A Personal LPWAN Remote Monitoring System

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***Abstract*—Firefighters are equipped with an immobility detector device also called the Personal Alert Safety System (PASS) that is integrated into the user's Self-Contained Breathing Apparatus (SCBA). If a firefighter remains motionless for a certain period of time, a loud audible alert is triggered to notify the Firefighter Assist and Search Team (FAST) deployed in the area of intervention that the wearer of the PASS device is in trouble and in need of rescue. However, this device is not reliable enough since it triggers frequently false positives which lead to developing a tolerance for sounding alarms among the crew. As a consequence, they do not seem to be concerned about it as they should and the alarms are just ignored sometimes. In this paper, we propose a PERsonal LPWAN sYstem (PERLY) for state assessment and localization of Firefighters during an intervention. Our proposal is more reliable compared to the PASS, it also adds additional important functionalities and minimizes the false positive alarms. The designed prototype and the proposed solution were adapted according to the needs and requirements of the fire brigade of the region of Doubs in France. Several interviews were held with the personnel from the fire and emergency response department that included discussions regarding the reliability, cost, and security of the system and the collected data. The interviews led to developing and validating the first prototype of a plug and play system that is specifically tailored for the needs of the fire brigade and also designed to work in areas with no network coverage.**

***Index Terms*—Wireless Sensor Networks, LoRa, LoRaWan, IoT, Firefighters.**

I. INTRODUCTION

Being a firefighter is one of the riskiest professions in the world. They run into buildings on fire, they are present at a scene of explosions, they are the first responders during a natural disaster, a wildfire, traffic accidents, and so many other catastrophes. This tough job can take both a physical and mental impact on those who perform it. Besides the great risk of being killed or severally injured during an intervention, numerous studies conducted in the United States (U.S.) [1] also showed that cardiovascular decease (CVD) is the most frequent cause of duty-related fatalities, accounting for almost half (45%) of deaths that occur among U.S. firefighters. Hence, the risk of a firefighter being severally injured, faint, suffer from a heart attack, or even die during an intervention is very high. Therefore, a system was developed to signal a "Man Down" situation, this system is called a PASS (Personal Alert Safety System) device. The latter was developed to protect firefighters from potential life-threatening events that can occur during an intervention. For instance, if a crew member is lost, disoriented or is running out of oxygen, he can trigger manually the PASS device alarm to summon the assistance of the nearby Firefighter Assist and Search Team (FAST). Moreover, this device will be activated automatically if the firefighter does not move for a predetermined period of time (usually 30 to 45 seconds).

However, a very common complacency is affecting the fire service. Most people have experienced a situation where an automatic fire alarm system is activated in a commercial building, yet, the people are still entering the building and business is being conducted as usual. Or to pass by a residual building with high alarm sounds activated and faces coming out of the upper-story windows watching fire trucks pull over. These ignored alarms could definitely lead to deadly consequences [2]–[4]. Firefighters have their own alarm that frequently results in an ignored or inappropriate response, it is the alarm from an activated PASS device. The first generations of the PASS devices needed to be manually armed by the firefighters, which leads to fatalities among crew members that entered the area of intervention without arming it. Therefore, new generation devices have been integrated into the user's Self-Contained Breathing Apparatus (SCBA), and they are automatically armed when the SCBA is turned on. When the SCBA is not being used the PASS device should be deactivated to prevent false alarms. But this does not happen all the time. For instance, a firefighter might need to remove the SCBA and put in on the ground to change the air cylinder, which triggers a false alarm thinking that he is not moving. Moreover, if a crew member did not move for a few seconds but he is okay and did not manually reset the PASS device, a false alarm will also be triggered. The frequent false positives resulted in having numerous PASS alarm activation on the fire-ground that no one reacted or responded to.

A. Background and Motivation

A variety of Wireless Sensor Network (WSN) systems have been proposed in the literature to support firefighters during their interventions. such as wearable body-sensors systems for health monitoring [5]–[7], navigation support systems [8]–[10], fire detection systems [11]–[13], etc. However, while the usefulness of these systems is acknowledged [14], they are only partially usable either because they rely on the existence of a pre-deployed and fix communication and/or localization infrastructure or because they are simply too complex to be accepted and used by firefighters. In our interviews with the personnel of the fire brigade department of the Doubs region, we obtained very useful system design information that helped us propose, develop and validate a personal alert safety system that is specifically tailored for their needs. The main system design requirements are the following:

- A simple, lightweight, and convenient system that could be easily integrated with the current equipment used by the firefighters and that could be accepted and adopted by the personnel.
- A plug and play system that does not rely on a pre-existing infrastructure.
- A system that is low cost, fully automated and requires minimum user intervention.
- A system that ensures reliable delivery of the emergency alert to the concerned rescue team.
- A system that reduces false flags, monitor the heart condition of firefighters and is able to localize a firefighter in case of an emergency.
- A low power, low energy consuming system that can last until the intervention ends.

