INDUSTRY 4.0 CONTRIBUTION IN LESS ENVIRONMENTALLY HARMFUL METHODS IN MACHINING PROCESSES: A REVIEW

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Abstract: *In a world where accelerated production follows strong technological development, issues such as cost reduction and the protection of the environment cannot be overlooked. At the same time, Industry 4.0 is expanding and its techniques have been applied in the most diverse areas. In this context, this paper seeks to develop a literature review regarding the application of Digital Twin, Internet of Things, and Artificial Neural Networks techniques, three of the main techniques of Industry 4.0, in machining process solutions seeking environmentally friendly solutions. To this end, criteria are proposed and research is carried out in a database of academic works. After the proposed methodology, it is concluded that most machining research that includes Industry 4.0 concepts is related to the application of Artificial Neural Networks. As an addendum, this paper also presents a proposal for a low-cost system that aims to prolong the useful life of cutting fluids, thus reducing the use of a fluid that is considerably harmful to the environment.*

Keywords: *industry 4.0,* environmental sustainability *processes, machining, cutting fluid*

1. INTRODUCTION

Despite being a topic that is gaining increasing attention only in recent years, the relationship between mankind and the environment has been discussed for about a few decades (Samuel et al., 2022). According to (Donaire, 1994), the series of cultural transformations that took place around the 1960s and 1980s created a new form of environmental awareness, and the protection of the environment was seen as one of mankind's most important and essential goals.

While the aforementioned concern has gained strength over the last few years, the relatively fast technological development also follows this path. And because of this, an increasing amount of resources are drawn from nature and more waste is created, often leading to a decline in quality of life and health for two main reasons: the environmental damage, as previously mentioned, and the direct harm the waste can cause to humans (Massaro et al., 2021; Mikhno et al., 2021). As it will be presented in this paper, one sort of these residues, which has a complicated treatment, is the cutting fluid, commonly used in a group of manufacturing processes known as machining (Khanna et al., 2021).

In the midst of the problem presented, engineers should seek the use of tools to promote sustainable development, respecting the limit between development and production and social and environmental issues. With this aim, manufacturing engineering has sought a sequence of solutions, among which the works of (Nadolny et al., 2021) and (Zhang et al., 2022), in which both researches sought to develop less harmful lubricants. While the former aimed at Environmentally Friendly Grinding Processes, the latter worked with Nano-enhanced bio lubricant, both achieving satisfactory results. In the material topics, (Li et al., 2021) looked for environmentally friendly methods for Micro-Textured Cutting Tools while (Samuel et al., 2022) addressed the need to replace synthetic fibers with natural fibers, through the development of Modeling and optimization of the manufacturing parameters. The synthetic type is non-environmentally friendly and of limited availability, while the natural one is eco-friendly.

In machining processes, the scenario is no different. With research dating from the beginning of the present century (Klocke et al., 2006; Kundrák et al., 2006), the search for practices that are less harmful to the environment is an old-time concern in this area. In this scenario, (Naveed et al., 2021) presented a review of state-of-the-art research on the use of biodegradable cutting fluid, which includes works such as the one by (Gupta et al., 2019), in which this author discusses the use of Vegetable Oil-Based Nano-Cutting Fluids for cutting Inconel-800 Alloy. At the same time, other alternatives to achieve cleaner processes are possible, such as optimizing the amount of cutting fluid - whether biodegradable or not - used during the manufacture of a component. For example, (Hadad & Beigi, 2021) achieved satisfactory results using an ultrasonic nozzle–minimum quantity lubrication system.

The search for engineering techniques that impact less negatively the environment is of extreme importance, which can be corroborated by research that does not seek the aforementioned objective only in machining processes (Rajmohan et al., 2020), but also in other manufacturing processes (Zhong, 2021). Parallel to the exposed scenario, the impact of Industry 4.0 (i4.0) technologies (Figure 1) on sustainability based on economic, environmental, and social aspects has been well recognized among researchers (Nara et al., 2021).

