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B2 Overhead Lines
PS3 Environmental and Safety Aspects from OHL

A wearable system for Work at Height Safety Management

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SUMMARY

Overhead line construction and maintenance activities involve an important number of tasks that are carried out by means of works at height procedures. This is particularly true for tower erection and conductor stringing tasks, where the presence of line crews working at height is nearly permanent during working days. Even though Personal Protective Equipment (PPE) specifically designed for these tasks has evolved and improved over the past years, the new Industry 4.0 era enables, among others, the development and use of IoT wearables to reach a new level in safety management, in which data and proactivity are key factors.
The Spanish TSO is committed to ensure people's safety while they perform the duties associated with their jobs through training in the correct use of working equipment, the application of individual and group safety measures, and by promoting and safeguarding the protection of the employees. To answer the strategic target of being a "Zero accidents" group, two main lines of action have been established: *Prevention and innovation culture*.

In this context, a novel, minimally invasive, light weight IoT wearable based on dedicated sensors is being developed. The use of deterministic algorithms outperforms other approaches based on the use of AI techniques. Also, expensive and time-consuming training is avoided leading to a shorter and simpler product deployment and certification.

The main goal of the system is to monitor that work at height is being carried out strictly according to a safety protocol previously stablished. For that purpose, sensors are attached to the PPE, in order to assess the correct usage of PPE during work at height. Attachment method is designed to avoid any negative impact in the safety function of the protection equipment.

Once the system is configured, it is able to notify the operator of possible safety hazards coming from the misuse of the personal protection equipment or even those coming from the violation of the safety protocol stablished for the particular working scenario.

These hazards are extremely difficult to detect by conventional visual supervision of the work being carried out. By using the proposed system, safety managers will raise awareness with regards to this potential safety hazards and will be able to take the appropriate actions, perhaps modifying or improving the training process. Developing the training process based on real worker behaviour data can significantly improve the efficiency of the safety management process.

Extensive testing of the system is being carried out in relevant scenarios to verify and improve the risk detection capabilities of the system.
For evaluation of system performance, a dedicated application has been developed.
Some initial results have shown that almost any hazardous situations can be robustly detected.
These scenarios have focused so far in the ascending or descending of overhead lines towers.

Some field testing has been carried out. Workers have been instructed to simulate risky situations while maintaining safety at all times. System will detect a violation of the safety procedures, thus alarms are raised and reports logged.

An app running on a standard smart phone or Tablet provides full anonymization of results while still supplying the most relevant statistical safety data for safety managers. This app can also be used at site by the Health and Safety supervisor to act accordingly in case of critical safety violation detection.

These promising results should be confirmed and reassessed in future project developments in which other manoeuvres and system improvements shall be included.

KEYWORDS

IoT, Wearable, Safety Management, IMU, PPE, Safety protocol.

1. INTRODUCTION

Among the top priorities of the Spanish TSO is ensuring people's safety while they perform the duties associated with their jobs through training in the correct use of working equipment, the application of individual and group safety measures, and by promoting and safeguarding the protection of the employees.
Overhead line construction and maintenance activities involve an important number of tasks that are carried out by means of works at height procedures. This is particularly true for tower erection and conductor stringing tasks, where the presence of line crews working at height is nearly permanent during working days. Even though Personal Protective Equipment (PPE) specifically designed for these tasks has evolved and improved over the past years, the new Industry 4.0 era enables, among others, the development and use of IoT wearables to reach a new level in safety management, in which data and proactivity are key factors.

Previous research has been done [1] [2] in order to assess what technology would better fit the mitigation of the different construction work hazards. As an example, the risk associated to the hazard of being caught-in or caught-between or struck-by a moving vehicle or equipment, could be mitigated by the use of proximity detection or location tracking technologies. Those technologies include RFID (Radio Frequency Identification), UWB (Ultra-wide band), infrared, radar, Bluetooth or GPS. Most of the hereinabove mentioned research covers only activities related to the construction sector, mainly buildings and industrial constructions.

Therefore, the first step has been to evaluate the feasibility of applying such technologies to the construction of overhead and underground lines and substations. An initial approach is shown in Table I below, matching the different hazards that may appear during the construction or maintenance activities of the most common TSO assets.