B. Contribution

Following the aforementioned requirements, we propose in this paper a personal alert safety system that is based on intercommunication between a Smart-Watch and a GPS enabled IoT device. These two components are supposed to monitor the status of the intervening firefighters and report an emergency alert alongside the GPS location of a firefighter to the FAST in case of emergency (”Man Down” situation). During our interviews with the fire brigade crew members, we have been informed that most of them already wear and use a smart-watch while operating. Therefore such a device would be easily integrated and accepted by the personnel. As for the GPS enabled IoT device we will be using a tiny and lightweight device that could be attached to the SCBA without being obtrusive. In addition, both devices will be fully automated and they require no user intervention.

The transmission of the emergency alert to the central command station is achieved using the LoRaWan network protocol. The latter is specifically chosen since it enables us to provide a plug and play system that requires no pre-existing infrastructure while covering a large area of intervention. In addition, LoRa is low energy, low cost, and it uses low radio frequency signals which can ensure a successful transmission over a long distance even with the presence of obstacles.

Finally, Our proposed system, can reduce false alarms, is more reliable, helps the FAST localizing the fallen firefighter and brings numerous other additional features and benefits compared to the traditional PASS device. These benefits and features are discussed in the upcoming sections of this paper.

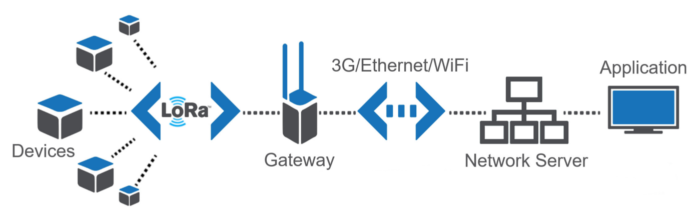
The rest of the paper is organized as follows: in Section II, a general overview description of the LoRaWan network architecture, components, and security is presented. In Section III a detailed explanation of the overall network infrastructure is provided. The proposed personal LoRaWan-based system (PERLY) is described in Section IV, while the system validation is demonstrated in Section V. This paper ends with a discussion around the future intended work in Section VI and a conclusion section, in which the contribution is summarized.

II. A General Overview of The LoRaWan Network Architecture, Components, and Security

In our proposed system we use the LoRaWan network protocol to transmit alert notifications to the Command Station (CS). As mentioned previously the benefits it brings (long-range, low cost, low energy, infrastructure-less, etc.) are essential for the requirements of the system. In this section, we will provide a brief introduction to the LoRaWan network architecture, the different components composing the network and finally its security.

LoRaWan is a wireless communication standard that stands for ”Long Range Wide Area Network”. Its main characteristics are that it allows low powered IoT sensor devices to communicate with internet-connected applications over a long distance (multiple kilometers). LoRaWan operates in an unlicensed frequency band ($867 - 869 Mhz$ for Europe). Therefore, it is perfectly possible for anyone to set up a network for the cost of a few hundred Euros or Dollars, that has coverage of a few kilometers. Figure 1 illustrates the different network components of the LoRaWan protocol. It mainly consists of 4 components, namely:

Fig. 1: The LoRaWan Network Architecture



- IoT sensor devices: these devices are categorized into three classes:
  1) Class A: it is the default class, it supports bi-directional communication with the gateway, and it requires low energy to operate. Uplink messages can be sent at any time, the device then opens two receive windows at specified times after an uplink transmission. If the server does not respond in either of these receive windows, the next opportunity will be after the next uplink transmission from the device.
  2) Class B: it also supports bi-directional communication and it extends class A by adding additional scheduled receive windows. The gateway sends time synchronized beacon allowing to know when the device is listening.
  3) Class C: are bidirectional with maximal receive slots. This means that they are continuously listening unless they need to transmit. Thus, Class C devices consume the most energy.
- The Gateway: it forms a bridge between the devices and the Network Server. Uplink messages are transmitted to the gateway using low power LoRa protocol, while the

