Article

Retrospective review of the group research (2015-2024). From the *Miniterms* to the *I3oT (Industrializable Industrial Internet of Things)*

Eduardo García [1], Nicolás Montés [2], Antonio Lacasa [1], Javier Llopis [1], Hilario Teruel [1], Manolo Segrelles [1], Jorge Correcher [1], Iván Peinado-Asensi [2], Daniel Ibáñez [1,3], Jesús Soret [3], Julio Martos [3], Lucía Hilario [2], Nuria Rosillo [2], Antonio Falcó [2], Judith Vizcaino [1]

[1] Ford Spain, Poligono industrial Ford S/N, 46440 Valencia, Almussafes, Spain;
[2] Department of Mathematics, Physics and Technological Sciences, University CEU Cardenal Herrera, C/ San Bartolome 55, ,46115, Valencia, Alfara del Patriarca, Spain
[3] Department of Electronic Engineering, Campus de Burjassot, Universidad de Valencia, 46100 Valencia, Spain

Abstract: This document aims to make a retrospective of our work in the Ford research group in collaboration with researchers from the CEU Cardenal Herrera University and the University of Valencia. The research group originated from the doctoral thesis by Eduardo García Magraner and his thesis was directed by Nicolás Montés in 2016. The *Mini-terms* were formulated for the first time in this thesis. From then on, the research group grew as the *mini-terms* began to consolidate both industrially and scientifically. At industrial level we were provided with a CDTI (Centre for the Development of Industrial Technology) which made it possible to massify the mini-terms at Ford factory in Valencia and at scientific level we attended different congresses. Especially relevant was ICINCO 2018 since the concept of the *mini-terms* could be presented to the programme chair of the congress, Oleg Gusikhin, (Global Data Insight & Analytics, Ford Motor Company, United States). His support led to the consolidation of the *mini-terms* through their standardization within Ford and also the consolidation of the group through the inclusion of the CEU Cardenal Herrera University in the *URP (University Research Program)*. The success of Eduardo García's doctoral thesis motivated the Foundation for Development and Innovation (FDI) to decide to fund doctoral theses within Ford, financing a thesis in collaboration with the University of Valencia and another one with the CEU Cardenal Herrera University. Moreover, Eduardo García's thesis motivated the staff of the plant to take the step to carry out doctoral theses, funded by the INNODOCTO programme of the Generalitat Valenciana.
Throughout this journey different awards have been won such as the *Henry Ford Technology Awards in 2019*, the *Factories of the Future Awards in 2021*, the *Global Manufacturing Technical Excellence Award in 2023* and the *Angel Herrera Award for the best research work in 2024*.
Twenty-four communications have been made to congresses, ICINCO being the congress with the highest number of communications. In particular, at ICINCO 2020, one of these articles was selected as the *Best Industrial Paper Award*. Thirteen articles have been published in indexed journals with an impact index and also three book chapters.
This document aims at reviewing the different tools and concepts developed and introduced by the research group as well as trying to define its objective.

Keywords: I3oT, Miniterm, Microterm Miniterm 4.0, C360, Manufacturing Maps, Cross PLC, Sub-Bottlenecks, Mini-Sym 4.0, Scan Time, Intelligence Sequencer, Digital Twin, Industry 4.0

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1. Factory conditions in the fourth industrial revolution. Welcome to *"the Jungle"*

The governance of factories in the automotive sector is extremely complex. These factories use thousands of robots, grippers, cylinders, conveyor belts, etc., each element with its components, electric motors, gears, chains and each element applied to different processes, such as welding, stamping, painting, etc. In addition, all this machinery interacts with the operators involved in different phases of the process who work assembling the components, verifying the quality of the parts, etc., and, in some cases they must modify machine parameters to guarantee the productivity and quality of the parts. The goal of automation is none other than to try to eliminate dependence on human factor. However, some machines are not able to adapt to all plant situations, which calls into question whether a complete automation of a factory without the human presence would be the most efficient approach, see for example, [1], [2]. Thus, the fact that operators can modify certain parameters of the machines responds to a reality in the manufacturing processes known as variability which may come from different sources, such as;