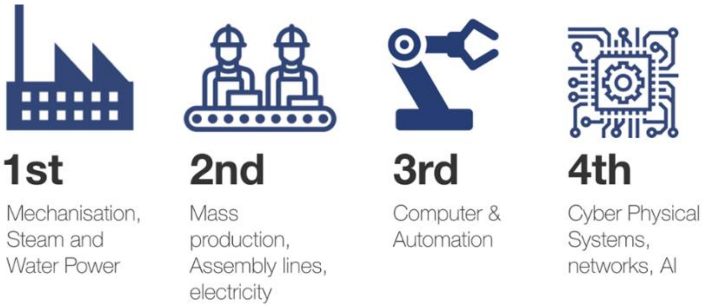

Figure 1. **The stages of the Industrial Revolution. Kankei (2022).**

According to (Lopes et al., 2017), the factor that will allow the development and evolution of companies in the coming years will be exactly the understanding of the client's problems and needs. That way, the companies can act accordingly to these needs and stay ahead of the competitors. The authors also point out that it will not be the easiest task to adjust to this new challenge imposed by the Fourth Industrial Revolution. While (Sony & Naik, 2019) defines Industry 4.0 as the transformation of organizations to the digital landscape, (Piccarozzi et al., 2018) argue that Industry 4.0 is based on the development of fully automated and intelligent production, that would also be able to communicate autonomously. More emphatically, (Kamble et al., 2018) state that the term discussed here presents a completely new perspective for the industry regarding the way that the integration of manufacturing processes and new technologies can achieve maximum production with less use of resources.

Although (Oztemel & Gursev, 2020) have reported that the term has several different interpretations, it is agreed in the bibliography that Industry 4.0 has a direct relation to the technological evolution of recent years, when increasingly more tasks have been performed according to the device evolution. In short, the techniques developed in the fourth phase of the industry operate with large amounts of data, via mathematical modeling and systems connectivity, in order to obtain results that assist in decision making. Intuitively, the architecture of this relationship tends to become more complex as the interaction between humans and objects grows, as explained by Simota and Steiner (2017) *apud* (Pinto, 2019). In this context, terms are born that are currently part of the routine of many areas of knowledge: artificial intelligence, machine learning, internet of things (IoT), digital twin (DT), deep learning (DL), and big data (BD) are some examples (Penumuru et al., 2020; Rai et al., 2021).

In the stated context, the present work seeks to carry out a review of the literature regarding research that has been applying Industry 4.0 techniques in machining processes, aiming to reduce the damages of human activities to the environment. Along with this, this article has, as an addendum, a project proposal that aims to prolong the useful life of cutting fluids, thus reducing the need to use a substance that is considerably harmful to the environment and which, at the same time, is fundamental for certain manufacturing processes.

2 INDUSTRY 4.0 AND MACHINING PROCESSES

The process of surveying for this work was initially based on the definition of two keywords: Machining process and industry 4.0. Using these terms, a search was performed on ScienceDirect, one of the main databases of academic works today, and 885 results were found. After an initial review of the most relevant works found and according to Figure 2, it was noted that the amount of research-related works has grown considerably in the last five years.

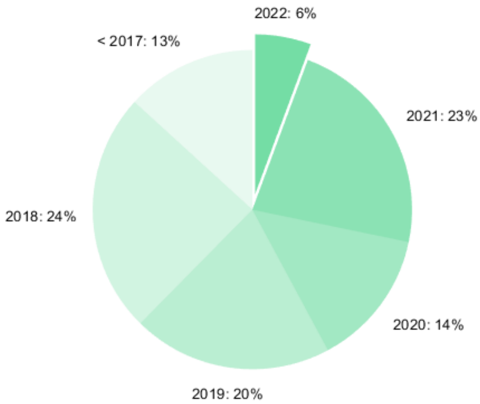

Figure 2. **Results per year.**

The observation above also corroborates what was previously exposed in this text regarding the arising and growth of the use of i4.0 technologies being a somewhat recent issue. With only two consecutive months and 50 searches found, the year 2022 already exceeds the number of works that were published per year in all the years before 2016, and in 2017 the result numbers are not twice the same as the ones found in 2022. Due to the aforementioned points, the works found were also filtered to consider publications from 2018 onwards.

After this initial analysis, a new key term was added to the search due to the objective of the present work. With environmental sustainability, the number of studies found in the entire period dropped to 54, and 51 of these publications were from 2018. According to related bibliographies (Dalmarco et al., 2019), some of the main Industry 4.0 technologies were raised in order to group the results, namely: The Internet of Things, artificial neural networks (ANN), and digital twin. With this, Figure 3 presents a flowchart with the cases found for each group, where within each of these a detailed reading was performed to exclude articles not related to machining.

