Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 72 (2018) 886–891

www.elsevier.com/locate/procedia

51st CIRP Conference on Manufacturing Systems

Improving a production site from a social point of view: an IoT infrastructure to monitor workers condition

Fabio Gregori [a]*, Alessandra Papetti [a], Monica Pandolfi [a], Margeherita Peruzzini[b], Michele Germani [a] *

[a]Università Politecnica delle Marche, Via Brecce Bianche 12, Ancona 60131, Italy
[b]Università degli Studi Di Modena e Reggio Emilia, Via Pietro Vivarelli, 10, Modena 41125, Italy

* Corresponding author. Tel.: +390712204880; *E-mail address:* f.gregori@pm.univpm.it

Abstract

In the context of Industry 4.0, this paper focuses on integration of workers in the digitalized factory. It proposes a method to design an IoT infrastructure and acquire human-related data from a production site in order to improve workers wellbeing and overall productivity. The method permits to identify bottlenecks and criticalities from a social point of view, focusing on the human performance, and define corrective actions at different levels (operations, plant layout or shift management). A case study was developed in collaboration with an Italian sole producer to validate the method and the related data acquisition system.

Peer-review under responsibility of the scientific committee of the 51st CIRP Conference on Manufacturing Systems.

Keywords: IoT; Industry 4.0; social sustainability

1. Introduction

The first part of the 21th century will be remembered as the “digital era”. The digital transformation is having a huge impact in every sector: from technologies to communication, society, economy, and industry. As far as industrial sector is concerned, it is possible to identify the fourth industrial revolution consisting in digitalization of processes. Technologies as virtual reality equipment, cloud computing, additive manufacturing are only a few of possibilities that are now available and quite mature for industrial applications, based on product and process digitalization.

This global transformation cannot neglect the main driver of development that governments have settled: sustainability. Sustainability is in fact the main driver of UN strategies for a proper development as stated by the 2030 Sustainable Agenda [1]. It is particularly effective in the context of industries, which have to deal with the resources management every day.

Also the Internet of Things (IoT) plays an important role in the present digital. The IoT market is having a huge impact on people; smartphone was the first approach between people and connected devices. Now connected phones are only the tip of the iceberg of the IoT revolution that led to cost decrease as well as social and cultural revolution. Factories are now adopting IoT technologies moving toward the paradigm of connected factories. A connected factory is a manufacturing site where not only raw materials, energy or products flows within a plant, but also data. Data represents the new “flowing thing” that can be easily related to both physical and digital items, the co-called Cyber-Physical Systems (CPS). As already stated by few entrepreneurs, data are the “new gold”; a correct data management should mean a fast track to win [2]. Furthermore, the social revolution about IoT system acceptance makes such technologies familiar to managers (which are introducing them) and workers (which will handle with them).

More and more companies are then riding this digital rush. Results are often huge amount of investments and technologies that are implemented in a manufacturing site without a proper growth strategy. Sometimes the introduction of innovations and new technologies does not directly mean a growth in terms of productivity. Moreover, there is another

2212-8271 © 2018 The Authors. Published by Elsevier B.V.
Peer-review under responsibility of the scientific committee of the 51st CIRP Conference on Manufacturing Systems.
10.1016/j.procir.2018.03.057

problem concerning with digital transformation: the request of new competencies and skills to handle with and manage digital systems [3]. In this context, indeed, the factory workers become operators 4.0. They have to interact with new manufacturing systems, the so-called Cyber-Physical Systems (CPS). Then, how it is possible to measure the performance of the new CPS and related human relapses? Which is the best way to develop a new manufacturing system, adopting 4.0 technologies that match plant sustainable requirements?

The present work is aimed at matching sustainability and IoT to improve manufacturing processes. The objective is to propose a method for the sustainable development of factories of the future.

Firstly, a clear state of the art on the concept of Industry 4.0 and sustainable manufacturing will be proposed. There will also be a specific attention on the concept of ergonomics, which is an important scientific basis for the present work. Then, a method to proper connect systems within a production site, acquire data and elaborate them for sustainable assessments is proposed. It aims to monitor workers condition, identify criticalities and define proper corrective actions (both real-time and offline). It should drive to sustainable innovations, exploiting the IoT as the enabler of social development. The case study will focus on a real plant in shoes industry, which has been sensorized in order to measure workers' performances and process inefficiencies from a social and sustainable perspective.

