

	VALIDATION AND IMPLEMENTATION OF A PLATFORM FOR MONITORING ERGONOMIC RISKS IN CONSTRUCTION.	Building technology 3305.22
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VALIDATION AND IMPLEMENTATION OF A PLATFORM FOR MONITORING ERGONOMIC RISKS IN CONSTRUCTION

David Sánchez-Martín¹, Catalina Mondragón-Enguïdanos¹, Amparo Verdú-Vázquez² y Tomás Gil-López²

¹ Acciona Construcción S.A (España)

² Universidad Politécnica de Madrid. ETSII (España)

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1.- INTRODUCTION

The aging of the workforce is a relevant aspect for companies, since the percentage of workers over 50 years of age is increasing and many countries are considering extending working life beyond 65 years of age. This reality affects both the health and safety of workers and the productivity and competitiveness of companies [1]. Aging at work is conditioned by work capacity, which is determined by the interaction between working conditions and workers' characteristics [2], [3].

This article analyzes the validation of a system of personalized body sensors with built-in intelligence, to monitor the worker in order to accurately obtain the level of risk associated with each of the tasks performed in their daily work. The development of this system is located within a series of developments belonging to the BIONIC project, a European project for the improvement of worker health, which aims at real-time risk assessment and guidance of aging workers, in all types of working and living environments [4], [5].

The system consists of a holistic, unobtrusive, autonomous and privacy-preserving platform of real-time risk alerts and continuous advice, which enables the design of workplace interventions tailored to the needs of workers and the levels of the aging workforce.

The overall system is based on the concept of a cloud platform, a sensor suit or Body Sensor Network (hereafter BSN) for use at work. The interaction between the worker and the BSN is done through an Edge device that acts as an interface between the cloud platform and the BSN. Through mobile applications, end users (senior workers, physicians and managers) can retrieve their processed data from the platform. Additionally, a *gamification* layer or app is available for workers that recommends exercises to help prevent injuries or counteract the one-sided stress of some tasks performed throughout the workday (Fig. 1) [6].

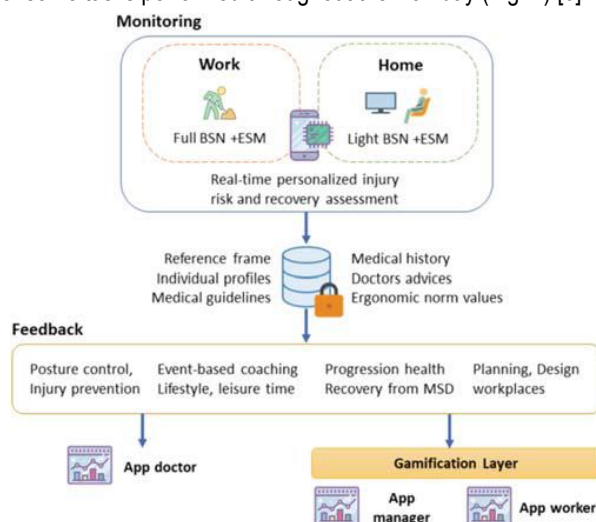


Fig.1. General scheme of the complete system.

The BSN is based on loosely integrated sensors that are placed on work or everyday clothing, with dynamic monitoring of overall body posture. The system will use kinematic data (e.g., body postures) along with kinetic, physiological, and environmental sensor data related to the workers' situation and their environment. [7].

The entire system is tested and validated in real construction scenarios through the actions described in this article.

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2.- SYSTEM OVERVIEW

This system consists of a series of application software layers in a heterogeneous and synchronized real-time network for the designed body sensor network (BSN). A prototype was developed that runs whole-body kinematics at 100 Hz, on an embedded application processor. In addition to OWAS and ISO 11226, an age-adapted ergonomic risk model has been developed and work has started on its implementation in the embedded application processor [8], [9]. The data platform, including authorization and storage services, has been implemented and tested.