- *Two identical machines may actually behave differently*: Many times machine or component manufacturers may provide curves to choose certain machine parameters that have been calculated under homogeneous laboratory conditions and as an average of tests with different components. In real situations two identical machines or components may not be subjected to the same working conditions and in critical processes this situation may not be extrapolable.
- *Lack of in-depth knowledge of the process*: There are processes such as the stamping in which there is no in-depth knowledge of how all the parameters may affect the process. This means that, although manufacturers provide curves and parameters to be adjusted, these features are only indicative and will eventually need human intervention, the operators' intuitive skills and learning based on experience, so they can finish fine-tuning those types of parameters in order to achieve the right quality.
- *Technologies from different generations co-existing in the same factory and machine:* When a company buys an asset, whether it is a machine, robot or press, the company will try to make it profitable over the years. When the machine breaks down and the broken component is replaced the new part is usually more updated which means that the machine will not behave the same.

At Ford factory in Valencia, where thousands of vehicles are manufactured daily, dozens of maintenance technicians and managers are trying to generate production as continuously as possible. The team in charge of maintenance and repair of faults is usually subjected to very high stress. Many of the maintenance operators try to anticipate machine failures but it is a utopian task since the failure can happen in any component and the warnings generated by the machines are usually insignificant. Any delay or quality failure that generates rework or scrap can result in large losses since it will directly increase the cost of manufacturing the product. This generates a very high level of pressure on both managers and other plant personnel since poor management can generate large economic losses. When something goes wrong we have to find the cause but sometimes the solution is not clear and then human intervention is needed with its intuitive skills and experience-based learning to unlock the problem. However, this pressure also prevents operators from optimising certain parameters of the lines because they prefer not to take the risk in case there are consequences. We can find a clear example of this problem when choosing the speed of industrial robots. These are always placed by default at 100% of their maximum speed and although the operators may detect that there is an idle time of the robots they prefer not to modify it.

1.1. Industry 4.0 and its technologies. Industrial issues

With the emergence of Industry 4.0 and its technologies, IIoT (Industrial Internet of Things), Big Data, Digital and Hybrid Twins, etc., a significant improvement in factory governance is expected in which data will become a lens through which Industry 4.0 can be understood [3]. When the industry or the responsible managers have to decide whether to install IIoT applications in their company on a massive level they are usually discouraged by several factors, these are:

- *Energy efficiency*, since most IIoT devices are powered by batteries, [4], [**?**], [6].

- *Interoperability*, since connecting so many devices is a serious challenge for the IIoT, [5].
- *Safety*, as information and privacy are vital at corporate level, [5], [**?**], [4], [6].
- *Scalability*, since the massification of IIoT solutions consists of a huge number of devices connected to each other in hierarchical subdomains, [5].
- *Maintenance and updates*, since system operators will not only have to manage the original system, but also manage all new systems and therefore, engineers will have to be trained for this, [5], [7].
- *IT/OT integration*: IIoT systems require the convergence of OT and IT for the integration of data from both parties, [7].
- *Cultural change*: Many of the industries resist change because they are afraid and do not understand the technology associated with IIoT, [7].

The transition from the current configuration of the installation of an industrial production governed by traditional ICS (Industrial Control Systems) to a configuration of Industry 4.0 requires a progressive transformation. It involves an adaptation of the devices and architectures used in ICS to adapt to the new paradigm in order to achieve both vertical and horizontal integration of devices at all levels, [8]. However, the updating of the existing elements in the factories is usually slow. In the automotive sector factories we can find thousands of robots, grippers, welding clamps, conveyors, elevators, clamps and a long etcetera, forming manufacturing lines, each sensed and governed mostly by PLCs. Companies have, as one of their objectives, to make their assets profitable and for this reason the technologies of the last 20/30 years coexist within large factories because the companies only update obsolete elements when they stop working or there is an urgent need to do so. This mixture of technologies and brands, together with the consequent unpredictability of breakdowns and line stoppages, the loss of production and the need to guarantee the daily production ratio is what makes today's factories known as *"the jungle"*.