gateway uses the conventional high bandwidth networks such as WiFi, 4G, Ethernet, etc. A device is not assigned to a specific gateway, all the gateways in the range of this device will receive the messages and will forward them to the Network Server using a packet forwarder software. It is the responsibility of the Network Server to filter packets and remove redundant data. As for downlink, the Network Server chooses the best gateway to forward the message to the targeted device.
- Network Server: this component is the brain of the network, it is responsible for the following tasks:
  - Aggregate all the upcoming data forwarded by all the gateways and their associated devices in the network.
  - Assign each device to a specific application and route the messages transmitted by each device to its corresponding application.
  - Control the LoRa radio configuration of the gateway.
  - Select the best gateway for downlinks.
  - Store messages until a Class A or B device is ready to receive them.
  - Remove duplicates.
  - Monitor the devices and the gateway.
- Application: it is the final destination of the transmitted data, it is written and customized by the manufacturer or the developer to suit its needs. It could be a mobile application, a Web application or any other type of application.

Security is also one of the main characteristics of the LoRaWan network. The communication between the sensor device and its corresponding application is protected via two security keys:

- The network session key: it is used by the sensor device to encrypt the whole frame (header + payload). The Network Server having the same key can verify the identity of the sender.
- The application session key: it is used to encrypt the payload in the frame. This key is only known by the application linked with this device, the Network Server cannot see what is in the payload, it only needs to know to which application should the message be forwarded. The latter decrypts the payload using the same key.

III. The Proposed System's Component Description

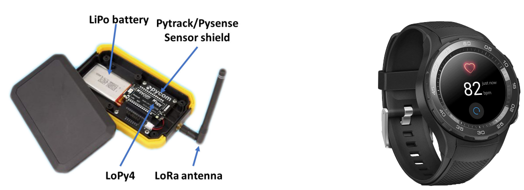
In this section, we will explain in depth the functionalities of each component, where it belongs and its role in the hierarchy of the network, and how these different components are interconnected in order to transmit an alert from a source to a destination.

In order to measure the heart rate of a firefighter, and detect mobility, a smart-watch is proposed as a sensing unit (Figure 2b). For this purpose, we use the Huawei Watch 2 that is equipped with the required PPG and Accelerometer sensors. An algorithm is implemented on the watch that can detect abnormal heart rate measurements and the activity state of the firefighter. Then, it decides whether the system wearer is at risk. If this is the case the watch transmits an alert message to the IoT device and the latter re-routes this message alongside the GPS coordinates of the concerned firefighter to the centralized control room (CCR) and to the on-ground chief (OGC) supervising the intervention in order to facilitate extraction.

The GPS enabled IoT device used in our prototype is the Pytrack sensor shield from Pycom (Figure 2a), it includes an accurate Global Navigation Satellite System (GNSS) and Glonass GPS in addition to a 3 axis 12-bit accelerometer. A LoPy4 module is attached to the Pytrack, the latter includes a LoRa and WiFi radio modules. A WiFi or a BLE socket is opened between the smart-watch and the LoPy4, it is responsible for transmitting the alert messages from the watch to the IoT Device. Once the LoPy4 receives the message, it orders the Pytrack shield to acquire the GPS location, and finally, the LoPy4 transmits the alert alongside the GPS coordinates via its LoRa radio module to the CCR and OCG. **NB**: In our prototype, we have used a WiFi instead of BLE to establish a communication link between the smart-watch and the IoT device, since BLE is not fully functional on Pycom devices.

Lastly, in addition to monitoring the firefighters, we were interested in monitoring the intervention area as well. For this purpose, we used the Pysense sensor shield from Pycom (Figure 2a) as an environmental sensor data collector. This device includes multiple sensors namely, ambient light, bio-metric pressure, temperature, humidity, dew point, and altitude. The role of the Pysense is to collect periodically (every 1 min) environmental data and transmit them automatically to the CCR and the OGC gateway. Information on the environment of the intervention, if visualized correctly, could help the OGC direct the actions of his team.