Table I. Technologies for monitoring common hazards during electric lines or substations construction or maintenance activities

Site hazards	Metrics	Sensing technologies
Caught-in or -between by a moving vehicle or equipment	Proximity detection, location tracking	RFID, UWB, infrared, radar, Bluetooth or GPS
Struck-by suspended load	Proximity detection, location tracking	RFID, UWB, infrared, radar, Bluetooth or GPS
Falls from height while tower ascending or descending	Body posture	Gyroscope, accelerometer, computer vision
Slips or trips, mainly substation works	Body posture, body rotation, body speed	Gyroscope, accelerometer, computer vision
Electrocution	Proximity detection, location tracking	RFID, UWB, infrared, radar, Bluetooth or GPS

Levels of risks vary among the different activities, being electrocution and falls from heights the activities with a higher risk of producing a severe accident. Consequently, research has been initially focused on falls from height while tower ascending or descending.

2. WORK AT HEIGHT IN OVERHEAD LINES

Work at height in overhead lines is quite different to work at height in the construction sector, mainly dealing with building construction. Although they share the use of some PPE, such as the safety rope or harnesses, general equipment and more importantly the nature of maneuvers carried out by workers is completely different.

The Spanish TSO defines in the Work at height safety handbook AM004 [3] the main particularities, advices, PPE and instructions to be considered when working at height in overhead lines or substations. This document is very specific to the type of work at height carried out during construction and maintenance of overhead lines and must be the primary source of information when designing a wearable system to monitor and mitigate risk in such activities. Some relevant information in [3], regarding the understanding of the paper, is summarized hereinafter.

The typical scenario described in [3] is depicted in the following images

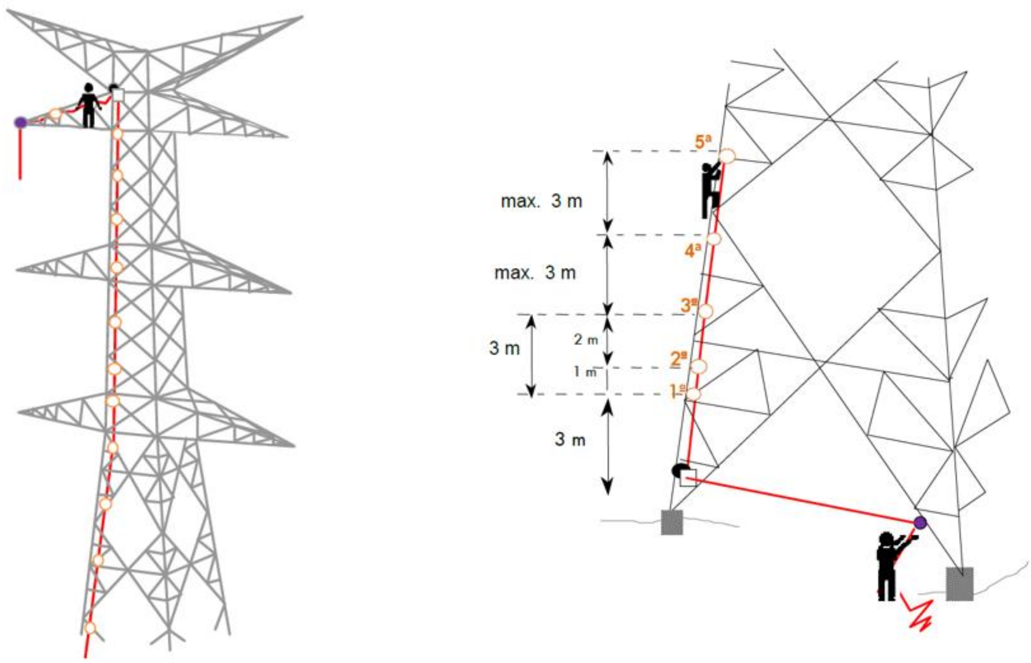

Figure 1. Extract from [3]. Use of safety rope and temporary anchors.

The image on the left (Figure 1) shows an installed safety rope ready to be used for subsequent operations.
On the right (Figure 1), distance restrictions between temporary anchor points installation are shown.

