Exploring the Role of User Experience in Enhancing IoT Applications for Smart Manufacturing: A Review

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***Abstract*—The paper highlights the lack of a human-machine experience within Smart Manufacturing when using Internet of Things technologies, along with challenges, and provides recommendations for enhancement. The use of Internet of Things technologies in Smart Manufacturing has grown steadily since the launch of Industry 4.0 in 2011. Since then, the data collected from these technologies have assisted manufacturers in becoming digitally savvy by helping them gain a deeper understanding of their production processes, how they can become more efficient, and by revealing innovative ways to grow their business whilst remaining competitive. However, an area that needs further consideration is the user experience of these technologies and the human they are designed for. This paper critically examines current frameworks and methodologies that have been created to enhance the human-machine experience of Smart Manufacturing systems, some of which target the needs of industry, individual, or Internet of Things technologies. From this review, we identify that there is not one framework or methodology that can cater to the needs of all three. Additionally, open challenges that have been encountered are discussed, and suggestions for possible future directions are explored, these include focusing on human-centred design and the well-being of workers by adapting Internet of Things interfaces to the system's user needs within a Smart Manufacturing realm.**

Keywords-Smart Manufacturing; Internet of Things; User Experience; Applications.

I. INTRODUCTION

The COVID-19 pandemic significantly affected sectors, such as tourism, hospitality, and aviation; however, it also had a major impact on manufacturing production lines and global supply chains, highlighting its vulnerability in areas including finance, organisation, and technology [1][2].

To navigate future pandemics, challenges, and uncertainties, businesses within the realm of manufacturing are investing in sustainable digital solutions to help future-proof their operations. According to the 2024 Material Handling Industry (MHI) Annual Industry Report in partnership with Deloitte, 85% of supply chain leaders are considering the implementation of Internet of Things (IoT) devices to their production lines within the next five years [3]. In addition, 75% are also considering the use of wearable and mobile technologies to augment operations [3]. If fulfilled, it is estimated that supply chain leaders could gain a 39% and 40% competitive advantage, respectively, over their competitors [3]. With the additional implementation of Artificial Intelligence (AI), supply chain leaders have the potential to disrupt the industry by 11% and potentially have a 40% competitive advantage [3]. Whilst these figures are promising, challenges remain in terms of a human-centred strategy, for example, the collaboration between the human workforce and automation according to 45% of supply chain leaders [3]. In the report 44% of leaders noted that one of the main reasons for incorporating such technologies is to enable better decision-making and visibility into data [3]. However, one of the top 5 challenges reported was a talent shortage [3]. John Paxton, the Chief Executive Officer (CEO) of MHI stated, "The focus on technology in supply chains is undeniable. But supply chains are run by people, and human-centricity is the key" [3].

Therefore, the User Experience (UX) of these technologies should be enhanced to work in conjunction with the employee by understanding and adapting to their needs, well-being, and intelligence regardless of their educational background or disabilities - UX relates to how a user interacts with an application [4]. In turn, this could produce a robust and empowering co-working experience between humans and machines, address the talent shortage and lack of a hum-centred strategy, and minimise the impact on business operations.

This paper utilised a hybrid methodology, comprising of a systematic and scoping review. A systematic structured approach with a predefined inclusion and exclusion criteria, and a scoping review to identify gaps within various formats of literature. The inclusion criteria are: a date range of 2019-2025; the scope of the review was within UX, industry, and augmented systems; the search terms consisted of augmented manufacturing, UX, and Industry 5.0; and the language of papers were to be in English. The exclusion criteria included: not within the predefined date range; not including the types of data defined or search terms; and not in the English language. The research questions are as follows:

1) *What frameworks and/or methodologies are currently being used to measure the UX of IoT technologies in Smart Manufacturing?*

2) *What challenges do the frameworks and methodologies present?*

3) *How can the UX of IoT technologies in Smart Manufacturing be enhanced?*

To address these aforementioned issues and utilise the methodology described to answer the research questions, the paper outline is as follows: Section 2 is an overview of UX in manufacturing, Section 3 details the background to IoT devices, Section 4 showcases frameworks and methodologies used to measure the UX in Smart Manufacturing, Section 5 provides challenges and Section 6 concludes this paper and outlines future work.