Fig. 2: The firefighter's equipement



(a) The IoT-device

(b) The smart-watch

The alert message transmitted by the Pytrack and the data transmitted by the Pysense passes by an intermediate LoRaWan gateway before reaching the centralized control room and the on-ground chief. Numerous Indoor and outdoor gateways are available [15], in our prototype, we used the 1Gate LoRaWan gateway [16] shown in Figure 3. Finally, for the network server, we have used the compact server for private LoRaWAN networks developed by Gotthardp [17].

To summarize it all, Figure 4 illustrates the proposed system. Each firefighter is equipped with both a Pytrack and a Pysense sensor shield, in addition to a smart-watch. The Py-

Fig. 3: The LoRaWan gateway

track acquires the GPS location information, and immediately transmits them to the LoRaWan gateway when it receives an alert from the smart-watch indicating that the firefighter is at risk and needs extraction. The Pysense, regardless of the state of its wearer, periodically collects and transmits environmental data to the gateway. This latter could be placed in a firetruck that is parked in the proximity of the intervention area in a location that provides the best line of sight with the firefighters. Moreover, in dense residual and industrial areas, pre-deployed gateways with optimally chosen locations that ensure maximum coverage could also be considered. The packets received by the Gateway, are re-routed via the conventional WiFi/GSM Protocols to a local Network Server that in turn forwards the information to the concerned application. The end application is responsible for alerting the operators (in the centralized control room or the on-ground chief) when a firefighter is at risk. Finally, as explained in Section II the communication route is encrypted all the way up to the application via a network and an app session key, preventing any possible attack aiming to sabotage the ongoing operation.

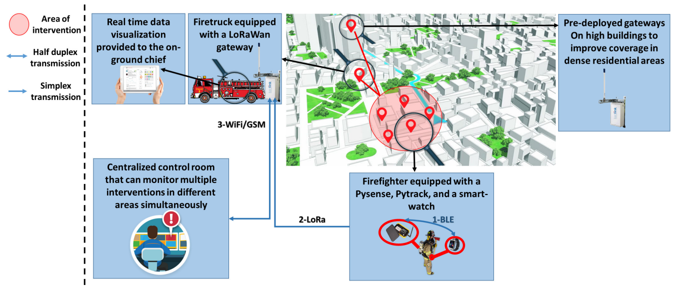


Fig. 4: The proposed remote monitoring system

IV. Software Implementation for Emergency Detection

In this section, we will explain the role of the Smart-Watch and the GPS enabled IoT device in detecting immobility or heart rate problems, alerting the FAST in case of emergency, and providing the latter with the GPS coordinates of the firefighters.

The Smart-Watch is responsible for monitoring the heart rate of the firefighter and detecting immobility. Mainly it performs the following tasks (Algorithm Smart-Watch) :

- Read the heart-rate measurements of the firefighter, using the integrated Heart Rate Sensor (PPG).
- Recognizes the activity of the firefighter (moving, immobile) using input from the accelerometer data provided by the 6-axis A + G sensor of the watch.
- Following both the heart rate measurements and the activity state, it computes whether the concerned individual is in an emergency state. If this is the case, it sends an alert notification via WiFi socket or Bluetooth low energy (BLE) to the GPS enabled IoT device.
- If an alert notification is sent, yet the concerned personnel moves again, or his heart rate is back to normal, a false flag notification is re-transmitted.

Once the receiving IoT device reads an alert notification, it performs the following tasks (Algorithm IoT-Device):

- Acquire the GPS coordinates and add them to the alert message.
- Transmits the alert via LoRa to a nearby LoRaWan gateway, which in turn re-routes the packet to the CCR and OGC.

The algorithms Smart-Watch and IoT-Devcice illustrated below summarizes the instructions performed by the smart-watch and the IoT device respectively.

Algorithm Smart-Watch

Input: $\lambda, \gamma, trh, HRmax, HRmin$

while battery !empty **do**
  if sensor is Accelerometer **then**
    calculate mobility using accelerometer data
    if $Moving$ **then**
      if Not-Moving alert is already sent **then**
        Send False Alarm alert to the IoT-device
      end if
    else
      if Not moving since more than λ seconds **then**
        make the watch vibrate, flash screen, and produce beep sound
        if Not-Moving alert is not yet sent & user did not deactivate the alarm **then**
          Send a "Not-Moving" alert to the IoT-device
        end if
      end if
    end if
  else if sensor is HeartRate **then**
    $HR \leftarrow$ Current Heart Rate from Heart rate sensor
    if γ seconds passed while $HR > HRmax$ or $HR < HRmin$ **then**
      make the watch vibrate, flash screen, and produce beep sound
      if "Heart-Problem" alert is not yet sent & user did no deactivate the alarm **then**
        Send Alert to the IoT-device
      end if
    else
      if "Heart-Problem" alert is already sent **then**

```
          Send False Alarm Alert to the IoT-device
        end if
      end if
    end if
end while
```