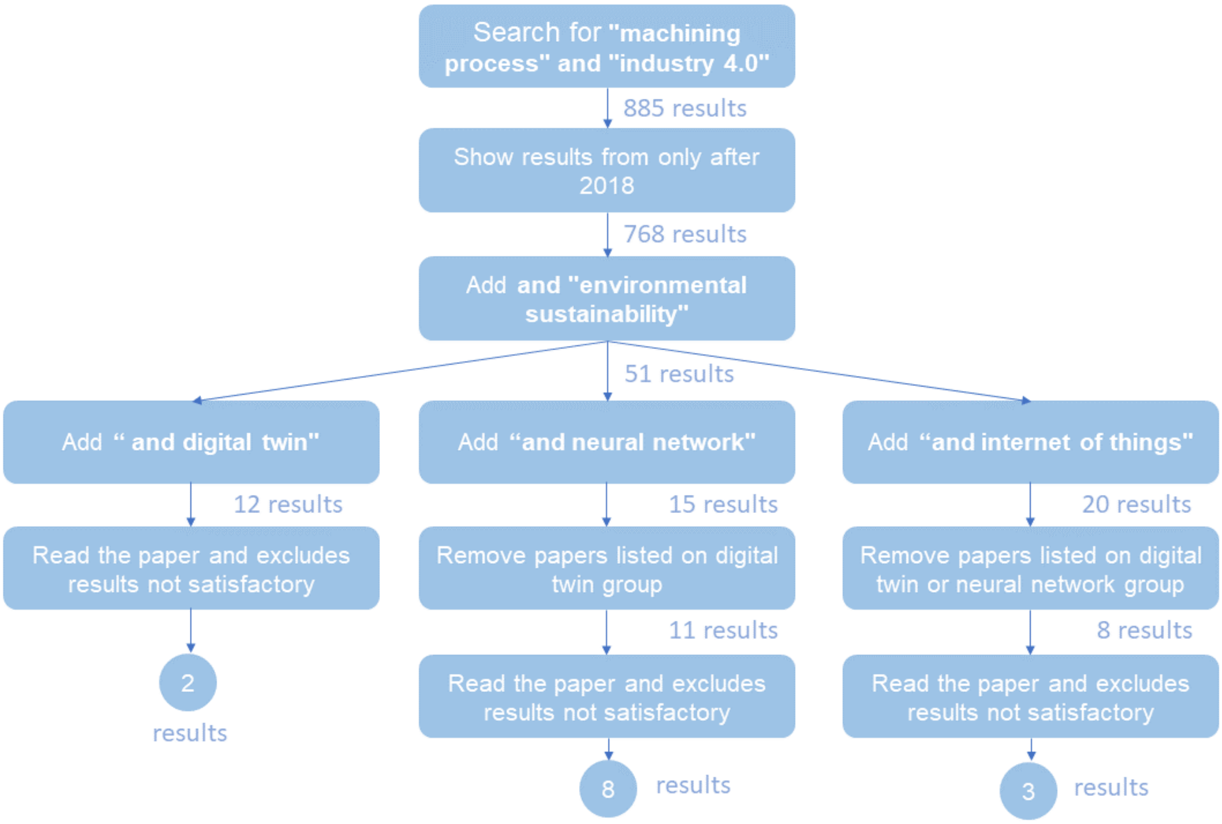

Figure 3. **Papers selection conditions.**

As observed in the figure above, among the results found in each of the three proposed pillars, some research met the exclusion criterion because they were repeated. After excluding these, 2, 8, and 3 results remained, respectively, for works involving the application of IoT, ANN, and DT concepts in machining processes aiming at environmental sustainability. These works are listed in Table 1, also respectively, and with their main objectives.

Table 1.a. **Internet of Things results.**

Author	**Description**
(Gao et al., 2019)	Collection of works among which those related to machining speak of intelligent machine tool (IMT), anomaly diagnosis for machining processes, and online diagnosis analysis
(ElMaraghy et al., 2021)	Address the new future Adaptive Cognitive Manufacturing System (ACMS) paradigm and its characteristics, drivers and enablers are articulated highlighting the digital and cognitive transformations.

Table 1.b. **Digital Twin results.**

Author	Description
(D'Addona et al., 2020)	Lay the basis for a Biological Transformation in Manufacturing (BTM) industrial breakthrough aimed at developing new sustainable microbial-based cutting fluids for greener machining processes
(Jamwal et al., 2021)	Approach new optimization techniques in the machining area
(Luan et al., 2018)	Increase the profit of an industry by identifying trade-offs between cutting tool cost, electricity cost, and machining quality
(Cao et al., 2019)	A systematic review of recent advancements related to tooling performance and functionalities, including tool materials, tooling fabrication processes
(Wang et al., 2020)	Approach the product-service system (PSS) business model with the application of industry 4.0 concepts
(Chandel et al., 2022)	Approach the product-service system (PSS) business model with the application of industry 4.0 concepts
(Zhou et al., 2022)	Use i4.0 features for the ultra-precision machining (UPM), the cutting-edge manufacturing method
(Pang & Zhang, 2019)	Address machining studies targeting green machining tools and processes