2. State of the Art

2.1. Industrial IoT

IoT has been recognized as one of top three technological advancements of the next decade [4]. The first and most recognized definition of IoT from a social perspective has been stated by Ashton in 1999 that defines IoT as a network that connects not only people, but also the objects around them [5]. Focusing on industrial applications, IoT has enabled the Industry 4.0 by the connection between physical and digital systems within the factory [6], according to the following design principles: interconnection, collaboration, security, and data analytics [7]. The new paradigm is changing the traditional manufacturing relationship between human and processes, proposing a new scenario were fewer operators are directly involved on the process and more people have to manage data of processes.

Another concept aside industry 4.0 is the Smart Factory, which is defined as "a pilot factory where cabling is no longer required" [8]. This definition embeds the concept of a plant where smart object interacts toward a factory-of-things. For making a factory-of things work all elements must become smart, i.e., they must offer a thin web server functionality to act as a service provider in a factory network. Besides the embedded sensors (e.g., temperature, brightness, humidity, speed, etc.), traceability, exchange and elaboration of data related to products, processes and people play a key role. Jeschke et al. [9] summed up many works arguing about the Industrial Internet of Things and the following topics emerged: CPS modeling, Communication and Networking, Artificial Intelligence and Analytics, and Evolution of Workforce and Human-Machine-Interaction. There are also industrial case studies such as the GE Brilliant Factory, which is a mix of digital technologies and lean principles, and the Scharnhausen Technology Plant FESTO that tried to collect few principles of Industry 4.0 such as human and robot collaboration, transparency in data, flexible manufacturing. Moreover, Shariatzadeh et al. [10] argued about the integration of digital model within the factory, proposing an approach to achieve interoperability of the systems within the plant.

Although a clear view of the technologies available was provided, no work argues about the mixing of the same and how to develop connected factories. The present work tends to define a structured method to design the digital factory of the future according to certain drivers.

2.2. Social sustainability in production sites

Many companies, nowadays, have shifted their point of competitiveness view on sustainability, considering it as a significant component of the operational strategies. This new philosophical asset needs to integrate environmental, economic, and social aspects of the production processes [11]. Social sustainability in production sites includes workers' rights, preventive occupational health and safety, human-centered design of work, workers' empowerment, individual and collective learning, employee participation, and work-life balance. Improving workplace practices beyond legal compliance can result in higher morale and job satisfaction. All these concepts aim to preserve or build up human capital, and they represent a conscious way to deal with human resources. In 2014, Zink [12] focuses on the needs of sustainable production system, defining that a correct design of a production system should include the human and social capital (e.g. health, motivation, participation, trustworthiness, skills, knowledge, identification). Dochery et al. [13] stated that the opportunity to develop as a person, a professional and a member of a society through work experiences is a basic human right. It is also highlighted that the sustainability of human and social resources is one of the foundations of economic sustainability. Decent work is good for society and for business.

Sustainability of human and social resources is needed to secure ecological sustainability, because only people and groups who operate sustainably are able to grasp, prioritize, and work toward ecological sustainability. Human factors are considered as well in the work of Siemieniuch et al. [14]. They stated the important role of sustainability engineering to mitigate the impact of global drivers (e.g. population demographics, food security; energy security; community security and safety). They remarked the central part of human even looking forward to the factory of the future.

2.3. Ergonomics in manufacturing system

In social sustainability, ergonomics would be one of the main aspects integrated into the health and safety requirements in manufacturing. The term ergonomics concerned with the study of work to fit with people. Workers come first, considering their capabilities and health conditions. Ergonomics can be also considered as an approach adapting tasks, work stations, tools, and equipment to fit the worker, it can help reduce physical stress on a worker's body and eliminate many potentially serious, disabling work-related musculoskeletal disorders or cognitive and mental workload. The ISO 26800:2011 [15] brings together in one document the basic principles and concepts of ergonomics. It describes the ergonomics principles to improve safety, functionality and the use of products in terms of efficacy, efficiency and personal satisfaction providing human wellbeing. The ISO standard provide the ergonomics and human centered design (HCD) requirements to understand the importance and relevance in the design process. Machinery designers have a wide list of standards and one of those is the ISO 12100:2010 [16], which specify basic terminology, principles and a methodology for achieving safety in the design of machinery. The same does the Safety Machinery Standards, which are specific to each machinery design considering ergonomics as one of the requirements to guarantee workers' safety and adequate health conditions. All those aspects are not just related to machinery, but also to the whole working environment. In fact, ergonomics can be extended to the entire organization every time human factors are involved into the design production process. Ergonomics is a multiple factor notion in which physical, cognitive, social, environmental and organizational ergonomics live together. Those mainstays suggest the integration of ergonomics in the design of a production system, which is one of the aims of this work. In this contest, the definition and implementation of participatory ergonomics programs could enhance people awareness, increases acceptance of control implementations and effectively support the adoption of the worker-centered approach.