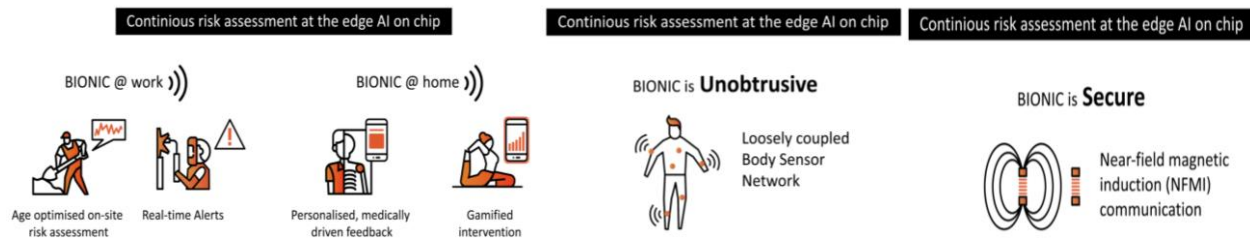


Fig.2. Main characteristics of the complete system.

3.- CHALLENGES AND OBJECTIVES

Expected progress of the BSN:

- Magnetometer-free and self-calibrating inertial body motion tracking, i.e. the sensor mounting on the body segment of the inertial measurement units can be automatically estimated together with human posture tracking, allowing minimal setup time and avoiding error-prone calibration phases for capturing inertial body motion and without using magnetometers, i.e. applicable in any industrial environment.
- Contributions to kinematic estimation from loosely coupled sensors, i.e., the body sensor network can be fully integrated into comfortable clothing and does not have to be firmly attached to bones and the obtained kinematic motion estimation generalizes to a wide variety of motions with calibrated kinematic uncertainty estimates.
- Feasibility of a long-term (one-day) fully mobile and online ergonomic assessment based on human motion capture.
- Modular multi-sensor network that can be easily synchronized and integrated into clothing.
- Mobile and consistent estimation of kinematics and load from low-cost pressure templates and kinematic motion tracking.
- New approach for a reliable GDPR-compliant tracking system.

The expected impact of the system is to facilitate long-term applicability of ergonomic monitoring and evaluation in the field for mobile measures that aid evidence-based medical support and prevention education with reliable data management.

The system is adjusted to the physical condition and age of the worker and should perform ergonomic monitoring and provide information to the user, for example, to perform preventive exercises at home.

The main objectives of this platform are:

- Monitoring and prevention of work-related risk factors for different types of musculoskeletal diseases (MSDs) and related disorders.
- Continuous, persuasive and medically discreet training, e.g., for men and women with chronic musculoskeletal conditions.

The scientific and technical objectives to achieve these goals are:

- To create an innovative, holistic and non-intrusive body sensor network (BSN) that can be freely and unrestrictedly integrated into sportswear, workwear and personal protective equipment.
- Enable fully mobile real-time and intelligent sensor data fusion and analysis.
- Management, analysis, presentation and protection of user data in accordance with GDPR regulations.
- Kinematic and biomechanical models for ergonomic risk assessment adapted to age and workplace analysis.
- Training and interaction with the user through games.

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- Validation of the system in a real environment, i.e. at the workplace, at home or in outdoor activities.

With a design oriented approach user requirements, usage scenarios, medical requirements and trust concepts for medical wearables in the platform framework have been defined. The state of the art of sensor hardware was reviewed and a set of sensors was discussed and selected with the consortium. Based on this information and end-user feedback, a biomechanical model and ergonomic tools were selected for this model (OWAS, ISO11226). A procedure and an application were implemented to generate a 3D morphometry of the user.

4.- SYSTEM VALIDATION

The validation of this system was carried out through several pilot tests that consisted of the continuous use of the BSN and the entire platform by different construction workers during a full working day and for several days. During this monitoring period they performed their usual tasks for the execution of construction works. The worker's movements were monitored by the system and compared in its database.