II. Overview of User Experience in Manufacturing

During the mid-1700s, factories started to transition from hand production to implementing the use of machinery to help speed up their processes [5]. This started with the use of steam engines, that were modified by James Watt and Matthew Boulton to be powered by coal and water, however, they resulted in messy and polluted working conditions [6]. Nonetheless, it was agreed by economic historians that this era, the First Industrial Revolution (known today as Industry 1.0), was "the most important event in the history of humanity" [5]. It was developed by humans, to be used by humans, and the factory became the centre of community life [5].

Fast forward ~90 years to 1870, and the Industry 1.0 community was greeted with the technological power known as electricity. This Second Industrial Revolution era shaped the modern world we know today. By integrating electrification into their factories, manufacturers were able to speed up their production lines, which led to greater outputs. This meant society could go further in the world with the development of cars and aeroplanes [5]. This point in time, known today as Industry 2.0, had a positive impact on the world, as it transformed the lives of humans and gave them a purpose in life; what was once a factory built around a community became a connected society worldwide.

For the next 100 years, the manufacturing world continued to blossom, with the development of analogue technologies, to the integration of digital and partial automation [5]. This meant that the need for human assistance and intervention was starting to fade as advancements in computing technologies meant sectors, such as aerospace were able to make aeroplanes land themselves and robots could assemble products on the manufacturing production line, instead of people. This era, known as the Third Industrial Revolution (Industry 3.0), also had an impact on the level of education required to understand such systems. Thus what started as a simplistic UX that was accessible to all workers during the First Industrial Revolution became complex by the third. In essence, this made the factory that was once known as 'the centre of community life' inaccessible to the working class. Subsequently, the global supply chain volume increased and with it came economic change [5]. The once connected society of the world, became a fast global financial contest.

As the level of automation increased, more machines were able to communicate with one another more efficiently via networks, naming them as "cyber-physical production systems" [5]. From this, digitalisation was born and with it these machines were able to produce vast amounts of data. In order to extract additional data from these machines, IoT devices were integrated, which allowed for real-time data to be visualised on dashboards and for intelligent decisions to be made by incorporating the use of AI and Machine Learning (ML) algorithms. For example, monitoring the health and condition of machinery to predict and alert an engineer to fix the issue before it becomes a problem, potentially halting production [5]. In turn, this allowed manufacturers to be flexible in terms of their production, and "produce high-quality personalised products at mass efficiency" [7]. In 2011, this was introduced to the world as the Fourth Industrial Revolution (Industry 4.0) [7]. However, it is only within the last few years that companies are beginning to see the value that IoT devices can offer. This era is changing the way humans work, meaning it is more about the machine (drive productivity) than it is about the human using it.

As previously highlighted, the UX of each Industrial Revolution has become less focused on the human operating the machinery, and more on the production process and technology, as that is bringing in financial gains. Therefore, the relationship between human and machine has faded. However, with the advancements in digital technologies accelerating each year, the gap between each Industrial Revolution is becoming shorter.

In 2020, the Fifth Industrial Revolution was born (Industry 5.0) [7]. This version is setting out to assist in the personalisation and humanisation of digital technologies by putting the human back "at the centre of the production process" [7]. This means that the relationship that human and machine once had is now to be reconciled, by removing the barriers to create a meaningful experience for all users, and create a long-term service for humanity. Afterall, these technologies are designed to have a human component to interact with the system efficiently and effectively [8]. However, it was reported that 50% of supply chain leaders said merging technologies with existing talent is a challenge [3]. Therefore, for Industry 5.0, the UX of manufacturing applications must be flexible and adaptable to their users' needs, well-being, and intelligence. For example, cars made by Tesla learn how the driver interacts with the vehicle through their behaviours, usages, and devices, and adapts content to their needs in real-time [9]. However, some supply chain leaders have expressed concern relating to ethics and governance, and the supplying of correct information to a human worker based upon their level of access with the role they have been assigned to [3]. Nonetheless, Industry 5.0 now has the opportunity to bring a new workforce together (human and machine), and for them to become a decision-support as opposed to a decision-making mechanism in the production process [3].

III. Background to Internet of Things Devices

IoT devices play a vital role in the collection of additional data from machinery, assist with automating tasks, and enhance decision-making for humans. However, due to the gap between each industrial revolution getting shorter, these devices are still being rolled out today for some manufacturers. This is partly due to manufacturers being uneducated regarding the value these devices could bring to their business, and the cost for implementing such technology.