3. How to design an IoT framework for manufacturing plants

From literature, it emerged that intelligent manufacturing and cloud manufacturing are still in the research or proof-of-concept stage, and have a limited number of real-life cases [17], which rarely focus on monitoring operators' daily tasks in order to improve their working conditions and wellbeing. There are needs for novel approaches to support the design and assessment of work design, which is the aim of this work.

This section describes the methodology to design a proper IoT infrastructure aimed at acquiring human-related parameters from the plant, to be implemented into a manufacturing line where workers and system interact each other. Such an infrastructure collects data from different entities (Figure 1) and communicates with a central server that embeds the intelligence to manage them to create significant information that permits a designer or an analyst to elaborate decision in a more fast and precise manner. Another problem that it aims to face is the availability of Big Data without a proper strategy to manage them. From a social viewpoint, the management of the human-related data about what is really occurring in a plant can make understand the workers' wellbeing and to improve it in order to increase the overall productivity.

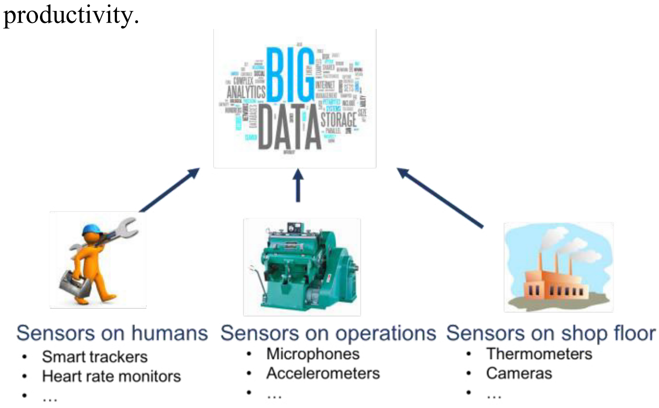

Figure 1. Approach idea

The main steps to configure the IoT framework can be described as follows:

1. <u>Definition of the framework aims</u>

In each environment, there is a bunch of data that should be measured. Thinking on a simple empty office there are many environment variables: temperature, humidity, luminance, area, height, etc. All of these belong to a different topic. Moreover, if it is considered a standard condition, the office should be populated by workers and variable increases: number of workers, vital signs, etc. This means that each IoT configuration needs a driver for a proper design. Indeed, implementing a complete network in a single stage could be very expensive and time consuming, and no economical returns should be obtained. The first step consists in defining the aim of the framework has to be developed that should be multiple then multiple variables should be interpolated in order to create an organized data network.

2. <u>Identification of the system / environment variables</u>

A connected factory can provide a lot of data related to machines, CPS, products, environment, and humans; the added value is to understand which are significative according to the goal of the analysis. For example, considering the machines it is possible to monitor energy consumption, productivity, speed, pressure, lube state, vibrations, etc. but only the last one could be taken into account if a social assessment is carried out. Therefore, according to the framework aims, in the second step the variables of the system are identified. Table 1 shows an extract of different drivers with related variables and proper measurement tool.

3. <u>Identification of sensors available on the market</u>

On the third step a benchmark from the market is performed. The designer, supported by a sensors expert, identifies all the sensors on the market that allow monitoring the variables identified. It is important to understand the acquiring protocols and report opportunity of tools. With a quick view on actual factories and processes it is not uncommon to see advanced manufacturing systems that are able to acquire data on consumptions but only for a real-time view without the opportunity to store them for future analysis.

This is the case that has to be avoided following this procedure.

4. <u>Selection of the most proper sensors minimizing the equipment</u>

This step consists in minimizing the costs and the equipment. Simpler is the network, simpler will be data interpretation. To simplify here do not means to have less information, but avoiding infobesity. In a lifecycle perspective, more sensors mean more maintenance, more updates, and more IoT variables. The best choice is to identify interoperable sensors that permit to acquire different data with an acceptable accuracy.

5. <u>Creation of the framework</u>

In this step the framework is assembled in the environment. It permits to realize an intelligent ecosystem where data generates corrective actions that should be executed manually or automatically.