The immobility state is computed according to the following method. We first acquire the 3 axes values (x,y,z) reported by the accelerometer sensor embedded in the watch at the current time t. Then, we calculate the value $currentAccel$ according to the following formula:

$$currentAccel = \sqrt{{x_t}^2 + {y_t}^2 + {z_t}^2} \quad (1)$$

Once $currentAccel$ is calculated, we subtract from it the previously calculated $currentAccel$ at the previous accelerometer data acquisition time $t-1$ ($\sqrt{{x_{t-1}}^2 + {y_{t-1}}^2 + {z_{t-1}}^2}$) which is refered to as $LastAccel$. The subtraction result is finally stored in the variable $delta$.

$$delta = currentAccel - LastAccel \quad (2)$$

Finally, a value called $Accel$ is calculated according to Equation 3. If the value of Accel is greater than the threshold value trh the Watch wearer is considered to be mobile, otherwise he is considered to be immobile.

$$Accel = Accel \times 0.9 + delta \quad (3)$$

Algorithm IoT-device

Input: N

```
while battery !empty do
    run the Listen to Smart-Watch thread
    run the Live GPS Location thread
end while
```

Live GPS location Thread

```
alt, lat ← Get GPS coordinates from Pytrack
Send GPS coordinates to the LoRaWan Gateway
wait N seconds
```

Listen to Smart-watch Thread

```
Listen to the open connection socket
if Alert is received from watch then
    alt, lat ← Get GPS coordinates from Pytrack and add
    them to the alert message
    Send alert message to the LoRaWan Gateway
end if
```

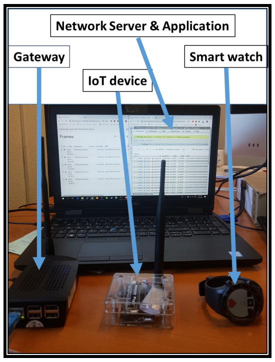
1) The additional benefits provided by our system: Compared to the conventional PASS device, this proposed system provides the following additional benefits:

- PASS transmits an alert if the firefighter remains immobile for 25 to 30 seconds. Our system can pre-detect the failing state even if the firefighter is still mobile through heart-rate monitoring. For instance, if the heart-rate of a certain individual remains higher or lower than the max/min rate for longer than it should, an alert is sent even if he's still mobile.
- Our proposed system is a plug and play, there is no need to manually arm or disarm the device as it is required by the PASS. Moreover, the smart-watch is a convenient device that is already used by the firefighters. They have it on their hand all day long even if there is no intervention. When an emergency occurs, the watch and the pre-equipped IoT device are already on standby.
- The mobility detection device is a smart-watch that is attached to the wrist, which is the most active body part of an intervening firefighter. In contrast, the PASS is usually fixed on the waist, therefore, it could trigger false positives when a firefighter is standing still yet performing an operation that requires minimum waist movement, or when the SCBA is posed on the ground in order to change an oxygen cylinder.
- When the PASS device emits an alarm sound, the FAST and the surrounding crew members will try to follow the path leading to the source of the sound, which can be difficult in a messy environment and the reflection of the echo. In contrast, our system can provide the FAST team with an accurate positioning of the fallen firefighter, which reduce the search time and increase the efficiency and the response time of the FAST.
- Our system covers a large area since it is LoRa based, a fallen firefighter can still send a notification to the FAST even if it located kilometers away (for instance a wildfire). As for the PASS device, if a firefighter was disoriented and moved far away from his team, there is a possibility that the alarm sound would not be heard when he is in an emergency.
- The heart rate measurements, and the activity state data can be collected and stored locally on the watch. They could be retrieved later at the end of the intervention, given as an input to Machine Learning (ML) algorithms that could help tune and personalize the Man Down detection algorithm in order to reduce further more the false flags.
- Last but not least, the real time information concerning the state of each firefighter and its surrounding environment, are visualized on a dashboard which could help the on-ground chief to better manage the intervention, anticipate future events, and predict the evolution of the intervention.