To carry out the system validation tests, scenarios and conditions were defined:

1. **Selection of the most suitable construction project:** the most suitable building site for the pilot tests was selected taking into account the requirements of the system and the most interesting tasks to be measured by the system. A building site with construction tasks in the field of building and dedicated mainly to masonry. We also tried to achieve the best harmonization between the construction activities and the scheduling of the activities, the workers and the pilot, the availability of the targeted worker profiles and the cooperation of the construction project managers and the Health and Safety personnel of the construction site.
2. **Planning of the pilot project:** The pilot tests were defined as two batteries of tests in 3 months. In those weeks the workers used the complete system in the first pilot and with the *feedback* received, improvements and updates of the system will be carried out for its definitive test in the second pilot.

For the pre-testing of the system, the involvement of 2 workers was planned for a week with discontinuous tests during which notes were taken and several improvements were made to the system during the course of the tests. These tests are defined in the following point (3).

For the planning of the pilots after the previous tests, 2 periods were estimated: a first pilot period in which 4 workers were involved during a working week whose tests were initially discontinuous on the first day, but after the good functioning of the system were carried out continuously during their working day on subsequent days. For the second pilot period, the planning responded to the measurement during 1 continuous working week without interruptions for 4 workers in a totally autonomous manner after the training and initiation session.

In total, the validation of the system was planned with 8 different workers (without taking into account the 2 pre-test workers) in 2 different scenarios, real construction scenarios in building sites in Spain.

Below is a summary table with the planning previously agreed upon during the development of the project by all the partners involved and where the trial periods, number of workers and other requirements are defined:

	Pre-test / Technical Validation	PILOT TESTS	
Duration / Schedule	NOV21	DEC 21- FEB 22	
Description	Tests with parts of the system in controlled environments. Users will be technical staff with the possibility of adding some real workers	Pilot tests in real conditions.	
Bionic systems operating (2 shirts, 1 helmet/cap, 1 trouser)	2	8	
End User App	First Version	Reviewed Version	
Testing period	1 day per worker / Occasional use in not continuous periods	Short-period tests 4-5 days per worker	Long-period tests Uninterrupted week
Proposed metrics	<ul style="list-style-type: none"> Technical tests Short questionnaire (overview, comfort) 	<ul style="list-style-type: none"> Online questionnaire (usability, comfort, TAM, NPS) 	<ul style="list-style-type: none"> Bulletin Board User interview (midterm-end of test) Online questionnaire at the end of the test. Changes in user capabilities
Users involved	ACCIONA 2 workers	4 workers	4 workers

Fig.3. Pilot planning according to system requirements.

3. **Start-up, pre-testing, configuration and learning of the system:** ROLL-OUT days in which the technicians involved learned the handling and operation of the complete system. This involves the connectivity of the system, the adaptability of the BSN suit and the assembly of the sensors and transmission equipment on the clothing, as well as the connectivity between all of them and their commissioning.



Fig.4. Checking the adaptability of the BSN (left and centre) and the correct display of the kinematics on the BIONIC platform (right).

Similarly, several tests were performed with real workers in a simulated and controlled construction environment in order to observe events that could occur in the real scenario and could be anticipated and resolved before they caused errors during the pilot tests.

4. **Selection process of the workers:** The selection process was carried out taking into account the basic requirements of the project, among which the following stand out: that the worker was middle to old age in order to achieve an improvement in their physical problems caused by years of work in the sector, that the worker was prone to the use of new technologies and their learning would be easier, as well as collaboration in the course of the pilot and that the Health and Safety technicians were part of it [10].
5. **Initial health study:** initial evaluation of the health status of the workers enrolled in the pilot in order to compare it with the results after the end of the pilot. It consisted of a short test on their occupational health, physical condition, habits and