6. <u>Conveyance of all data in a single device</u>

The creation of the framework (step 5) is strictly correlated to step 6. In fact, it is necessary to convey data in a single device (e.g. database manager) in order to properly collect, manage and elaborate them for the analysis.

7. <u>Set the rules to improve the environment</u>

The definition of rules permits to exploit data collected by the sensor to improve the system with proper actions. Here is the difference between a sensorized environment and an intelligent environment. In a sensorized environment, looking to the previously mentioned office, the temperature sensor acquires temperature data and shows a countable number (e.g. 18°C). Human when feeling cold, check the number and increase the temperature since it feels good. In an intelligent environment, there is a sensor in the environment and the human too. If the temperature is under a certain threshold, the thermostat automatically increases.

8. <u>Installation of actuators in the system</u>

The installation of proper actuators enables the automatically execution of corrective actions according to the rules defined in the previous step.

Such a methodology should be conducted by a precise actor, a new professional figure in the context of the future factory: the IoT Engineer. This figure should be an expert of both sensors and processes. Each process has in fact a proper set of sensors that permits to monitor it. Similar issues are argued also in the work by Peruzzini et. al [18] where IoT is tested as an enabler of Industry 4.0.

Table 1 –Matching between drivers, variables and sensors

Driver	Variables	Sensors
Productivity	Type of operation	Video Camera / PLC info
	Productivity [pieces/hour]	EMS/ERP
…	…	…
Thermal Comfort	Temperature [°C]	Thermometer
	Humidity [%]	Humidity Sensor
	Pollution [CO2 ppm]	Pollution Sensor

4. Case study

In order to understand the effectiveness of the methodology a case study was performed. This was developed in an Italian large company, Eurosuole, who produces soles. This company is settled in the middle of Marche Region where many companies related to shoes supply chain have growth. Eurosuole is one of the worldwide top player for rubber soles and polyurethane soles. These are in fact the main departments of the company.

4.1. Goal

The scope of the case study is to define the social relapses of the as-is process understating the opportunity of a redesign of the same. The assessment has to focus particularly on the packaging operation. This choice has been driven by the innovation plan of the company. This is in fact a completely manual operation that could be boosted by innovation.

4.2. IoT infrastructure design

In this case, the IoT infrastructure will include a network connectivity, hardware to collect data and connected sensors. Going in deep with the network a research of technologies was performed in order to develop the best IoT framework on the basis of the analysis scope. According to the social variables, the framework will be composed by: video camera, heart rate sensor, cognitive stress sensor, posture sensor, temperature sensor, humidity sensor, pollution sensor, tripod, wi-fi router, and cables for A/C connectivity. After the market research, the framework has been simplified by:

- 1 Camera, which permits a visual control of the operations to identify all the single working tasks of the operator, control the system real-time and, after the test, interpret and align data to the operations. It is important to understand what a signal means in terms of operations. Without the vision data, there is a lack of information;
- 1 pair of smart glasses for mental load recognition. After a deep research on the market the JINS MEME Smart glass were chosen. The academic version was acquired in order to manage raw data specifically. They have 3-point electrooculography sensor that permits to capture eyes movements, as an indicator of the mental workload [19]. This choice has been driven by the need of a tool that does not affect the everyday work of the operator;
- 1 smart Heart sensor that allows monitoring heart rate, breathing rate, posture and activity. The device accuracy and versatility were the main purchase drivers;
- 1 smart pollution detector, which embeds multiple sensors measuring temperature, humidity, fine particles, total VOC and carbon dioxide;
- 1 step monitor that provides different modes of wearing to be less intrusive;
- LTE router;
- PC for data storage;

- Tablet for real time monitoring.

The adopted approach has allowed the attainment of the objectives through a participatory ergonomics action. The management commitment and the workers' involvement in the choice of the improvement strategies of the workplace and the working conditions leading to the awareness of the importance of the analysis. The acceptance of the wearable devices was promoted thanks to the workers who understood the benefit and no risk of monitoring activity. The workers' participation at the study was voluntary.

4.3. Factory social assessment

In first place all the tasks have been identified performed by the worker. Figure 2 shows the assessed area. The workstation consists in the conveyor belt where soles flow and the operator tasks to pack them.