The main objective of the proposed system is to closely follow the worker behaviour to check that operations are been carried out in conformance with the stablished requirements in [3].

Reporting of unconformities to safety managers will provide them with an invaluable feedback for taking corrective actions before an actual accident happens.
Sensor units have been designed to be attached to PPE in order to achieve the system goals.

Following, a list of the most common PPE required when ascending or descending from an overhead line tower is shown:

- Fall arrest body harness
- Temporary anchor devices with locking carabiners
- Mobile fall arrester for rope
- Safety rope
- Double adjustable progression lanyard

Typical use of these PPE is shown in the following figure:

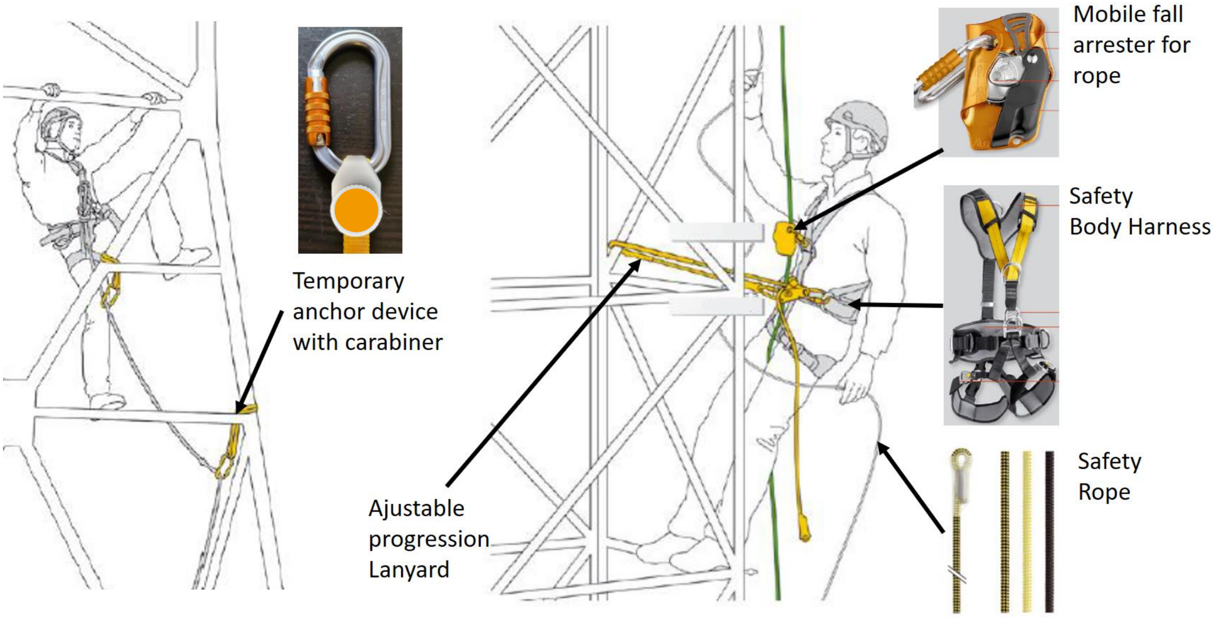

Figure 2. Examples of PPE used during construction or maintenance activities in OHLs. Note: Temporary anchor device is shown with a sensor prototype attached for the sake of early system understanding.

An early conclusion of system development is that measurement of key magnitudes in a relatively small set of wearable sensors can provide enough information to detect any hazardous misuse of PPE for the target scenarios.
With regards to the scenarios in which safety should be monitored, construction and maintenance works in overhead lines comprises very different activities. In this way, initial development works will focus on the ascending and descending scenario. It is expected that the insights and conclusions for this main scenario will then be extrapolated to full set of scenarios.

Next steps include verification of the above-mentioned hypothesis by thorough laboratory and controlled field tests with trained workers. At this stage the better IoT / IoB technologies for successful product deployment should be analysed, taking into consideration technical, economic and easiness of use criteria. With regards to the latter, it is an objective that the system is minimally invasive in order to guarantee that workers activity is absolutely not affected by the system.

3. INITIAL RESEARCH AND TESTING

Several methods have been proposed for automated supervision of work at heights:

- Computer vision-based systems [4].
- Dedicated sensors for relevant magnitude measurement [5].