Since their initial launch in Industry 4.0, the price of IoT devices has come down and they are now affordable for most companies, especially those who utilise legacy machinery, as they can be a cost-effective alternative to purchasing new machines. By integrating these devices, they can enhance the overall production line by providing information on four key areas, such as products, people, processes, and infrastructure [10]. Devices consist of sensors, Radio-Frequency Identification (RFID) tags, and actuators to name a few [11]. These IoT devices are connected to a network that allows them to communicate with each other and provide a unified service to their user(s). When interacting with each other, this relationship is known as thing-to-thing, however, when a human interacts with an IoT device this relationship is referred to as human-thing [11].

With thing-to-thing, there are two subset levels of interaction, Internet and thing. Internet pertaining to the connection between other devices regarding quality and responsiveness to provide reliable services [11]. Whereas at thing level, this relates to its battery level (if applicable), energy consumption, interoperability, and installation difficulty to name a few [11]. Both levels impact the human-thing interaction, the UX behind it, the IoT system as a whole (interaction, privacy and security), and whether it is meeting the expectations and needs of its users [11].

The UX of IoT devices and their data is extended to the platforms they are connected to. The data collected from each device can be portrayed via a visual dashboard in a meaningful way for all members of the workforce to view, monitor, and assist with decision-making. One challenge with this is achieving interoperability – integrating outputs from a diverse range of devices produced by various manufacturers into a single platform, where they function together as one cohesive system. This enables data aggregation and analysis, providing valuable insights that support decision-making between humans and machines [3]. Platforms, such as Home Assistant are already accessible to members of the public to implement and experiment within the comfort of their own homes [12]. Systems like Home Assistant are necessary and relevant for the Smart Manufacturing realm to adopt and assist workers with their daily tasks. However, the UX surrounding these applications and how it can be enhanced to adapt and support not only its users, their intelligence and needs, but also current and future industrial revolutions is a question that remains.

IV. FRAMEWORKS AND METHODOLOGIES USED TO MEASURE THE USER EXPERIENCE IN SMART MANUFACTURING

The research indicates that when it comes to evaluating the UX of interfaces, they are predominantly associated with web applications and neglect industrial systems. It has been highlighted that there is a need for a tool, framework and/or methodology to assist with the evaluation and enhancement of Human Machine Interfaces (HMI) in industry, particularly within Industry 4.0 as it is associated with IoT devices [13].

Few emerging evaluation methods focus on the experience of IoT devices, though they are not necessarily within the realm of Smart Manufacturing. Nonetheless, they are of interest as they could be adaptable to other domains that incorporate such devices. For example, research conducted by Rodrigo et al. proposed a framework that consists of a checklist to conduct a UX evaluation of IoT scenarios [11]. This checklist was evaluated by Human Computer Interaction (HCI) experts and three versions were created to cater for a variety of users and their needs. For example, version one contained all the necessary fields, version two provided examples for those who are not as familiar with the checklist; and version three is a compact version offering visualisations.

The checklist consisted of measurements pertaining to the IoT scenarios ease of use (likert scale), applicability to all intended users, concreteness, clarity, ease of understanding, impartiality, parsimony, and pertinence to context [11]. To evaluate the checklist, users assessed the UX of a smart bulb to which positive results were obtained. This method highlighted that the checklist is suitable for evaluating the UX of IoT devices and assisting evaluators who may not be well-versed in the UX domain. Also, whilst this checklist was not tailored to the Smart Manufacturing domain, it has the potential to be used across a variety of realms. However, an area that it did lack was the assessment of an interface that an IoT device would portray its results to.

Research conducted by Aranburu et al. consisted of the creation of a tool known as eXperience Capturer (XC) [13]. It was developed due to the absence of evaluation tools specifically for the industrial HMI. The tool which is user-centred can be used in multiple ways, for example pre-interaction, during interaction, and post-interaction. It evaluates emotional and usability parameters during each phase mentioned, and combines quantitative and monitoring methods when a user conducts a test consisting of a series of tasks [13]. During testing it proved successful and emphasised the need for new methods to be utilised within the industrial domain to assist users with UX knowledge. By achieving this the communication and interaction between machine and user enhances and opens new avenues for technology to be implemented. However, whilst it was able to assist with the UX of HMI within an industrial domain, it lacked in the assessment of IoT devices where the interface is associated with and the human operator.

As highlighted throughout this paper, IoT devices provide additional information to users in the workplace and portray results via a visual interface. Whilst this is of interest, the relationship between human and machine (as well as thing) needs to improve.