2. Objetive of the research group

In modern factories, real-time control systems improve responsiveness, efficiency, quality of the final product, etc. This concept has been generalized to what is now known as "Industry 4.0". These systems include the internet of things, cloud computing, big data, etc., all focused on industrial parameters. However, the industry faces a great challenge, which is none other than the cost of generalizing the techniques established in the literature. In order to create a Big Data of machine parameters, we would need to sensor all the machines, since, for example, the failure of one of them (or a simple component) would cause a line stop. The only solution available today in the literature and also in the industry regarding the prediction of breakdowns is through the use of sensors for vibration, sound, temperature, flow, pressure, etc. The generalization of these techniques would involve an investment in hardware of millions and millions of euros for companies with large factories such as the automotive sector. This means that companies have not been able to move towards proper maintenance in industry 4.0. and instead they have opted to sensorize critical machines and/or have a group of operators who, equipped with this type of sensors (in portable version), need to carry out periodic inspections of each particular machine.

Thus, industry and science face a great challenge which is none other than discovering how to develop tools for Industry 4.0 that allow in an easy, cheap, massive way and in real-time to optimize manufacturing processes, maintenance, quality, etc.

There is a large gap between the problem requirements of real configurations and the progress of research developed by universities. Many times ideas are proposed and experiments are developed in the universities themselves that become unfeasible when the technology transfer needs to be carried out in companies. ***This research group was born with the aim of trying to eliminate the distance between the university and the companies, developing tools that generate viable solutions for the industry while advancing scientific knowledge.*** This document aims to be a review of the tools developed at Ford factory in Valencia and which, in addition to generating an industrial impact, have also had a scientific impact through publications in prestigious congresses and/or indexed journals.

3. *I3oT (Industrializable Industrial Internet of Things)*

With the aim of generating IIoT solutions that are able to adapt to the reality of the factories and the needs of the IIoT tools previously exposed, in Ivan Peinado-Asensi's doctoral thesis, see [9], directed by Nicolás Montés and Eduardo García, and presented in 2024, photograph A4, a new concept is proposed, the *I3oT (Industrializable Industrial Internet of Things)*. The idea of this new concept is the use of the installations available in the factories to develop IIoT applications from them. The machines installed in the industry operate automatically and have sensors that provide the information received by the PLC to control the lines. The factories have an IT/OT network from which the machines communicate and the factory is managed. Under this paradigm, *I3oT* applications would be easily extrapolated and scalable to other systems at a very low cost, allowing the definitive establishment of Industry 4.0 and its technologies in the industry, see [10].

3.1. Miniterms

One of the first (I3oT) applications developed were the so-called Mini-terms. These were developed in the doctoral thesis by Eduardo Andrés García Magraner, see picture A1, directed by Nicolás Montés, see [12]. These mini-terms are based on programming a timer in the PLC or PC-Line so that through the sensors installed for the normal operation of the line we can measure the time it takes for the line elements to perform their task. This data is sent through the OT and IT networks for analysis and processing. Deterioration over time is an indicator that the component is near the end of its useful life and may produce a line stoppage. The great advantage of using the *mini-terms* is that there is no need to install new sensors and their industrialization is immediate. Currently, at Ford factory in Almussafes (Valencia) there are more than 46,000 elements or components under surveillance with this technology which can detect anomalies in pneumatic and electrical welding clamps, screwdrivers, clamps, elevators, etc. Therefore, the use of mini-terms to anticipate machine failure is generating important benefits at industrial level such as the increase in TAV (Technical Availability), >6%, see [40].

The massive implementation of *mini-terms* in the factory was carried out thanks to the fact that we were granted a project funded by the CDTI in 2019, see [25], for the development of industrial Big Data based on mini-terms, known as *Miniterm 4.0*, this work was finished in 2021. Today, this project has not only been implemented in the Valencian factory but it is also being expanded to the rest of the factories.

Due to the great interest shown by Ford Motor Company the CEU Cardenal Herrera University was also included in March 2019 in the URP (University Research Program) based at Ford headquarters in Deaborn for research collaboration with universities, see [21], being the first Spanish university that has achieved it. Oleg Gusikhin (Global Data Insight & Analytics, Ford Motor Company, United States) presented the diploma of election at an event held at Palacio de Colomina (Valencia), see photo A2, where attended a large number of the research team members of the CEU University and the Ford Factory of Valencia, see A3.

