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Enabling technology for maintenance in a smart factory: A literature review

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Abstract

Industry 4.0 technologies are transforming the factory in an "intelligent" or "smart" factory. In a such context, a greater efficiency and innovative relationship is basically demanded within the whole production chain, including suppliers, producers, and customers.
To be more competitive, companies are becoming increasingly aware that maintenance plays a key role during the digital transformation from the perspective of both technology and management. In this work, we perform a literature review of published cases to investigate how maintenance is changing through technologies of Industry 4.0 currently used in maintenance. We found 34 papers in literature involved in analyzing relations between maintenance and Industry 4.0 technology. The analysis of such studies let us to establish the current technology state-of-art and identify the most suited technology that today is employed in maintenance tasks. In particular Industrial Internet of Things and Cloud Computing are more common in the analyzed studies, confirming how these concepts and technologies are at the basis of Industry 4.0

Keywords: Industry 4.0, Maintenance, Intelligent manufacturing systems, mart factory

1. Introduction

Industry 4.0 involves the introduction of Cyber Physical Systems (CPS) and Internet of Things (IoT) within

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manufacturing process environment [1,2]. They represent the natural evolution of previous computerization and automation of the third revolution [3]. Industry 4.0 is enabled by the so called “nine pillars” of advanced technology alongside relevant changes in management for manufacturing and human resources [2-5].
Such technologies are able to convert a conventional factory into a “smart” factory [6], characterized by automation and optimized manufacturing processes, they include: 1) Industrial Internet of Things (IIoT); 2) Big Data; 3)Horizontal and vertical integration of systems; 4) Simulations; 5) Clouds; 6) Augmented Reality; 7) Autonomous Robots; 8) 3D printing and 9) Cyber Security.
According to [7], Industry 4.0 priorities include a full integration between maintenance planning and production, allowing companies a more economic production system.
Maintenance is part of main value supports of Industry 4.0, they are “Asset utilization” and “Services and aftersales” [8]. Furthermore, maintenance management is commonly considered the first step to take in Industry 4.0 environment to have technical and economic advantages [9].
A literature review allows to create a solid base for all members of the scientific community [10]. Although in a synthetic form, it is generally included as “background” section in the article introduction. As it is possible to see in recent articles [11-19], it generally identifies gaps in knowledge or provides theoretical foundations for the proposed study.
The aim of this study is to perform a literature review to investigate the implications of Industry 4.0 technology in maintenance activities.

2. Method

In order to investigate the implications of Industry 4.0 technology in maintenance activities, a comprehensive literature review was carried out.
The literature search included Scopus, Science Direct and Google Scholar, using exploratory keywords, such as “industry 4.0”, “maintenance”, and names of all the industry 4.0 pillars.
Such keywords were used both singularly and in conjunction among themselves, by the use of Boolean operators “OR” and “AND”. Additional keywords, that are raised during the first search phase, have been used for further literature explorations. The time period considered for research is from January 2015 to July 2020.
Only articles from journals were collected, because of their relevance and availability. Relevant studies with title and abstract that matched the scope of this review were first collected and, after a carefully analysis, definitively included for the final analysis. Results are presented in the next Section 3 and they consist in a descriptive analysis and a thematic synthesis. The methodology and the criteria adopted for identification of the papers are detailed in table 1, while the number of papers identified in each step is shown in table 2.

Table 1. Summary literature review process.

Step 1 and **Step 2** *Finding and evaluation of articles*	**Electronic databases** Scopus (scopus.com), IEEE (ieeexplore.ieee.org), Google Scholar (scholar.google.com) **Search Period** 2015 - 2020 **Inclusion Criteria** Articles with title and abstract that matched the aim of our study have been first collected and, after analyzing the entire contents of the article, they were assessed for considering their final inclusion in our database. **Exclusion Criteria** Articles and conference papers and in languages different from “English” **Search Strings** “industry 4.0” AND “maintenance” Other combinations with: “operator 4.0”, “human factor”, “augmented reality”, “Big Data Analysis”, etc…
Step 3 *Assessment of findings*	**Analysis phase** Iterative collection of articles within the database

Step 4 *Reporting of findings*	**Synthesis phase** Relevant aspects are extracted from database and discussed

Table 2. Summary of the literature review search process

	Keywords	Identified articles	Articles post removing duplicates	Articles post abstract review	Articles post full text review
Total	"Industry 4.0" and "maintenance"	*527*	*221*	*69*	***34***

3. Results: descriptive analysis and thematic synthesis

We collected and analyzed a total of 34 articles present in literature from 2015 to 2020. 2015 was chosen because it represents the beginning of the academic discussion about maintenance in an Industry 4.0 context. Most of the papers involve case studies or conceptual works. Case studies generally aim to validate theoretical aspects by the use of empirical applications.