V. System Validation

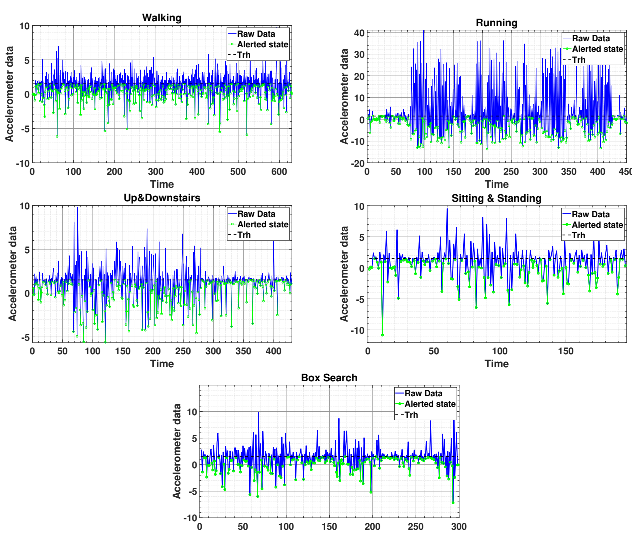
A system prototype consisting of a single smart-watch, IoT device, and a gateway has been validated in an experiment that was carried out on the university campus where our laboratory is located. The used equipment and the setup are illustrated in Figure 5.

Fig. 5: The used equipement



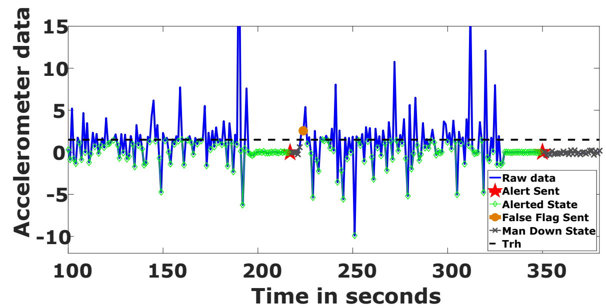
The wearer of the smart-watch has been asked to perform the following exercises: standing up, sitting down, running, walking, going upstairs, going downstairs, opening a box and taking items out of it while staying at his place, and finally, standing still and not moving for a certain duration. This test was carried out to check whether certain activities can trigger a false Not Moving alarm. None of the aforementioned activities has triggered an alarm as seen if Figure 6. The green diamond-shaped marker shows when the value of $Accel$ falls below the predefined threshold trh (alerted state), which means the watch wearer is not moving but is not considered as a Man Down since the duration in which $Accel$ is below trh is not greater than λ.

Fig. 6: Accelerometer data for different movements



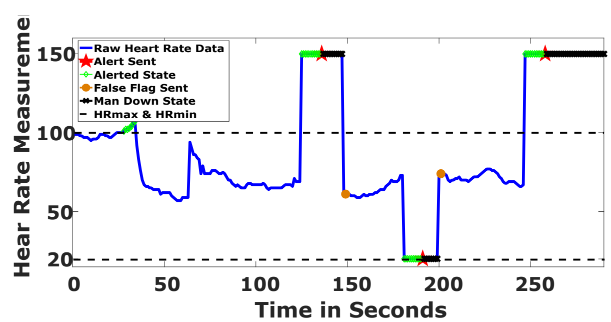
An alarm was triggered only when the smart-watch wearer was asked to stand still and did not move for a certain duration. In Figure 7 we can see that a Man Down alarm is triggered only when the Alerted State is maintained for a certain predefined duration. In our application, for the sake of testing, we fixed this duration to 20 seconds. In Figure 7 we can see how an alarm is sent (star-shaped red marker) to the IoT-device when the watch-wearer did not move for 20 successive seconds, thus declaring a Man Down situation. Moreover, after the first alarm was sent, the watch wearer was asked to move immediately. As a consequence, the smart-watch transmitted a false alarm to the IoT-device (represented by a circle-shaped orange marker). In contrast, when the second alarm was triggered, the watch wearer was asked to remain immobile. Thus, no false alarm was transmitted afterward.