The project *Miniterm 4.0* received the *Henry Ford Technology Award 2019* granted by Ford Motor Company to the best technological innovation in the *"Manufacturing"* category. The award was presented at an event held at the Henry Ford Museum in Dearborn (Michigan), by the president and CEO of Ford Motor Company, *Jim Hackett*, and the director of the *Henry Ford Technology Awards*, Ken Washington, see A6. In A7 you can see the work team celebrating the achievement of the award.

In 2020, the *Advanced Factories*, an international congress on innovation, automation and industry 4.0, dedicated to the applications of artificial intelligence in the field of industrial production, included the project *Miniterm 4.0* as one of the three finalists within the prize *Factories of the Future Awards*, see photo A8.

The project *Miniterm 4.0* has generated a multitude of scientific publications, see [11], [13], [15], [16], [18], [19], [20], [22], [24], [40]. In particular, the article by [40] was published in the scientific journal *sensors* (SJR Q1 (6.8) Instrumentation, JCR Q2 (3.9): Instruments and Instrumentation). Recently, the concept of mini-term has been published in the official magazine of the Spanish Maintenance Association (AEM), see [55].

The publication of the project in the scientific journal *sensors* together with the industrial and media impact of *Miniterms 4.0* led to the Ángel Herrera Award for the best research work in the Area of Engineering and Architecture of CEU Universities in Spain, see photo A9.

Ford has recently been granted a patent, see [54], to protect potential applications of mini-terms in vehicle maintenance.

3.2. Criterion C-360

In Ivan Peinado-Asensi's doctoral thesis, see [9], directed by Nicolás Montés and Eduardo García and presented in 2024, photograph A4, the use of the concept *I3oT* was proposed for the stamping process through what was called the *Criterion C-360*. With this criterion, 360 values per cycle are generated from the variables or sensors available in the stamping process. There are 360 values per cycle using this criterion while in the *mini-terms* there is one value per cycle which allows us to evaluate the possibilities of the *I3oT* philosophy when applied to other industrial processes. The applications that this (*I3oT*) system can have in the stamping process, and in particular, of the criterion C-360, are yet to be discovered. In Ivan Peinado-Asensi's doctoral thesis, [9], *I3oT* applications have been developed for predictive maintenance based on tonnage sensors, which are other tools used for energy saving and finally, the feasibility of developing a digital twin for the stamping process is also explored through the *I3oT* philosophy. The following sub-sections show more information about these applications. The *Criterion C-360* has been published in different prestigious congresses such as the *International ESAFORM Conference on Material Forming*, see [34] and the most important congress of specific stamping, the 42^{nd} *Conference of the International Deep Drawing Research Group*, [48].

3.2.1. Predictive maintenance on presses. Gravity Centre (GC)

One of the ways to monitor the health of the press is checking that the effort made by the press in carried out in the most balanced way. In the tool developed in Ivan Peinado-Asensi's doctoral thesis, [9], the tonnage variables are used to calculate the Gravity Centre of the moving parts of the press which are the slide and the die that move through the press gibs located in the 4 columns of the press. The system calculates the 360 values of the gravity centre for each stroke and when the centre goes out of the set limits an alarm is generated to alert the maintenance operators that something anomalous is happening. This system is installed in production in order to anticipate failures of the press. This application has generated several scientific publications, see [29], [50], [46]. In particular, the work by [40] was published in the scientific journal *sensors* (SJR Q1 (6.8) Instrumentation, JCR Q2 (3.9): Instruments and Instrumentation).

Recently, in [46] the author analyses TDA (Topological Data Analysis) techniques for fault prediction using the signals measured by the *Criterion C-360*, in particular persistence diagrams.

In 2021, the *Advanced Factories*, the international congress on innovation, automation and industry 4.0, awarded this application with the prize *"Factories of the Future Awards 2021"*, in the category of *"Leadership in the digital transformation of the industrial plant*, see A10, A11.

This project was also awarded in 2023 with the *Global Manufacturing Technical Excellence Award (GMTEA)*, see photo A12.

In [46] the author analyses TDA (Topological Data Analysis) techniques for fault prediction, in particular persistence diagrams.