Therefore, research conducted by Villani et al. proposes a general holistic framework known as INCLUSIVE [14]. This framework focuses on the connection between human and machine, as the researchers detail the "presence of human operators remains fundamental in industrial workplaces" [14]. Therefore, their work suggests the introduction of automation, whereby a machine adapts to the user's capabilities and effort and assists them with their working tasks [14]. This framework specifically targets Industry 4.0

and was tested within three domains: woodworking machinery for small companies, automation solutions in developing countries where operations are mostly manual and robotics are used during the assembly of appliances; and the management of large plants and warehouses with Laser-Guided Vehicles (LGV). This broad testbed showcases the frameworks flexibility and ability to relieve some complexity that modern production systems and operations bring to users by offering usable interfaces, with smooth and easy interaction [14].

The framework consists of three modules – measure, adapt, and teach [14]. Each module of the framework communicates together and use an adaptive automation middleware for hardware independence and modularity [14]. To understand their users more when moving around a machine, they utilised a wearable device known as Empatica E4 wristband, this captured their heart rate, skin temperature, and Galvanic skin response [14]. When they were not moving around a machine, their pupillary response was recorded via an eye tracking system. This research found that heart rate variability was one of the most responsive factors when measuring human reactions or strain. What is interesting, however, is that they found the higher levels of strain meant higher levels of satisfaction, as this was deemed as arousal and not stress, whilst good for short term, it could be harmful in long term [14]. Therefore, the amount of time between machine and human should be limited and breaks should be utilised.

Using each testbed, it was identified that the framework was accessible to all users irrespective of their age, education level, cognitive and physical impairments, and experience in the task to be performed. They also found that 80% of users became more productive and it helped them cooperate with machine/robot more efficiently [14]. By incorporating this framework, it allowed elderly, disabled or inexperienced users to stay in their jobs for longer, interact with complex automatic systems, and access working positions that they would be inaccessible to in other domains [14]. However, whilst this framework has proven to be successful with testbeds, there is still a lack of trust and acceptance from users. Therefore, before it could be implemented permanently, further research needs to be conducted (longitudinal tests) with users.

Research conducted by Johnston et al. presented a framework that is similar, meaning, it also measures three parameters, however, they are known as Dynamic, Adaptive, and Intelligent [15]. Dynamic refers to the contextual information surrounding the user, device, and their physical environment to provide a basic UX; Adaptive measures the user's capabilities and knowledge set to offer an enhanced UX; and Intelligent uses ML algorithms to deliver the appropriate interface by utilising user behavioural datasets [15]. This framework does not take into consideration the use of IoT devices. However, it could still be used in the manufacturing domain to assess the UX of IoT interfaces that portray data from sensors to workers from the workplace.

As previously outlined, manual work by humans is still a key area within the Smart Manufacturing domain, especially in terms of fixing defects in automated production lines. Research conducted by Stoll et al. proposes an Adaptive Visual Assistance systems using Spatial Augmented Reality (AVISAR) [16]. This framework adapts based on different repair tasks and the layout of a worker's manual assembly workstation, as well as the human themselves based on their skills and needs [16].

The user's assembly workstation is the key area of focus. The AVISAR framework utilises a projector to project information for the worker to utilise when working with an object. Information being projected consists of in-situ, where a faulty area of a circuit board is highlighted, and repair instructions which are displayed on the white surface [16]. This framework has the potential to work with IoT devices, for example, as future work the use of RFID tags could allow the system to recognise the user and adapt the workstation to suit their needs via saved user profiles, based on their level of education, disabilities, etc. [16]. By using a projector, it allows a user to utilise gestures, this indicates to the system that they are ready for the next stage of the repair task and for it to provide the next set of visual instructions. However, as this is a Spatial Augmented Reality (SAR) application, adaptations can be limited due to the type of projector and its projection rate. Therefore, the projector would have to be upgraded, and to allow for more scalable solution, the use of a Raspberry Pi would be implemented to make the deployment of the system more cost-effective and smaller (easier to use and implement) [16].

As highlighted, there are multiple solutions that can assist in the enhancement of IoT devices with the UX behind those and their associated interfaces. However, each company/organisation is unique, and one approach will not be suitable for all. Therefore, it is important for each organisation to "define and follow" a route that is both "structured and comprehensive", by achieving this it avoids "haphazardly" integrating new technologies in isolation [3].