Fig. 7: Accelerometer data for a not-moving state



The objective of the second test was to verify whether the watch would send a Heart Problem alarm to the IoT-device in case the heart rate remained under or over a predefined threshold. Moreover, this test was also set up to verify whether a false alarm would be reported if the heart rate of the watch-wearer went back to normal. As we can see in Figure 8, as long as the heart rate is within the lower-bound and the upper-bound threshold, which was fixed to 20 and 100 respectively just for sake of testing, the smart-watch will not send an alarm to the IoT-device. When the heart rate surpasses one of the fixed thresholds for a certain duration of time (fixed to 10 seconds for this test), an alarm is immediately sent to the IoT-device. Since it would be logistically difficult to force the heart-rate of the watch wearer to surpass the thresholds. We did this systematically by adding two buttons to the smart-watch application, one of them, when pressed, would either set the HR automatically to 150 and the other to 20 until they are pressed again. Similarly, to the previous test, when an alarm is sent, if the heart rate is back to normal, a false alarm is sent afterward, by doing so canceling the previous alarm.

Fig. 8: Heart Rate Data



In order to visualize the exchanged messages, the device was connected through a serial cable to a laptop device in order to access the LoPy4 shell command window. As we can see in Figure 9, the sensor when powered up, it opens a TCP socket and waits for the smart-watch to connect. Once the application on the smart-watch is opened, it automatically connects to the LoPy4. When a connection is established a message is shown (Connected to the following device: IP:port). The smart watch can typically send 4 different messages to the LoPy4:

- ”Not Moving” declaring that the watch-wearer was immobile for a certain duration of time.
- ”Moving Again - False Flag” declaring that the watch-wearer is moving again and the previously transmitted alarm is a false one.
- ”Heart Problem” declaring that the watch-wearer is facing heart issues.
- ”Heart Ok - False Flag” declaring that the watch-wearer heart is ”Ok” and the previously transmitted alarm is a false one.

Every time the IoT device receives an alarm. It first acquires the GPS location using the Pytrack device, then it sends the acquired GPS location alongside the message reported by the watch to a LoRaWan Gateway that is in range. When No alarm has been received, the GPS location can be transmitted every N seconds (Optional feature and N is predefined by the user) to the LoRaWan gateway in order to localize in real-time the intervening firefighters and keep track of them.

Fig. 9: Intercepting alert messages from the GPS enabled IoT device

```
Connected to the following device: 192.168.4.3:49346

Alert: Not Moving!

Calculating GPS coordinates
Latitude: 47.64275, Longitude: 6.839307
Sending Coordinates to the LoRaWan Gateway: b'|\xf8\xd6\x02\x00\x00\x00\x00\x0b\
\h\x00\x00\x00\x00\x00'


Alert: Moving Again - False Flag

Calculating GPS coordinates
Latitude: 47.64275, Longitude: 6.839307
Sending Coordinates to the LoRaWan Gateway: b'|\xf8\xd6\x02\x00\x00\x00\x00\x0b\
\h\x00\x00\x00\x00\x00'


Alert: Heart Problem!

Calculating GPS coordinates
Latitude: 47.64275, Longitude: 6.839307
Sending Coordinates to the LoRaWan Gateway: b'|\xf8\xd6\x02\x00\x00\x00\x00\x0b\
\h\x00\x00\x00\x00\x00'


Alert: Heart Ok - False Flag

Calculating GPS coordinates
Latitude: 47.64275, Longitude: 6.839307
Sending Coordinates to the LoRaWan Gateway: b'|\xf8\xd6\x02\x00\x00\x00\x00\x0b\
\h\x00\x00\x00\x00\x00'
```

When a LoRaWan gateway receives a packet from an IoT device, it transforms this packet into a conventional UDP packet and transmits it to the Network Server which could be directly installed on the gateway or on a distant server.

The data packets received by the gateway were visualized using a simple web application that we have developed for this purpose. Figures 10 and 11 show a screen-shot of the web application.

NB: Figure 10 shows the reported locations on the map in addition to pre-filled locations used for API testing purposes.

The developed web application shows the location of the firefighters on the map in case of an emergency. It also shows underneath the map a list of the received alerts. The user could also chose a matriculation number belonging to a specific firefighter (Figure 10) to show historic environmental data (Figure 11).