3.2.2. Energy saving in the stamping process

In Ivan Peinado-Asensi's doctoral thesis, [9], a framework for reducing energy consumption in stamping presses is presented based on the (*I3oT*) methodology. It is proposed to optimize the accessible parameters from the *Criterion C-360* for the energy saving of the stamping process. The three parameters that can be modified and affect energy consumption are the press speed, the tonnage (which can be modified by adjusting the height of the press slide) and the compensation pressure. The first two ones can affect the quality of the product if their adjustments are not adequate but the third variable only intervenes in the process as an auxiliary element of the press providing equitable consumption throughout the cycle. In [9] an algorithm is developed to optimize the compensation pressure value and implemented in the PLC to obtain the value. The results of this algorithm have been published in [36], [52]. In particular, the article [52] was recently published in the scientific journal *Heliyon* (JCR Q1 (4): Multidisciplinary). The tests developed show that, with the correction of the compensation pressure, an average of 7.18% has been saved in energy consumption. Excess effort was also detected in the tonnage with the gravity centre monitoring tool and its correction generated a saving of 13.7%.

3.2.3. Digital Twin

Other application for the system (*I3oT*) using the *Criterion C-360* can be seen the development of a digital twin of the stamping process, this use is explored in *chapter 6* of Ivan Peinado-Asensi's doctoral thesis, see [9]. The digital twin intends to use the full potential of numerical simulation fed by real data using the *Criterion C-360*. Numerical simulation in the stamping process is mainly used in the press design process to define both mould geometry and process parameters. As evidenced in [30], most of the sensors available in the press have their raison d 'être for the adjustment of the parameters obtained from the simulation in the process of installing a new part or its readjustment during the process, therefore, the connection with a simulation model is direct since most of the parameters necessary for the simulation can be obtained from the *Criterion C-360*. Exploring how to develop a digital twin for the stamping process has generated different scientific publications, see [30], [35], [53]. In particular, the article by [53] was recently published in the scientific journal *International Journal of Material Forming* (JCR Q2 (2.4): Metallurgy & Metallurgical Engineering).

3.3. Modelling and simulation of manufacturing lines

In Eduardo Andrés García Magraner's PhD thesis, see [12], the manufacturing line simulation techniques based on mini-terms were presented for the first time with the intention of being able to more accurately measure the JPH that a manufacturing line is capable of producing with the current state of its components. The simulation technique used a machine with the status for each of the line stations, blocking, waiting and working statuses, in which the time that the station was working was obtained from the Gaussian distribution of the mini-terms measured directly from the line. This simulation concept was expanded and published in the 17^{th} *International Conference on Informatics in Control, Automation and Robotics 2020*, see [23]. This article was selected as the *Best Paper Industrial Award* of the congress, see photo A13. This type of simulation was published in [37] and named *Mini-Sym 4.0*.

3.3.1. *Manufacturing Maps*

In [31] the author proposes the use of Petri nets together with *mini-terms* for the modelling of manufacturing lines. A Petri net is a mathematical or graphical representation of a system for discrete events and was defined in the 1960s by *Carl Adam Petri*. At industrial level Petri nets have a great application in the modelling of industrial processes. One of the great applications emerged in 1977 with the creation of GRAFCET *(Graphe Fonctionnel de Commande Etape Transition)*. GRAFCET is a graphical representation model of the successive behaviours of a logical system predefined by its inputs and outputs and is the basis of the programming of the PLCs. In [38] a step is taken further and Petri nets are used to model the factory by layers in order to build a factory model through the *Manufacturing Maps*. These maps are intended to be the Google Maps of a factory. On the top level we would have the *commodity view*, a complete view of the factory whose level would be more focused on senior managers and then, we would go down layer by layer passing through the *line view* and *station view* until reaching the machine level where we would have directly the *mini-terms*. The *manufacturing maps* have two fundamental components, Big Data based on *mini-terms* and Petri Nets. Big data provides the sub-cycle time data of the components and Petri nets provide the complete modelling of the factory that allows to reconstruct the information based on *mini-terms* at any level, see [38].