V. CHALLENGES

As highlighted throughout this paper there are several challenges, all of which remain unanswered. These challenges were derived through the identified gaps when conducting the scoping review and are defined below.

1) Lack of a cohesive framework or methodology

Firstly, there is not one framework or methodology that can cater to all the needs of industry, individuals, and IoT devices. As indicated from the research conducted, these have been identified as separate systems that focus on at least two of the three main parameters, but not as a collective.

By combining these three parameters, one framework would be established that could be used within Smart Manufacturing to assist with the enhancement of HMI and IoT technologies. By achieving this, the human-machine experience is enhanced whilst catering to the well-being of our workers and keeping the industry up to date with the latest Industrial Revolution.

2) Lack of manufacturing focus when understanding the experience of IoT devices.

As the implementation of Industry 5.0 draws closer (personalisation and humanisation), the requirement for systems to incorporate all three parameters is necessary, as it will require knowledge of the system, its user and the devices in which they are using as well as the task in hand. As portrayed, the use of IoT devices is still trickling its way through the manufacturing industry compared to others (Smart Home), and the UX underpinning these devices is still being evaluated by researchers.

In the realm of manufacturing, there have been setbacks when implementing such technologies, namely due to cost, lack of education, and not seeing its true potential. However, for this to change, the relationship between human, machine, and thing needs to improve. To achieve this, there needs to be trust and acceptance from all workers when machines attempt to adapt to their behaviours to offer a personal and humanised experience. As opposed to machines or technologies being implemented to replace workers, which typically brings negative experiences - this has been the most challenging area.

Therefore, by having a framework that is specifically for the manufacturing domain and the three parameters mentioned, this will in parallel, bring trust and acceptance to all workers, whilst enhancing the UX of IoT applications.

3) Lack of a manufacturing interface for IoT devices.

Today, there are ~18 billion connected IoT devices worldwide, with this figure set to almost double to 32.1 billion by 2030 [17], however, a challenge that remains in this area is interoperability. Some manufacturer's devices are 'locked' and only operate on their system; others are open-sourced and can be used with any interface. To overcome this, there should be a universal ethical approach to allow all IoT devices to be used with various systems, such as Home Assistant. It will be highly unlikely that one manufacturer will be able to produce all IoT devices for mankind. Therefore, at minimum, there should be one interface that can be used by all while understanding its user and the operational environment. Achieving this would, cater to the needs of Industry 5.0 and allows for most companies to transition to the next revolution with ease and less friction on training and financial costs. This would bring long term success and value to each company over time and the longevity of the products being made [3].

VI. Conclusion and Future Work

This paper has critically examined current frameworks and methodologies that have been created to enhance the human-machine experience of Smart Manufacturing systems, along with providing answers to the research questions previously defined.

In terms of limitations of the following review, there is a lack of research in the field of Smart Manufacturing on how to enhance the UX of IoT technologies. This is highlighted by the number of frameworks and methodologies identified and reviewed in this paper. This could also be due to the inclusion and exclusion criteria. Therefore, for future research, the amount of search terms would be increased. However, upon review, it was evident that this is an area that is starting to gain traction.

It has also been identified that most industrial companies are only now implementing IoT devices in their production due to costs coming down. However, the UX of these devices and their associated applications should focus on enhancing usability to better engage and support the user operating them. Therefore, each user's needs must be considered to adapt the interface appropriately, irrespective of their educational background and disabilities. Several frameworks are being developed; however, no such framework caters to Smart Manufacturing, the IoT device(s), and the system user. This is a remaining challenge and should be addressed in the future. By achieving this, it would allow manufacturers to reduce errors and become more resilient, whereby they are capable of minimising future uncertainties that may come down the tracks [18], whilst improving the human-machine relationship and the well-being of our workers.

As future work, Augmented Reality (AR) or Virtual Reality (VR) could be used to improve worker safety [19]. Training sessions with such technologies would allow the user to learn how they operate over time and highlight areas of concern and offer recommendations on how they could be addressed. The foundation of this method was highlighted via the use of a projector, however, this approach has the ability to adapt to the user, their needs and the task in hand. This method could incorporate the recommendation previously mentioned of having one interface and adapting to the IoT devices or machinery that is in its line of sight. In this way, the human-machine experience enhances and becomes one cohesive system whilst keeping the well-being of our workers a top priority. This recommendation acts as the scientific contribution of this paper and for Industry 5.0.

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