As previously described, Industry 4.0 is enabled by the so called "nine pillars", but only some of them play a key role in maintenance activities. In particular Industrial Internet of Things and Cloud Computing are almost present in each study, confirming how these concepts and technologies are at the basis of Industry 4.0[23], while it would seem that Cybersecurity technology is not relevant for maintenance purposes.

The *Industrial Internet of Things* (IIoT) refers to Cyber Physical Systems (CPS), that consist in systems interconnected via internet, allowing exchange of data in a local or global scale and without any human intervention [20-22].

Such machine-to-machine interaction represents a technological driver for innovative forms of collaboration and information within the farm. CPSs have a direct effect on maintenance, allowing to improve it in terms of efficiency and quality. In fact, thanks to multiple sensory input/output devices, they provide triggering and predicting services, promoting a remote diagnostic [23,24].

Big Data is defined as "the amount of data just beyond technology's capability to store, manage and process efficiently" [25]. In an Industry 4.0 context, where a relevant amount of real time data is collected from CPSs, Big Data analysis assumes a key role also for maintenance planning [26].

For instance, in [27] authors study a monitoring system for conditions of bearings and gears based on diagnostic algorithms and wireless data transmission. Qiao and Weiss present a prognostic system for industrial robots based on an advanced sensor system with the purpose to optimize maintenance strategies [28]. In particular, available Big Data technologies allow to support predictive maintenance, providing a framework for data processing able to solve several weaknesses related to such strategy [29].

Simulation refer to a digital tool able to assist the production systems design. Simulations are used in value networks and for the optimization of real time data from intelligent systems [30].

Simulations techniques can be used in predicting performance of manufacturing systems and supporting maintenance decisions [31,32]. According to [32], simulations reduce cost and time of maintenance, easily adapting to changes or to the level of available information. For example, Susto et al. (2018) apply simulation to predict maintenance operations basing on historical database [33].

Cloud technology includes "on-demand" digital storage solution and cloud computing [6,34]. Therefore, cloud technology plays a key role for maintenance, allowing to share data from CPSs and using "on-demand" processing resources and devices when necessary [35-37].

Augmented Reality (AR) consists in an interaction among humans and machines for superimposing digital data on reality, merging them in a coherent way [38]. According to [39], AR can be considered the most relevant technology of Industry 4.0 and it represents an effective support for maintenance, being able to guide operator for diagnostics, as well as inspection and training [23]. For example, Gattullo et al. (2019) discussed a methodology to obtain an AR-based technical documentation that consists in the conversion of texts or pdf files [40]. Tablet AR are often used for

maintenance purposes [23,40,41]. However, tablets have relevant limitations, such as battery power requirement and not being a hand-free technology. For this reason, wearable AR or head mounted devices (HMD) are becoming ever more popular [23].
Robotic applications can fulfil several services, interacting with both cobots and operators in performing their tasks [42,43]. In fact, "Cobots" are robots that interact with other robots and humans, and they are also able to learn from them. Robots can be used in acquiring data during inspections or to execute maintenance tasks. In this context, Human-Robot interaction can be considered as a key aspect to perform maintenance [44], while in [45] the authors see in Unmanned Aerial Vehicles (UAVs) a proper tool for engineering structures that are distributed in long distances.
Additive manufacturing refers to the possibility to obtain 3D printed physical objects, converting digital designs, such as 3D CAD [46].
Additive manufacturing allows to generate 3D-printed prototypes that are useful for study and understand production techniques and maintenance tasks in an easier and faster way [30].
Finally, *Cyber Security* is the technology used for protecting shared information and CPSs from the well-known cyber-attacks [47]. Finally according to [23] security can be considered a relevant aspect to take into account and it should be always guaranteed. Furthermore, the authors state that also maintenance of complex and advanced systems requires security features for both hardware and software parts.
As discussed in previous sections, Industry 4.0 technology naturally meets the requirement of a predictive, proactive or prescriptive maintenance policy. Innovative and effective solutions, as remote or self-maintenance, are enhanced by Industry 4.0 technology, offering to industrial practitioners, senior managers and decision makers attractive solutions.
Each of the nine technologies previously described can have a role in maintenance, indicating how maintenance management can change to take advantages from a digitalized factory. Furthermore, new skills are demanded to Operator 4.0, that can interact with autonomous robots, additive manufacturing and augmented reality by use of wearable, HMD, glass data or tablets. The main key factors and criticalities in implementing Industry 4.0 technologies are summarized in table 3.