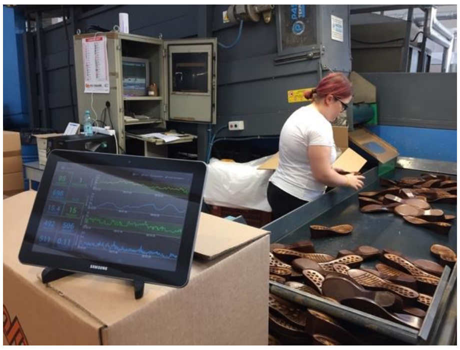

Figure 2. Operator in action and real-time monitoring

Eleven tasks have been identified: box preparation; label printing; box classification by label; soles picking; defects identification; soles packing with related equipment; soles count; box closing; box transport; boxes count, and work report. When the empty box is ready on its stand, the operator (OPL_1) proceeds to the PC device to print box label (Figure 2). Here the operator prints each box correct label, with the sole model and the size, according to the production scheduling. OPL_1 is the only that interacts with this PC in the packaging area. Then OPL_1 starts the product picking and packing. The products flow on the conveyor belt and the operator must select the correct size and pairs according to the label information, check painting quality, fill the box.

In fact, some problems related to the painting could occur. Soles flow on the conveyor belt after an automatic painting and drying system. Visual control of the operator is the final check of the quality of that process before the packaging. Each box has to be completely filled before the closure. Soles have to be packed in layers divided by separating foil. There is a stack of sheets that the operator has to separate then put in the boxes in order to ensure that the soles do not ruin during transport to the customer. During the packaging, operator has to count the soles before closing the box. When count is finished, box has to be transferred manually to a boxes stack were a forklift would act when the job related to a certain product is complete. Finally, the operator updates the work paper. When the complete task list is performed it starts again the working procedure cycle from point 1 to 11 of the tasks list. The shift was monitored for 5 hours.

4.4. Results

From the social assessment, two main criticalities of the packaging operation emerged:

- A critical task related to the foil separation due high workload;
- Critical box placement due a low back posture non-compliant load bay.

According to the mental load analysis the foil separation sub-task is one of the most impacting on the operators. Graphs of mental load during the foil separation are reported in Figure 3. The operator has a big concentrated peak (sec 2409-2410). This operation has a similar impact during the whole working time. It is mental impacting because the small thickness of foils.

Figure 3. OPL_1 Foil separation EOG report

Figure 4. OPL_1 separating foils

Table 2 sums up the posture analysis. After data cleaning, 20202 measurements were considered valid. Data cleaning involved all the data acquired during the band installation. In relation with ISO 11226:2000 [20] three different ranges were identified. Each range concerns the inclination degree of the low back posture. In general, during the operations the low back posture is correct for OPL_1; 94,88% of measurements verified the safe conditions (low back inclination is no more than 20° with respect to vertical axis). The unsafe conditions (0,06%) are only a few but it has to be noted that are mainly registered during the box placement on the lower pallet level (Figure 5).

Another relapse of the workplace monitoring, from the social sustainability point of view, is the indirect empowerment of workers. During the testing phase some workers, even not directly interested by the analysis, understood the purpose of the study to improve the working environment, thus when the air-quality sensor indicated a red illumination of bad air, their proactive response was the opening of the main door to change the airflow.

Table 2 – Operator posture analysis (morning shift)

LOW BACK POSTURE (ISO 11226:2000) Total valid measurements: 20202		
X<20°	20°<X<60°	x >°60
19168	1021	13
94,88%	5,05%	0,06%

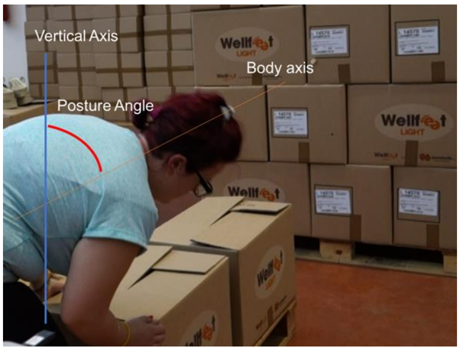

Figure 5. OPL_1 box placement on 1st pallet level

5. Conclusions and future work

This paper presented a method to define an IoT framework to monitor workers on a manufacturing plant from a social point of view. The assessment permits to understand bottlenecks and criticalities that should be improved by new technologies, better organizational choices, or better process management. The improvement of the manufacturing system from the social point of view have positive relapses on both the operators' health and company productivity. Controlling working conditions through a proper sensorized system enhance operational safety, prevent occupational diseases and disturbs, avoiding absenteeism, turnover, and workers performance reduction. It also improves workplaces reaching a win-win situation for both operators and company. Workers involvement also created a successful workplace where wellbeing has been promoted thanks to the new cultural safety support provided by people awareness.Without the IoT framework, where few data had linked each other, the same assessment was not possible.