Computer vision-based systems are sensitive to scene cluttering and occlusion, furthermore training of the CNN (Convolutional Neural Network) used for detection is expensive and time consuming.

Dedicated sensors, especially inertial measurement units (IMUs), best suit the requirements of scenarios of interest depicted in [3], furthermore robustness of the algorithms used is more easily assessed compared to AI based systems.
Regarding the use of dedicated sensors, especially IMUs, there have been a very limited of previous reports in the field of building construction [5]. Construction and maintenance of overhead lines imply activities such as tower and fitting inspection, insulator string replacement, tower erecting, conductor stringing and so on. These activities and their safety procedures are very specific to electrical systems and therefore a specific assessment and research is needed.
Furthermore, whereas previous works concentrates in detection of fall portents for accident prevention, our work concentrates in the detection of any violations of the procedures described in a well stablished safety protocol [3]. This way, results of system operation at field will directly translate into suggestions for protocol modification or training procedures improvement, providing health and safety managers with new tools for safety management including lessons learned during actual operations.

After an initial research, the final decision was to use dedicated sensors (wearables) attached to PPE.
To achieve effective supervision of procedures described in [3] a prototype system has been built with several sensors attached to the different safety devices. Figure 3 show examples of the developed sensors attached to their respective PPE.

Figure 3. Examples of PPE sensor attachment.
Note: Internal hardware / architecture is identical for all sensor regardless the PPE to which they are attached. Only the bottom half of the enclosure is adapted to the different mounting options.

A supervision application running in mobile devices (intended to be used by the crew supervisor) uses visual and synthetic voice warnings for risky operations pinpointing.

For system validation and algorithm parameter tuning a second application permanently monitors the key magnitudes measured by the wearable sensors using the same RF network.

A low power wireless network has been built for the connection of sensors to the supervisor application and the validation and logging application.

Field deployment of sensors in a relevant scenario is shown in Figure 4:

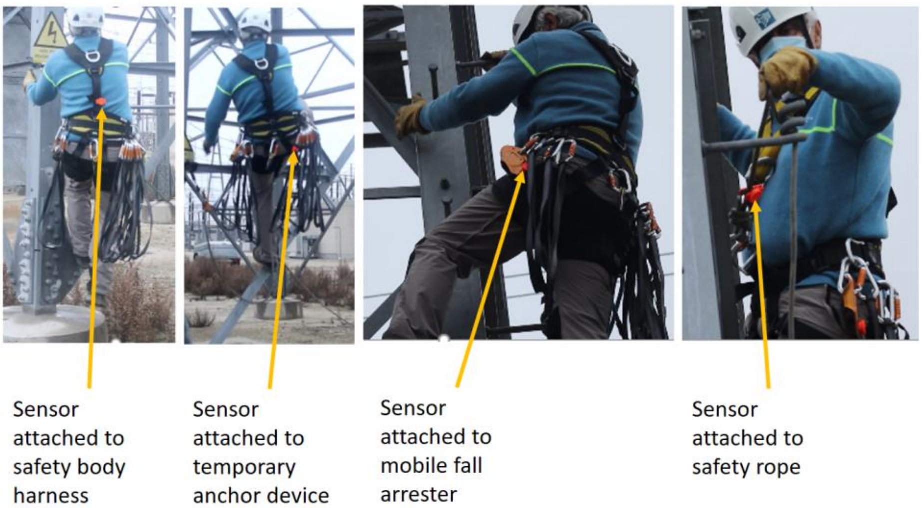

Figure 4. Field deployment of sensors in a relevant scenario

For evaluation of system performance, a dedicated application has been developed. The application supports the following functionalities:

- Intuitive visualization of important measurements.
- State machine events and states graphical visualization.
- Real-time slider tuning of algorithm parameters.
- Video and data collection synchronization.
- Raw data logging for further analysis.