Table 3. Overview for the implementation of Maintenance 4.0 technologies.

Key factors for maintenance 4.0	*-CPSs, Big Data Analytics, Cloud databases, Simulations* *- AR (wearable, HMD, glass data, tablets)* *- Autonomous robots*
Critical Aspects	*- Accuracy of simulations* *- Reliability of health indexes* *- Reliability of artificial intelligence* *- Potential lack of complete wireless connection*

4. Conclusion

The main purpose of this literature review was to obtain the state-of-the-art of Industry 4.0 technologies used today in maintenance tasks and to understand how it is changing to fit into the Industry 4.0 context. To do this, we selected and analyzed 34 articles present in literature from 2015 to 2020.
Industry 4.0 technology offers relevant possibilities for supporting maintenance and, as emerged from literature, we realized how a proper and modern design for maintenance is highly demanded in a smart factory.
We found that Industrial Internet of Things and Cloud Computing are generally included as enabler technologies in each study analyzed, let us to affirm that such technologies are not only the basis for Industry 4.0 but also for the so called "Maintenance 4.0".

On the other hand, the most suitable technology for maintenance purposes seems to be AR. In particular, AR tablet play a key role for maintenance, although their relevant limitations in terms of practicality and safety. In fact, they are a no hand-free solution and then wearable AR, such as smartwatches, are preferred.

The study also brings to light some critical aspects of maintenance transformation. Complexity of the technology and the need of advanced decision-making algorithms are important aspects to consider in the design of maintenance strategy. Also important is the reliability of artificial intelligence, health indexes and the accuracy of simulations. Furthermore, some smart devices have physical limitation as weight and a potential lack of complete wireless connection.

Finally, our literature review did not find significative studies that discuss maintenance from a perspective of the aforementioned technology of "horizontal and vertical system integration" pillar. We believe that the complexity of such technological pillar represents the starting point for a further review, analyzing the way in which maintenance tasks are integrated in the whole supply chain.

References

[1] Kagermann H, Wahlster W HJ (2013) Recommendations for implementing the strategic initiative Industrie 4.0: securing the future of German manufacturing industry. Berlin

[2] Jazdi N (2014) Cyber physical systems in the context of Industry 4.0. In: Proceedings of 2014 IEEE International Conference on Automation, Quality and Testing, Robotics, AQTR 2014

[3] Alqahtani AY, Gupta SM, Nakashima K (2019) Warranty and maintenance analysis of sensor embedded products using internet of things in industry 4.0. Int J Prod Econ 208:483–499. https://doi.org/https://doi.org/10.1016/j.ijpe.2018.12.022

[4] Cristians A, Methven JM (2017) Industry 4.0: Fundamentals and a quantitative analysis of benefits through a discrete event simulation. In: Challenges for Technology Innovation: An Agenda for the Future - Proceedings of the International Conference on Sustainable Smart Manufacturing, S2M 2016. pp 177–182

[5] Jones M, Zarzycki L, Murray G (2019) Does industry 4.0 pose a challenge for the sme machine builder? A case study and reflection of readiness for a uk sme. IFIP Adv. Inf. Commun. Technol. 530:183–197

[6] Zolotová I, Papcun P, Kajáti E, et al (2018) Smart and cognitive solutions for Operator 4.0: Laboratory H-CPPS case studies. Comput Ind Eng. https://doi.org/https://doi.org/10.1016/j.cie.2018.10.032

[7] Rødseth H, Schjølberg P, Marhaug A (2017) Deep digital maintenance. Adv Manuf 5:299–310. https://doi.org/10.1007/s40436-017-0202-9

[8] McKinsey (2015) Industry 4.0: how to navigate digitization of the manufacturing sector. Detroit. Michigan, USA

[9] Mosyurchak A, Veselkov V, Turygin A, Hammer M (2017) Prognosis of behaviour of machine tool spindles, their diagnostics and maintenance. MM Sci J 2017:2100–2104. https://doi.org/10.17973/MMSJ.2017_12_201794