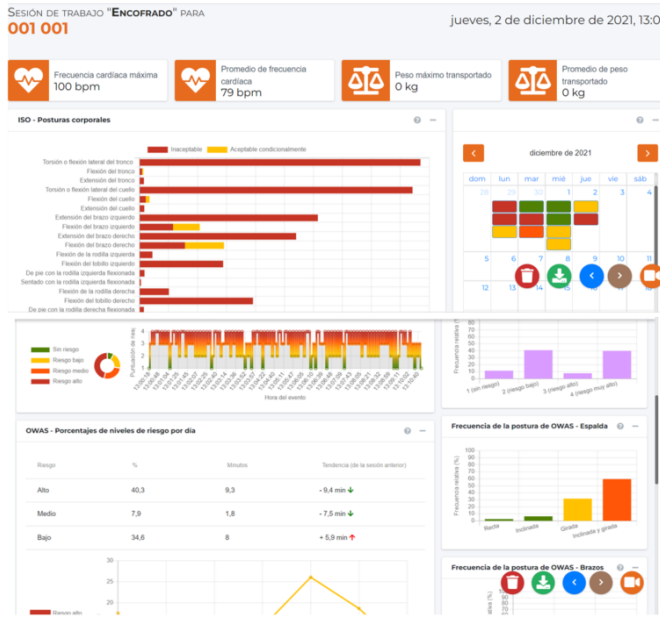
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injury history. Thanks to this, after the pilot tests, workers receive through the system a series of tips through the *gamification* application with which to improve their physical health both at work and in their private life. [11].



Fig.5. Images of the gamification app showing the virtual trainer, the daily and weekly records and the screen of the weekly challenge proposed to the worker.

6. **Training:** process of training workers in the use of the complete system. The enrolled workers were trained to better understand the context and objectives of the BIONIC project and to become familiar with the BIONIC technology, how they will use it and the different steps to be followed during the pilot.
This training process was individualized and dedicated to each worker. They were instructed in the use of the complete platform, the connectivity and maintenance of the BSN, the functionalities of the mobile devices, as well as the calibration process.
7. **Pilot test for system validation and data collection:** consisted of the use of the complete system by construction workers during their full working day and several weeks of measurement. The objective was to test the functionality of the system, the adaptability of the BSN to this work environment and to collect ergonomic data from the construction workers. In this way the efforts recorded and the data obtained can be compared with the corresponding OWAS and ISO and medical experts and prevention managers can draw better conclusions obtained with the data visualization platform [8], [9].



	OWAS Postures	%
Arms	Both below shoulders	55
	One over shoulders	30
	Both above shoulders	15
Back	Straight	55
	Bent	10
	Twisted	25
	Bent and twisted	10
Legs	Standing	40
	Standing, weight on one straight leg	15
	Standing with both legs flexed and the weight balanced	5
	Standing/Squatting with both legs flexed and the weight unbalanced	5
	Kneeling (on one or two legs)	15
	Walking	20

- Additional ergonomics aspects:
- Neck flexion and neck flexion + twisting
 - Neck extension
 - Arm / hand force
 - Wrist ulnar deviation

Fig.6. Data display screens, ergonomic risks and estimated ergonomic assessment. Estimated ergonomic assessment.

The workers performed their usual tasks on site without interrupting the progress and planning of the work. The BSNs collected data from workers related to different tasks in the construction field.