The effectiveness of the proposed method has been validated through an industrial case study, developed in collaboration with an Italian sole producer. The proposed approach led the company to adopt proper technologies with structured innovation plan, supporting its transition toward the sustainable factory of the future. The method also supported the company in the correct data acquisition and management, increasing its awareness and enabling faster and more effective improvement actions implementation. The study demonstrated that IoT environments should be an opportunity to improve process sustainability by implementing automatic actions toward a thinking factory.

Thanks to the positive results of this research, further studies will focus on defining a set of guidelines and KPIs to support the definition of new standard that better define the role of human in the Industry 4.0 context. Moreover, the same approach will be extend to other IoT frameworks related to different working environments (e.g. office) or sustainability drivers (e.g. resource efficiency and energy monitoring).

References

[1] United Nations. Transforming our World: The 2030 Agenda for Sustainable Development, 2015.
[2] Mamonova S, Triantoro TM. The strategic value of data resources in emergent industries. International Journal of Information Management, 2018; 39: 146–155.
[3] The Boston Consulting Group. Industry 4.0 The Future of Productivity and Growth in Manufacturing Industries, 2015.
[4] McKinsey Global Institute. Disruptive technologies: Advances that will transform life, business, and the global economy, 2013.
[5] Ashton K. That "Internet of Things" Thing: In the Real World Things Matter More than Ideas. RFID Journal, 2009.
[6] Kagermann H, Lukas W, Wahlster W. Industrie 4.0 - Mit dem Internet der Dinge auf dem Weg zur 4. industriellen Revolution. In: VDI Nachrichten, Issue 13, 2011.
[7] Hermann. M, Pentek. T, Otto. B. Design Principles for Industry 4.0 Scenarios: A Literature Review; 2016.
[8] Zuehlke D. SmartFactory-Towards a factory-of-things. Annu. Rev. Control, 2010; 34: 129–138.
[9] Jeschke S, Brecher C, Meisen T, Özdemir D., Eschert T. Industrial Internet of Things and Cyber Manufacturing Systems. In: Jeschke S., Brecher C, Song H, Rawat D (eds) Industrial Internet of Things. Springer Series in Wireless Technology. Springer, Cham, 2017.
[10] Shariatzadeh N, Lundholm T, Lindberg, Sivard G. Integration of digital factory with smart factory based on Internet of Things. Procedia CIRP, 2016; 50: 512–517.
[11] Jasiulewicz-Kaczmarek M, The role of ergonomics in implementation of the social aspect of sustainability, illustrated with the example of maintenance. Occupational Safety and Hygiene Arezes et al. Ed. Taylor and Francis Group, London, 2013. pp 47-52
[12] Zink K. J., "Designing sustainable work systems: The need for a system approach," *Appl. Ergon.*, vol. 45, no. 1, pp. 126–132, 2014.
[13] Docherty, P., Kira, M., Shani, A.B., What the world needs now is sustainable work systems. In: Docherty, P., Kira, M., Shani, A.B. (Eds.), Creating Sustainable Work Systems, second ed. Routledge, London and New York, 2009.
[14] Siemieniuch C. E., Sinclair M. A., and Henshaw M. J. C., "Global drivers, sustainable manufacturing and systems ergonomics," *Appl. Ergon.*, vol. 51,104–119, 2015.
[15] ISO 26800:2011 - ISO 26000:2010 – Guidance on social responsibility - International Organization for Standardization, Geneva
[16] ISO 12100:2010 - - Safety of machinery — General principles for design — Risk assessment and risk reduction - International Organization for Standardization, Geneva
[17] Zhong, R.Y., Xu, X., Klotz, E., Newman, S.T., Intelligent Manufacturing in the Context of Industry 4.0: A Review, Engineering, vol. 3, 2017, pp. 616–630.
[18] Peruzzini, M., Grandi, F., Pellicciari, M. (2017). Benchmarking of tools for User eXperience analysis in Industry 4.0, Procedia Manufacturing, Vol. 11, pp. 806-813, DOI 10.1016/j.promfg.2017.07.182.
[19] T. Ogawa, M. Takahashi, and R. Kawashima, "Human Cognitive Control Mode Estimation Using JINS MEME," *IFAC-PapersOnLine*, vol. 49, no. 19, pp. 331–336, 2016.
[20] ISO 11226:2000 Ergonomics -- Evaluation of static working postures