[10] Lau F, Kuziemsky C (2016) Handbook of eHealth evaluation: an evidence-based approach

[11] Mosconi EM, Silvestri C, Poponi S, Braccini AM (2013) Public policy innovation in distance and on-line learning: reflections on the Italian case. In: Organizational Change and Information Systems. Springer, pp 381–389

[12] Nosi C, Pucci T, Silvestri C, Aquilani B (2017) Does value co-creation really matter? An investigation of Italian millennials intention to buy electric cars. Sustainability 9:2159

[13] Belfiore G, Falcone D, Silvestri L (2018) Assembly line balancing techniques: Literature review of deterministic and stochastic methodologies. In: 17th International Conference on Modeling and Applied Simulation, MAS 2018. pp 185–190

[14] Silvestri L, Falcone D, Belfiore G (2018) Guidelines for reliability allocation methods. In: The International conference on modelling and applied simulation, MAS 2018, pp. 191-198

[15] Silvestri L, Forcina A, Arcese G, Bella G (2020a) Recycling technologies of nickel–metal hydride batteries: an LCA based analysis. J Clean Prod 123083. https://doi.org/https://doi.org/10.1016/j.jclepro.2020.123083

[16] Silvestri L, Forcina A, Arcese G, Bella G (2019) Environmental Analysis Based on Life Cycle Assessment: An Empirical Investigation on the Conventional and Hybrid Powertrain. In: Conference on Sustainable Mobility. SAE International

[17] Silvestri L, Forcina A, Silvestri C, Ioppolo G (2020b) Life cycle assessment of sanitaryware production: A case study in Italy. J Clean Prod 251:119708. https://doi.org/https://doi.org/10.1016/j.jclepro.2019.119708

[18] Di Bona G, Forcina A, Falcone D, Silvestri L (2020) Critical Risks Method (CRM): A New Safety Allocation Approach for a Critical Infrastructure. Sustainability 1–19. https://doi.org/10.3390/su12124949

[19] Forcina A, Silvestri L, Di Bona G, Silvestri A (2020) Reliability allocation methods: A systematic literature review. Qual Reliab Eng Int

[20] Atzori L, Iera A, Morabito G (2010) The Internet of Things: A survey. Comput Networks 54:2787–2805. https://doi.org/10.1016/j.comnet.2010.05.010

[21] Gubbi J, Buyya R, Marusic S, Palaniswami M (2013) Internet of Things (IoT): A vision, architectural elements, and future directions. Futur Gener Comput Syst 29:1645–1660. https://doi.org/10.1016/j.future.2013.01.010

[22] Xu LD, He W, Li S (2014) Internet of Things in Industries: A Survey. IEEE Trans Ind Informatics 10:2233–2243. https://doi.org/10.1109/TII.2014.2300753

[23] Roy R, Stark R, Tracht K, et al (2016) Continuous maintenance and the future – Foundations and technological challenges. CIRP Ann 65:667–688. https://doi.org/https://doi.org/10.1016/j.cirp.2016.06.006

[24] Dinardo G, Fabbiano L, Vacca G (2018) A smart and intuitive machine condition monitoring in the Industry 4.0 scenario. Meas J Int Meas Confed 126:1–12. https://doi.org/10.1016/j.measurement.2018.05.041