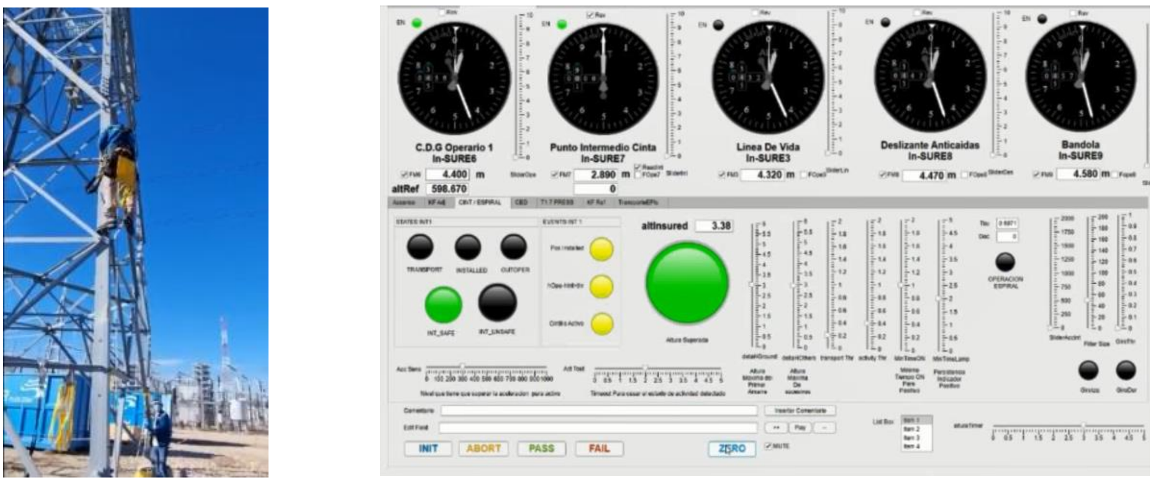

Figure 5. Validation application running synchronized with real time video

Examples of analysis of acquired data are provided in the Figures 6 and 7:

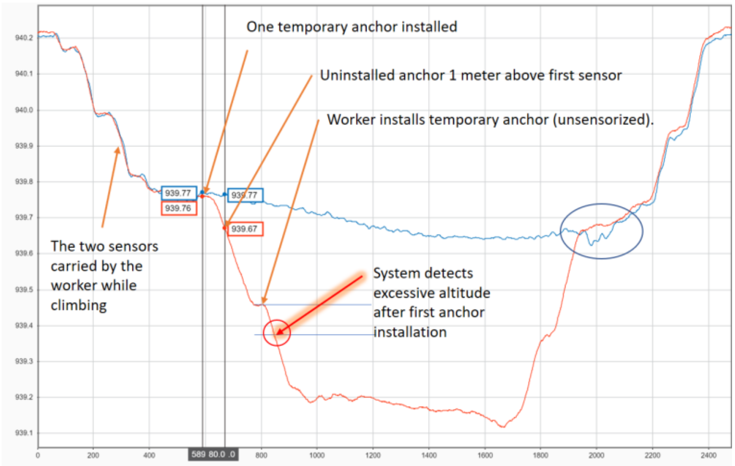

Figure 6. Tracking and supervision of temporary anchors installation

Figure 6 shows how the installation of temporary anchor devices can be fully supervised in order to check that the maximum distances between anchor points as described in [3] are fully respected.

For system field testing, a worker is instructed to climb the tower carrying three temporary anchor devices. Sensors are attached to two of them (blue and red lines in the figure), while the third is used to make sure that the worker is not exposed to a real risk during the risky situation simulation. This technique has been used during system testing as a mean of simulating risky events without compromising workers' safety.

System will detect a violation of the limits for distances stated in [3] for temporary anchors installation by means of tracking the PPE (blue and red lines in the figure). Consequently, and alarm should be raised, and corresponding reports should be logged.