Table 1.c. **Internet of Things results.**

Author	Description
(Sreerag et al., 2021)	Discuss new processes aiming at lower consumption of resources in the production chain
(Piwowar-Sulej, 2021)	Discuss staff preparation for industry 4.0 embracing sustainability
(Kopacek, 2018)	Approach process automation aiming at lower resource expenditure

3 A LOW-COST SYSTEM PROPOSAL TO REDUCE CUTTING FLUID CONSUMPTION

Facing the solutions provided in the previous paragraph, this work also seeks to present a proposal for a low-cost system for automatic pH control in cutting fluids. In this system, through a programmable logic controller (PLC), the useful life of the cutting fluid is analyzed, since the deregulation of acidity is one of the factors that contribute to the proliferation of living beings and the consecutive reduction of their useful life, thus requiring greater use of this substance harmful to the environment.

A programmable logic controller is a mechanism that has revolutionized the industry in the last decades. It has such strong potential, that it has become a key integrator for future process revolutions, such as the case of the composition of said Industry 4.0. To program this equipment, a common technique used is the block diagram, also known as Ladder Diagram. According to (Vieira, 2003), programming in the Ladder diagram is simple and allows communication with other PLCs programmed in other languages. This language is still completely didactic, being similar to the assembly of the old relay panels.

Therefore, with all the advantages mentioned, the use of a PLC is ideal for process automation. In order to accomplish this, a PLC with a suitable degree of protection (IP) must be carefully chosen, since, according to (Zeilmann et al., 2018), the chemical composition of the fluid presents itself as a possible culture medium for microorganisms, which reduce the lifespan of the fluid and represents a health risk to the workers. If the equipment is not well chosen, it could be damaged by this chemical composition.

Despite the predicted environmental issues and the fact that cutting fluids present difficult maintenance since ideal conditions must be reached for their correct use as a cooling mechanism, they are essential for several applications in machining processes. Another factor that surrounds those fluids is the increasing number of Environmental Laws that dictate their use, since harmful effects can be observed in the environment when their disposal is done incorrectly (Gajrani et al., 2021; Sankaranarayanan et al., 2021).

According to (Catai et al., 2002), about one million liters of drinking water can be contaminated if they come into contact with about one liter of used oil. Along with all the environmental issues mentioned above, the increasing use of these fluids due to the constant growth of industrial production is noticeable. In this context, it is of fundamental importance for the maximum prolongation of these fluids' lifespan, by means of suitable treatments, to reduce their disposal.

In Machining, the importance of using the cutting fluids can be represented according to (Zeilmann et al., 2018). According to the mentioned authors, not using the fluid generates more friction and adhesion in the tribological pair tool-piece, which means that there will be a greater thermal load, increasing the wear of the tools and, consequently, reducing their lifespan. Figure 4 shows the rate of heat generation in the tribological pair.

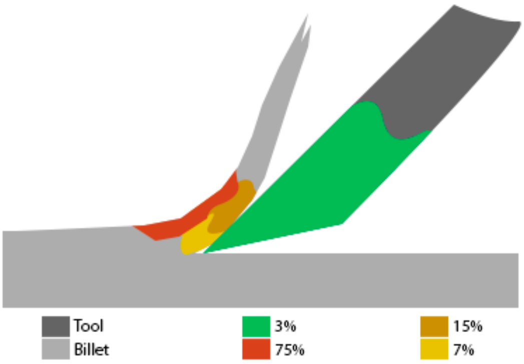

Figure 4. **Heat generation in machining.**

In a competitive market, in which any decrease in expenses makes a difference (Silvestri et al., 2020), industries do not give up the production of cutting fluid, even though the environmental damage is known. The absence of cutting fluid does not only affect the tool's lifespan, but also the final piece. In addition to that, performing dry machining can lead to an inferior surface finish, resulting in dimensional losses. The use of cutting fluids, however, does not only present qualities. By increasing the thermal cycle of the tool, since the heat exchange is accelerated, it can exhibit thermal fatigue and early crack, considerably reducing the process life.