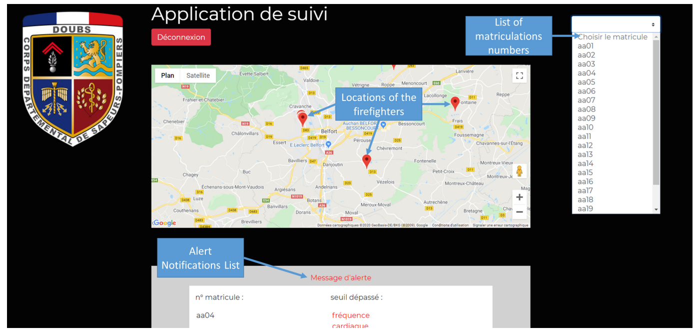


Fig. 10: Web application screenshot 1

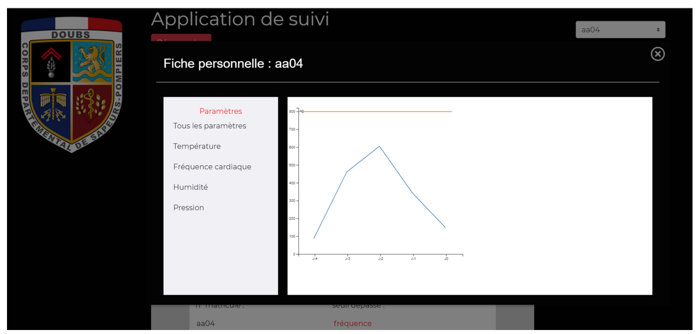


Fig. 11: Web application screenshot 2

Alongside the packet we can acquire additional information such as the device’s unique address, in order to identify the transmitting device, the Received Signal Strength Indicator (RSSI) and the Signal-to-Noise Ratio (SNR) that are indicators of the signals strength. These two previous values in addition to the time travel of the packet can be used to estimate the location of the device even when the latter fails to acquire its location using the GPS (Indoor). The idea is to localize this device using Information such as the packet time of flight reported on different LoRaWan gateways that are in range and a path loss model that is computed using the reported RSSI and SNR. Indoor localization is not our main objective in this paper, however, it is a problem that we are going to address in future works. Finally, the battery voltage of the sensor and an incremental frame count is transmitted with every packet. The battery voltage is important to monitor the lifetime of the system, and the frame count is an indicator that a frame was not successfully received.

VI. Future Work and Discussion

In this paper, we presented a simple prototype that validates the intercommunication between the different components of the proposed system. The most important aspect of the latter is the communication between the smart-watch and the IoT device. By introducing the former we have added an additional layer to the LoRaWaN protocol, thus making it a LANLoRaWaN protocol. However, the system is not yet completed. We aim in our future work to accomplish the following tasks before introducing a fully functioning product:

- Give as input the stored heart rate data to ML model which can help us tune the heart problem detection algorithm in such a way that it is personalized according to the identity of the watch-wearer. For instance, the heart rate dangerous zone (the lower, upper threshold in the algorithm) could significantly vary according to the age, sex of the firefighter as well as if the firefighter exercises routinely or not.
- When a firefighter is located underground or in an area where the equipped Pytrack could not find any satellite in range, we could use the SNR, RSSI and the ToF of the signal reported on multiple receiver gateways that are in the range of the transmitting LoPy4, in order to approximate its location. Moreover, the previously reported locations before entering a non-covered area could also be used to predict more precisely the location of the fallen firefighter.
- Conduct a comprehensive study on the battery lifetime of the watch and the IoT device and improve our algorithms to become energy efficient and reduce battery consumption.
- Conduct a comprehensive study on the transmitted signal path loss and the system coverage in different environments.
- Last but not least, when all the previously mentioned tasks are completed, we intend to test our product on large scale with the help of the fire brigade of the Doubs region, in close-to-operational conditions.

VII. Conclusion

In this paper, we proposed a monitoring LoRaWan based system to improve the safety of firefighters. It uses a smart-watch to collect heart rate measurements and to detect mobility, and it reports any abnormal heart rate or immobility to a centralized control room and the on-ground chief. In addition to emergency detection, the system includes environmental sensors that enable real-time monitoring of the intervention area. Our proposed system provides numerous additional benefits compared to the traditional PASS device, the most important of them all is that increases the system's reliability, it reduces false alarms, and it enables a real-time localization of the intervening team. A first prototype that aims to verify the intercommunication between the different components of the system was tested. The obtained results were promising and demonstrated its feasibility. For future work, we aim to add numerous additional features to our proposal to finally deliver a product that will be tested in close-to-operational conditions with the Doubs fire brigade.

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