

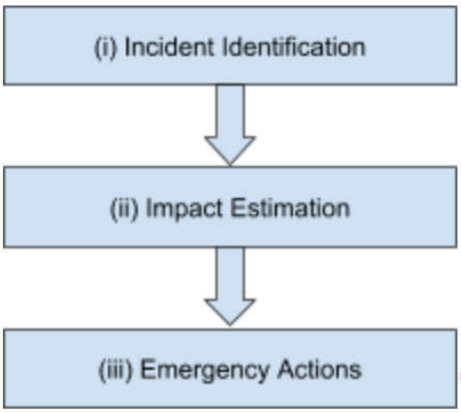

Figure 6. Emergency Management System Flow

An emergency management system should answer the three questions; *What is happening? , What may happen?, What to do?.* For an emergency management system, the design of the knowledge model may be: (i) identifying undesirable situations, (ii) analysing their causes and predictable effects, and (iii) identifying actions to be applied on the causes in order to avoid the expected undesirable impacts. Three main classes (Figure 6) has their own design.

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