The proposal suggested here will perform the control the pH of cutting fluids in manufacturing processes by using a PLC. The system has manual and automatic versions, allowing testing and maintenance to be done when necessary. In addition to these features, the development of a supervisory system is proposed, which, among other possibilities, allows control of the system in remote mode directly from control rooms. Figure 5 presents the model of the project to be developed, where the main rectangular tank is responsible for storing the cutting fluid coming from the machining process while the two upper tanks store base and acid additives, respectively, to be released as they are required by means of solenoid valves. These valves, in turn, are activated by means of electrical commands received from the PLC.

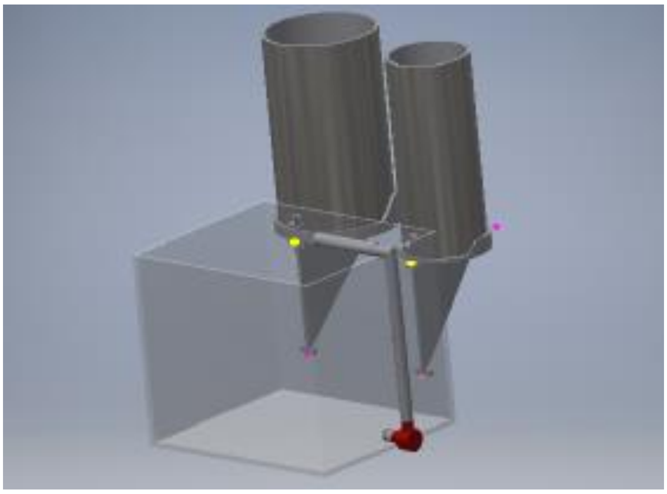

Figure 5. **Proposed structure for the device.**

Besides the research on the issues of cutting fluid conditions, factors such as materials and operating conditions for pumps, containers, and piping were analyzed. It was done considering that the system will work under conditions that may affect it or even lead to failure or a considerable reduction in lifespan, which would make its operation impracticable. The list of materials used is shown in Table 1.

Table 2. **List of bills.**

Material	Quantity
PLC	1
Hydraulic pump	1
pH sensor	1
Solenoid valves	4
Acrylic	20 sheets, 40 x 40 x 5 mm
Relays	6 meters
PVC pipe	Ø1' - 2,5 meters
Fittings for PVC (Tee)	Ø1' - 2 units
Fittings for PVC (Elbow)	Ø1' - 4 units

It is important to emphasize that the project proposal presented in this paper seeks a low-cost solution, which means that the first assemblies are restricted to the use of reused materials from recycling centers. For this reason, a PLC for more basic applications like the HI Technology ZAP 91X is proposed. For using this model, however, the PLC will be enhanced with analog-digital converters, since this controller has only eight digital inputs and eight digital outputs in its default configuration.

Since the control of the pH of cutting fluids is a widely used process that often does not rely on automation, it would be interesting to create a system that automates it, which would ensure the process greater precision and quality of service to the operator. Industry, in the present times, cannot be separated from the quality of life, either for the environment or for the human being, and these two are directly interconnected.

Therefore, with the considerable increase of automation in manufacturing processes and processes made with programmable controllers and the internet of things (directly linked to Industry 4.0), it is of fundamental importance to develop a project in which the control of the lifespan of an extremely hazardous product is done in an automated way, ensuring greater quality, greater precision and, consequently, less damage to the health of the employees and smaller impact to the environment.

4. CONCLUSIONS

The growth in the use of Industry 4.0 techniques is present in the most diverse areas of knowledge. According to the present work, from 2018 onwards the use of these techniques in machining processes becomes increasingly present, with a considerable part of these works still related to how to practice cleaner machining in terms of having good synergy between operators, environment, and process effectiveness in the sense of reducing time and increasing the quality of the final product.

In this scenario and considering three of the main features of i4.0, the present work sought to carry out a survey of related bibliographies and it was observed that most of the works applied in the manufacturing area were portrayed here to address the use of neural networks for simulation and optimization of processes. There is also the application of the Internet of Things and Digital Twins aiming at the optimization of machining processes, but in a less expressive way when compared to neural networks. In order to corroborate these observations, we recommend the development of the review portrayed here in other academic databases as well as the search for other techniques such as Cyber-Physical Systems (CPS), Cloud Computing, and Cognitive Computing, for example.

Finally, the present work also presented a low-cost project proposal that seeks to optimize the consumption of cutting fluids, through the use of programmable logic controllers, one of the pillars of i4.0. Through this proposal and the review developed here, it is expected that future works can take advantage of the ideas discussed and the scenario exposed in this paper, aiming at increasingly environmentally friendly solutions.

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