3.4. Cross-PLC

The objective of the design of the *I3oT* cross platform, *Cross PLC*, is the development of an application that facilitates communication with the Programmable Logic Controllers (PLCs) that allows information to be extracted from them with the least possible impact on the systems installed in the factory. To do this, the tool has been designed with the following characteristics:

1. *Passive communication*: The receiver initiates communication when it is ready to send data, and the sender simply listens and responds to requests. For example, in a sensor system in a production plant the sensors would only send data when they detect a significant change in plant conditions.
2. *Actuator model*: In this model, actuators are independent computational entities that can run concurrently and asynchronously. Each actuator has its own internal state and can communicate with other actuators by sending them messages. This ability to communicate between actuators is essential to build distributed systems in which multiple components must interact with each other efficiently and scalably.
3. *Native communications*: Cross PLCs focus on efficient and versatile communication with PLCs taking advantage of the native communications of the different PLCs available on the market: Rockwell, Siemens, OMRON, ABB, Schneider, Allan Bradley, etc., using specific protocols of each of them to maximize compatibility and efficiency in communication. The actuator model allows the Cross PLC application to be developed according to the communication needs and the different brands existing in the factory.

The Cross PLC is a tool that is currently in charge of extracting information from the manufacturing lines at the plant in Valencia for the vast majority of applications set out in this document, see [56].

3.5. Sub-Bottlenecks

In [38] it is proposed to merge the *mini-terms* with the modelling of the production lines by using Petri nets and developing what has been called *manufacturing maps*. The use of the *manufacturing maps* together with the techniques proposed in the literature for the detection of bottlenecks through Petri Nets could make the bottleneck be dynamic taking into account all the variability of the process since *manufacturing maps* are based on real-time measurements of the *mini-term*. In [28], [57] the author proposes to go a step further and use the possibility of arranging the information at *mini-term* level in order to define, for the first time, the concept of *"Sub-Bottleneck"* using *mini-terms*. In [57] the PROMETHEE algorithm is used to make suggestions for online actions based on the *"sub-bottlenecks"* detected and the cost/benefit ratio of each action.

3.5.1. Energy savings on production lines

As mentioned in the introduction, the pressure to which the operators are subjected limits them from optimising certain parameters of the lines because they prefer not to take a risk in case of consequences. We can find a clear example of this problem when choosing the speed of industrial robots. In large factories such as Ford Valencia there are thousands of robot arms that are usually placed by default at 100% of their maximum speed which may generate unnecessary energy consumption. In [14], [17] the author seeks to develop an algorithm to reduce the speed of the robot arms automatically in order to generate that energy saving. The level of energy savings depends on several factors but the most influential one is line imbalance because is usually common in the lines that produce different models and their variants. In [17] the simulation of the manufacturing lines presented in [23] was used to estimate energy savings managing to reduce consumption by 57%. Also in [17] a simulation was carried out in a real mono-model line achieving a saving of 11%.

3.6. Scan Time

One of the problems detected with the use of the *mini-terms* is that, as a mini-term is a sub-cycle time, it can become a short time value that may be close to the PLC's Scan time. This means that, when the time value is close enough, the data of the *mini-terms* may become discretized due to the value of the *scan time*. This may lead to false positives in fault detection through the *mini-terms*. In [33] the Gaussian mixture model is used to reconstruct the data and avoid these false positives. However the discretization value measured from the *mini-term* is not only the value of the *scan time* of the PLC but it also includes all the delays of the other communication and transmission systems that interact with the PLC. Therefore, in [58] this measurement is used as a virtual sensor to measure the delays that these systems are showing, generating losses, especially in critical elements in which the cycle time is short or we find bottlenecks.

3.7. Intelligence Sequencer

When ordering a production stack for the automotive sector with the vehicles to be produced we can find different vehicle models and even the same model may have different characteristics. The same model may have 3 or 5 doors, may or may not have a sunroof, etc., which generates significant variability between models and, therefore, between cycle times and this will make the bottleneck to be dynamic. In addition, component deterioration and its own inherent variability add more complexity to the problem of optimizing a production stack. In [49], [45] the authors studied how to optimize a production stack based on the current state of the manufacturing line by using the *manufacturing maps*. The complete modelling of the 8XY line and the knowledge of all models and variants, as well as the welding points, offsets and real-time measurements of the *mini-terms* were used to be able to perform an optimization adjusted to the current state of the line. Manufacturing the production stack with the optimal sequence can produce an average improvement of around 5.1% of the production time compared to the most unfavourable case, which means that when manufacturing 10,000 cars, a 5.1% of extra cars could be produced in the same time, this is, 510 extra cars.