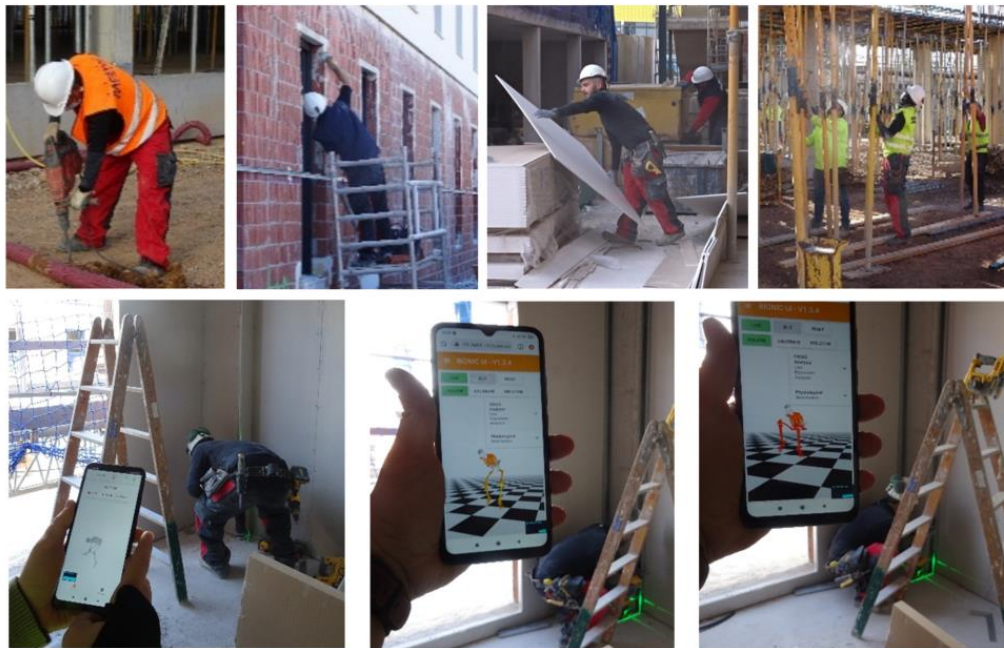


Fig.7. Test images of workers performing construction tasks while wearing the BSN. Worker using the BSN while technicians visualize ergonomics and OWAS on the data visualization platform. The progression of pain in the worker's physiognomy can be observed in real time.

8. **User evaluation:** Participating workers gave their opinions on the complete use of the system, which includes the use of the BSN during their workday, the use of the mobile devices that complete the system together with the BSN, the

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visualization of the platform where to check the ergonomics and physical risks associated with their tasks, as well as the training and assistance received by the technicians regarding the system during the whole pilot.

This evaluation has been carried out through two activities that collect the perception of users in aspects related to usability, comfort, satisfaction and future use perspectives:

- Evaluation questionnaire: ask end users about their satisfaction with the system. The results will be used to improve the usability of the system from a human point of view.
- Interviews: some interviews were conducted with the participants to get their opinion about the system.

The results allow us to have a perspective on the possibilities of implementing the system in real environments, as well as the detection of aspects that can be susceptible to improvement.

The results are based on the application of a quantitative methodology based on the design and proposal of a survey that has been passed to all the workers involved in this pilot experience; and together with this quantitative methodology, the qualitative methodology has been used.

Objectives:

1. Evaluation of the satisfaction in the use of the system, from the point of view of the training received-required, the ease-comfort of the equipment, the textile materials used, the BSN (Body Sensor Network), the power supply and a proof of concept of the application of gamification.
2. Evaluation of the comfort of the different components of the equipment, tools, calibration... Especially in this case the interview will be applied to complete the questions of the questionnaire or to provide everything that is not included in the questionnaire and that is of interest to the worker.

The methodology for the elaboration of the questionnaires was based on the adaptation of standardized scales to the characteristics and performance of the system, taking into account the contexts of use.

The results of some of them are shown below:

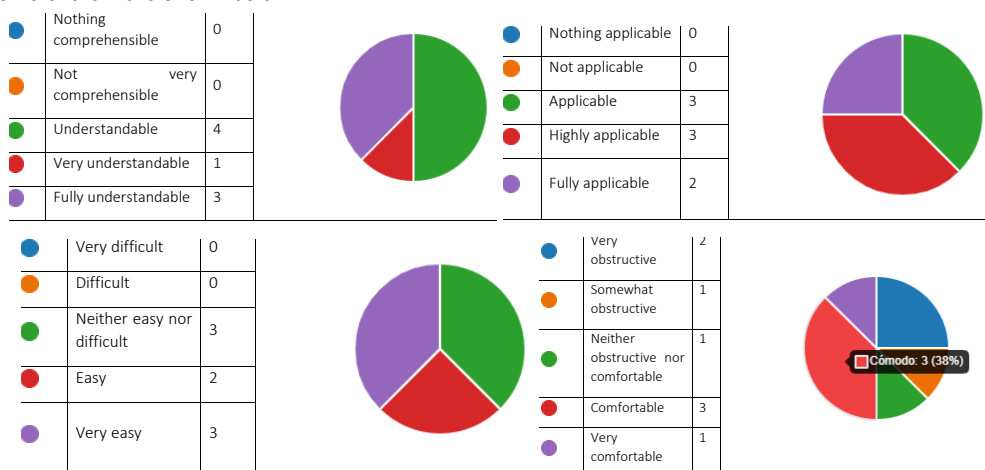


Fig.8. Responses in order to the following questions: was the training received easy to understand, do you consider the system interesting for future application in the construction field, was the BSN calibration process simple, how intrusive or comfortable was it for you to perform your usual tasks, do you consider the system intrusive or comfortable for you to perform your usual tasks? How intrusive or comfortable do you consider the system to be in performing your usual tasks?

9) Conclusions and evaluation of the system:

- The BSN system or sensor suit meets the "loosely coupled architecture" requirements, forming a non-intrusive system for the worker that does not interfere with their mobility or the performance of their normal tasks during the workday.
- The BSN system or sensor suit meets the requirements of ease of assembly, calibration and commissioning. The workers' learning how to use it and the ease with which they acquired the knowledge for the calibration and commissioning of the

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system makes them practically autonomous when using the system in consecutive days, after the first tutored session the worker was able to perform the consecutive tests by himself,

- The ergonomic data recording system worked satisfactorily. Initially, in the first tests, the visualization and recording of the data was not 100% as desired, but this was solved during the initial tests before the pilots, for which the initial calibration stages were key for the subsequent data collection to be reliable with reality. After improving the calibration process of the sensor system and performing it correctly, it was demonstrated that the data did respond to normal or expected records.
- Another objective achieved was the correct choice of the tasks to be monitored, since it gave the experts the possibility of collecting and studying the desired data since no machinery was used (except light machinery) and they were able to observe both the efforts and the ergonomics of the worker during his entire working day.
- The visualization platform, both via web server and mobile devices, was really satisfactory. For the employee, it was really helpful in understanding the reason and use of the system. For the ergonomics experts, it provided, in addition to the archived record, real-time data both in the office and on-site of the movements and efforts made by the worker during the pilot tests. This greatly enriched the experience and provided the system with a virtually instantaneous evaluation system, including the ability to correct postures or efforts while performing certain tasks.
- The "gamification" and training platform for the worker turned out to be more interesting than expected. Workers were involved in its use and reported the importance of this type of ergonomic and physical advice to improve their work and personal life, highlighting the prevention of future injuries.

As aspects to be taken into account for the improvement of the system and difficulties identified after the evaluation carried out by experts and workers, the following aspects should be highlighted to evolve and develop in the next version of the system:

- Some workers reported that the portable battery that supports the BSN or sensor suit could be relocated elsewhere. Initially it is located in one of the side pockets of the pants and for some it was slightly annoying, but not limiting. Depending on the task at hand, a new location on the waistband of the pants or tool belt is suggested. The system is adaptable and can make this improvement, which will be taken into account for future versions of the system.
- Occasionally, some errors were detected in the translation of ergonomic data into the OWAS and ISO systems. These events can be subsequently resolved by collecting and studying the data from the server where they are archived so that they do not represent a loss in the study of the data. It was shown that if the calibration is good the data translation is also good. We are currently working on improving this to avoid as much as possible the occurrence of any of these occasional errors.

With all this, it can be concluded that, although the system can be further matured, the methodology for its testing is satisfactorily approved by the project partners. The pilots carried out were more than satisfactory, more than fulfilling the initial expectations and objectives for the validation and implementation of the system and its platform.

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