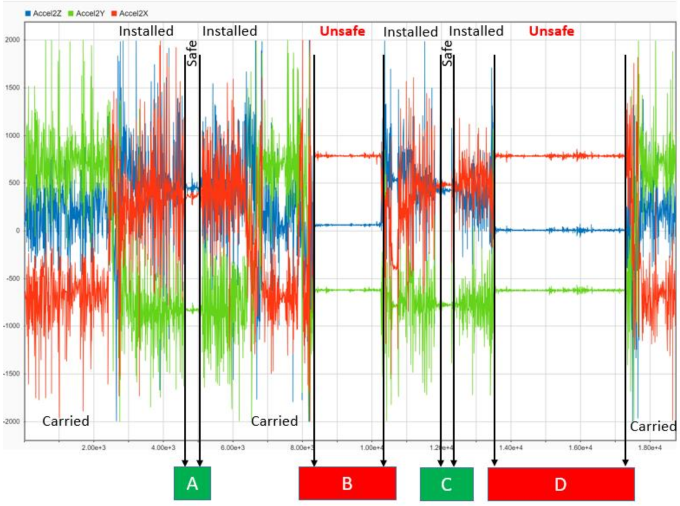

Figure 7. Accelerations measured on temporary anchor devices while climbing with two PPE with attached sensors.

In B, D time intervals, system detects absence of acceleration while the worker climbs. This is an abnormal situation showing that temporary anchor point is not properly installed.

In A, C time intervals, system detects absence of significant accelerations while the worker is not climbing and the situation is interpreted as normal.

It is remarkable that signal to noise ratio is enough to guarantee robust detection of significant events.

Although system is currently based on a preliminary version of algorithms and reduced data acquisition, information provided so far can be readily used by safety managers for both safety protocol compliance and workers training program improvement.
It is important to note that our main objective is to verify that safety protocols are being respected. Visual inspection of safety protocols by ground crew supervisors is a difficult task due to the inherent nature of the working scenarios, particularly the observation of workers´ behavior at a distance above 20 meters or even more.

4. FINDINGS AND CONCLUSIONS

The Spanish TSO is committed to ensure people's safety while they perform the duties associated with their jobs through training in the correct use of working equipment, the application of individual and group safety measures, and by promoting and safeguarding the protection of the employees. An Action Plan for the health and safety improvement, with a horizon 2020 – 2023, has been established. The main goal of the Action Plan is to answer the strategic target of being a "Zero accidents" group, in which two main lines of action have been established: *Prevention and innovation culture*.

Work at height during construction or maintenance of overhead lines is one of the activities with a higher risk of producing a severe accident. Hence, an innovative research with a technological start-up has started to tackle the target of being a "Zero accidents" group.

An IoT wearable based on dedicated sensors is being developed. The use of deterministic algorithms outperforms other approaches based on the use of AI techniques. Also, expensive and time-consuming training is avoided leading to a shorter and simpler product deployment and certification.

The main goal of the system is to monitor that work at height is being carried out strictly according to a safety protocol previously stablished. For that purpose, sensors are attached to the PPE and a series of algorithms are currently under development.

Once the system is configured, it is able to notify the operator of possible safety hazards coming from the misuse of the personal protection equipment or even those coming from the violation of the safety protocol stablished for the particular working scenario.

Initial testing in some relevant scenarios has shown that almost any hazardous situations can be robustly detected. These promising results should be confirmed and reassessed in future project developments.

A small, low cost and low power processor has been demonstrated to be able to cope with both detection algorithms and communication stack workloads. High safety integrity levels can be achieved by continuous monitoring of sensor health from an application in a mobile communications device. Even sensor to sensor supervision is possible. Additionally, a high level of redundancy is intrinsically built in the system as all sensors have the same internal hardware / architecture and most of the time more than one sensor can be used to measure the same magnitude or parameter of interest

Present work has focused on manoeuvres of ascending and descending from an overhead line tower. Future work will include other manoeuvres such as insulator string replacement, tower erecting, conductor stringing and so on.

Improvement of energy consumption should be a main concern in future development work. Initial laboratory testing at low RF communication rates reasonably promises ability to use energy harvesting techniques leading to an improvement in energy management.

By using the proposed system, safety managers will raise awareness with regards to potential safety hazards and will be able to take the appropriate actions, perhaps modifying or improving the training process. Developing the training process based on real worker behaviour data and lessons learned can significantly improve the efficiency of the safety management process.

This research is an important step towards the Spanish TSO target of being a "Zero accidents" group. There is a focus on innovation as a digital transformation tool regarding occupational safety where health and safety innovation is managed by making technology available to people.
As shown in this paper, innovation management is carried out by seeking an impact on the health and safety procedures, promoting for that purpose the use of new technologies.

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