3.8. Detection of Secondary wear on welding clamps by virtual sensor

Detection of secondary wear of welding clamps is critical for maintaining the efficiency and quality of welding operations. The secondary part, which is responsible for transferring the electrical energy from the transformer to the electrode, is subject to constant wear due to the heat and pressure during the welding process. Detection of wear in secondary components is therefore essential to avoid potential issues such as increased energy consumption, decreased quality and frequent downtime. In *chapter 5* of the doctoral thesis by Daniel Ibáñez Bordallo, see [59], in 2024, see photograph A5 directed by Jesús Soret Medel, Julio Martos Torres and Eduardo García Magraner, this problem is analysed and solutions are proposed. In [39] the author discusses the importance of monitoring secondary wear, highlighting the importance of keeping accurate records of wear in secondary parts and replacing them when necessary to avoid unexpected downtime.

The method presented in [39] is optimized in [51] so that wear can be detected early. In [51] the control variable of the IGBTs (trigger angle) is used to implement a virtual sensor of the secondary resistors. This method can predict secondary operator wear and alert before any major issues arise. The article by [51] was published in the scientific journal *sensors* (SJR Q1 (6.8) Instrumentation, JCR Q2 (3.9): Instruments and Instrumentation).

This project was also awarded in 2023 with the *Global Manufacturing Technical Excellence Award (GMTEA)*, see photo A14.

4. Other non-*I3oT* developments

4.1. Misalignment sensor based on magnetic field analysis

An initial proposal is presented in [26] for a new method to detect misalignment through the analysis of the magnetic field generated by the electrodes in short circuits, in this proposal it is discussed the importance of electrode misalignment as a mechanical factor in the RSW and the problems caused. In [27], [44] the author delves into the optimization of the method and examines the strength of the magnetic field in the welding electrodes through simulations. In [43] an implementable solution is presented for the detection of misalignments in real industrial production lines through the development of an AdHoc sensor. This sensor has already been implemented in the production line being able to anticipate failures in welding spots and significantly reducing projections.

5. Conclusions

This document provides a retrospective of the different tools and concepts introduced by the group in the scientific literature. In turn, this retrospective allows us to interpret the group's objective since its inception, which is none other than ***trying to eliminate the distance between the university and the company developing tools that generate viable solutions for the industry while advancing scientific knowledge.*** This objective has materialised in a new concept that has intrinsically been the philosophy of the vast majority of developments carried out by the group, the *I3oT (Industrializable Industrial Internet of Things)*. This concept requires the development of IIoT applications using the installations available in the factories as the only source of information. As seen in this document, the group has used this concept in the implementation of the vast majority of applications carried out and will also continue using it as a guide for future developments.

Appendix F Photographs

Figure A1. PhD thesis presented by Eduardo Andrés Garcia Magraner

Figure A2. Delivery of the certificate of election to CEU Cardenal Herrera University by Oleg Gusikhin

Figure A3. Ceremony of inscription of Universidad CEU Cardenal Herrera in the Ford University Research Program

Figure A4. PhD thesis presented by Daniel Ibañez.

Figure A5. PhD thesis presented by Daniel Ibañez.

Figure A6. Ford Valencia team members and Nicolás Montés from UCHCEU, along with Jim Hackett, Ford Motor Company President and CEO

Figure A7. Ford Valencia team and Nicolás Montés celebrating the achievement of the Henry Ford Technology Award 2019

Figure A8. The research team members as finalists of the prize Factories of the Future Awards 2020

Figure A9. Members of the research team collecting the Angel Herrera Award for the best research work 2023

Figure A10. The research team members after receiving the prize *Factories of the Future Awards 2021*

Figure A11. Members of the research team after receiving the prize *Factories of the Future Awards 2021*

Figure A12. Members of the research team after collecting the *Global Manufacturing Technical Excellence Award (GMTEA) 2023*

Figure A13. Members of the research team after collecting the *Best Paper Industrial Award obtained at the ICINCO Conference 2020*

Figure A14. Research team members after collecting the *Global Manufacturing Technical Excellence Award (GMTEA) 2023*

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