[25] Kaisler S, Armour F, Espinosa J, Money W (2013) Big Data: Issues and Challenges Moving Forward
[26] Peres RS, Dionisio Rocha A, Leitao P, Barata J (2018) IDARTS – Towards intelligent data analysis and real-time supervision for industry 4.0. Comput Ind 101:138–146. https://doi.org/10.1016/j.compind.2018.07.004
[27] Ooijevaar T, Pichler K, Di Y, Hesch C (2019) A Comparison of Vibration based Bearing Fault Diagnostic Methods. Int J Progn Heal Manag 10:
[28] Qiao G, Weiss B (2019) Industrial Robot Accuracy Degradation Monitoring and Quick Health Assessment. J Manuf Sci Eng 141:1. https://doi.org/10.1115/1.4043649
[29] Sahal R, Breslin JG, Ali MI (2020) Big data and stream processing platforms for Industry 4.0 requirements mapping for a predictive maintenance use case. J Manuf Syst 54:138–151. https://doi.org/https://doi.org/10.1016/j.jmsy.2019.11.004
[30] Chong S, Pan G-T, Chin J, et al (2018) Integration of 3D printing and industry 4.0 into engineering teaching. Sustain 10:. https://doi.org/10.3390/su10113960
[31] Purohit BS, Manjrekar V, Singh V, Lad BK (2018) Investigating the value of integrated operations planning: A case-based approach from automotive industry AU - Kumar, Sandeep. Int J Prod Res 56:6971–6992. https://doi.org/10.1080/00207543.2018.1424367
[32] Goodall P, Sharpe R, West A (2019) A data-driven simulation to support remanufacturing operations. Comput Ind 105:48–60. https://doi.org/https://doi.org/10.1016/j.compind.2018.11.001
[33] Susto GA, Schirru A, Pampuri S, et al (2018) A hidden-Gamma model-based filtering and prediction approach for monotonic health factors in manufacturing. Control Eng Pract 74:84–94. https://doi.org/https://doi.org/10.1016/j.conengprac.2018.02.011
[34] Hassan QF (2011) Demystifying cloud computing. CrossTalk 24:16–21
[35] Wan J, Tang S, Li D, et al (2017) A Manufacturing Big Data Solution for Active Preventive Maintenance. IEEE Trans Ind Informatics 13:2039–2047. https://doi.org/10.1109/TII.2017.2670505
[36] Fernández-Caramés TM, Fraga-Lamas P, Suárez-Albela M, Vilar-Montesinos M (2018) A fog computing and cloudlet based augmented reality system for the industry 4.0 shipyard. Sensors (Switzerland) 18:. https://doi.org/10.3390/s18061798
[37] Mourtzis D, Vlachou E (2018) A cloud-based cyber-physical system for adaptive shop-floor scheduling and condition-based maintenance. J Manuf Syst 47:179–198. https://doi.org/https://doi.org/10.1016/j.jmsy.2018.05.008
[38] Figueiredo MJG, Cardoso PJS, Gonçalves CDF, Rodrigues JMF (2014) Augmented reality and holograms for the visualization of mechanical engineering parts. In: 2014 18th International Conference on Information Visualisation. pp 368–373
[39] Masoni R, Ferrise F, Bordegoni M, et al (2017) Supporting Remote Maintenance in Industry 4.0 through Augmented Reality. Procedia Manuf 11:1296–1302. https://doi.org/https://doi.org/10.1016/j.promfg.2017.07.257
[40] Gattullo M, Scurati GW, Fiorentino M, et al (2019) Towards augmented reality manuals for industry 4.0: A methodology. Robot Comput Integr Manuf 56:276–286. https://doi.org/https://doi.org/10.1016/j.rcim.2018.10.001
[41] Aschenbrenner D, Maltry N, Kimmel J, et al (2016) ARTab - using Virtual and Augmented Reality Methods for an improved Situation Awareness for Telemaintenance**funded by the Bavarian Ministry of Economic Affairs, Infrastructure, Transport and Technology in its R&D program 'Bayern digital'. IFAC-PapersOnLine 49:204–209. https://doi.org/https://doi.org/10.1016/j.ifacol.2016.11.168
[42] Djuric AM, Rickli JL, Urbanic RJ (2016) A Framework for Collaborative Robot (CoBot) Integration in Advanced Manufacturing Systems. SAE Int J Mater Manuf 9:457–464. https://doi.org/10.4271/2016-01-0337
[43] Sadik AR, Urban B (2017) An ontology-based approach to enable knowledge representation and reasoning in Worker-Cobot agile manufacturing. Futur Internet 9:. https://doi.org/10.3390/fi9040090
[44] Koch PJ, van Amstel MK, Dębska P, et al (2017) A Skill-based Robot Co-worker for Industrial Maintenance Tasks. Procedia Manuf 11:83–90. https://doi.org/https://doi.org/10.1016/j.promfg.2017.07.141
[45] Seneviratne D, Ciani L, Catelani M, Galar D (2018) Smart maintenance and inspection of linear assets: An Industry 4.0 approach. Acta IMEKO 7:50–56
[46] Chua CK, Leong KF, Lim CS (2010) Rapid prototyping: Principles and applications, third edition
[47] Wells LJ, Camelio JA, Williams CB, White J (2013) Cyber-physical security challenges in manufacturing systems. Manuf Lett 2:74–77. https://doi.org/10.1016/j.mfglet.2014.01.005