INNOVATIVE ASPECTS OF ROBOTICS IN THE SERVICE OF LOGISTICS 4.0

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Abstract

The article concerns the application of industrial robots (IR) in selected areas of logistics. In the article there are given premises, from the point of view of which it is worth to consider issues focused around robotics in the context of Logistics 4.0 (L4.0). For this purpose, the results of the research of scientific and business publications (desk research) are presented. In addition, the identification and classification of IR in the aspect of their use in L4.0 is given. Further, selected examples of IR that can be used in selected areas of logistics were identified. Next, an analytical model helping to assess the level of innovativeness of a group of solutions was presented, and finally, the innovativeness of the identified IR was assessed in terms of their inclusion among the machines that can be or are the subject of research in L4.0.

Keywords: Logistics 4.0, AGV, LGV, AMR, industrial robot, mobile robot, robotics

1. INTRODUCTION

The world of logistics, as well as the world of industry, entered the next stage of change almost a decade ago. This stage is characterized by a wealth of innovations, experimentation with technological novelties and even a kind of industrial revolution, called as the 4.0 revolution. Logistics 4.0 (L4.0) is a relatively new, complex concept directly related to Industry 4.0 (I4.0), while I4.0 is a term describing a general view of "intelligent factories" of the future, just as the term "intelligent logistics" is a reference to L4.0. Solutions of L4.0 are focused on autonomous trucks used for supplies, drones for supporting of internal logistics processes as well as external last mile deliveries, shared capacities on exit from internal facilities, etc. The implications for I4.0 in logistics are described in [1]. This relative novelty of L4.0 concept can be confirmed by trend analysis in Google Trends or by analyses carried out on the basis of documents collected in scientific databases such as Web of Science (WoS), Scopus, Google Scholar, as presented below.

The analysis performed with the use of the Scopus database (Nov 3, 2019) is worth considering. When the keyword “Logistics 4.0” was introduced in relation to the search of three records at the same time, i.e. title, abstract, keywords, the following results were obtained. 39 documents were found, e.g. 17 in 2019 up to date, 10 in 2018. Meanwhile, WoS database was searched in all fields with the same keyword - date of analysis: Nov 3, 2019. Only 16 documents were found, e.g. 6 in 2019 up to date, 5 in 2018.The analysis performed with the use of the Google Scholar scientific database (date of analysis: Nov 3, 2019) is worth considering as well. It is compared to analogical analysis performed on Feb 22, 2019 (given in brackets in the **Table 1**). 480 records were noted in that database (in previous analysis it was 270 records), of which 149 were published in 2019 (previously 13 records) and 280 in 2018 (previously 111 records). Admittedly, 2019 was not the end of the year when the article was written, but an increase in publications of this type is expected, as interest in I4.0 and L4.0 is significantly growing. The statistics in **Table 1** shows that potential of L4.0 accrues.

Among the issues related to L4.0 that are of particular technological interest are as follows: Internet of Things (IoT), robotics, big data, cloud logistics, augmented reality, low-cost sensors technology, identified in 2016 as particularly significant and subject to intensive development over the next 5 years, [2]. A further group of concepts are autonomous vehicles, 3D printing, self-learning systems, digital identification, bionic aids, unmanned aerial vehicles - in 2016 they were considered to have been developed later than the five-year period mentioned above [2]. The report [3] recalled the same concepts for the first group of concepts, and the second group of concepts included: artificial intelligence, block chain, virtual reality and digital twins, wireless connectivity of the next generation. Taking into account the first group of terms, it can be observed that the accompanying terms are intertwined, because these technologies are interrelated and mutually reinforce their capabilities in terms of their application in the broadly understood logistics systems. These include in particular: IoT, robotics, big data and low-cost sensor technology. Devices and machines equipped with elements described by these terms belong to the group of devices and machines centered around I4.0, and therefore L4.0. This article is devoted to them, e.g. it discusses the topics of robots equipped with sensors, collecting large scale data, whose analysis has an impact on the improvement of logistics systems.

Table 1 Desk-research results of keyword ("Logistics 4.0") searching in selected databases - dates of analysis: November 3, 2019 (February 22, 2019)

Year of analysis	Scopus	Web of Science	Google Scholar
2019/2018/2017	17 (N/A)/10 (5)/3 (3)	6 (2)/5 (5)/3 (N/A)	149 (149)/280 (111)/340 (56)
Previous years than above	5 (5)	2 (2)	480 (270)

2. PREREQUISITES FOR THE RESEARCH ISSUE SELECTION

The importance of using robotics in L4.0 was estimated at approximately 75 % of the scale indicated in the report [2] (a high level on this scale means that entities focused around a given concept will contribute to the development of new ways of doing business, while a low level means ensuring the possibility of gradual improvement of the situation, which means that the lower the representative of a group of concepts is on the scale the faster it can make innovative changes in the business). The potential of robotics was high in the scale of interest of companies implementing the so-called I4.0. This trend "outclassed" IoT, which according to the report was to be the peak of significance for the current year. This means that in the opinion of the authors of the report, the interest in robotics will increase even more, as this trend in the scale indicated in the report [3] seems to exceed 95 % on the scale of significance of the application of all sorts of trends. The madness of robotization in L4.0 is reinforced by the fact that one of the largest companies dealing with B2C e-commerce has 45,000 mobile robots in the company's warehouses since 2012, [4].

3. CLASSIFICATION OF INDUSTRIAL ROBOTS

The subject matter of robotics research is naturally robots (including industrial robots - IR). IR as defined as an automatically controlled, reprogrammable, multipurpose manipulator programmable in three or more axes, which can be either fixed in place or mobile for use in industrial automation applications, [5]. According to [6,7], there are four basic types of IR: sequential, trajectory controlled, adaptive, mobile. Due to the withdrawal of the standard on 6 September 2018 [7], the classification of IR presented in [8] is referred in this publication. This classification is shown in **Figure 1**. Addressing the issue of robot applications in L4.0 is even more important as the density of robots in the world is increasing, which can be seen in **Figure 2a**. This density is understood as the number of IR per 10,000 employees in a given country [9, 10]. In recent years the use of IR has significantly increased. **Figure 2b**. shows the estimated numbers of IR deliveries for 2008-2021. From the I4.0 point of view, the level of innovativeness of solutions can be assessed according to [11].

From a technological point of view, classification by areas of application seems to be more important [13,14]. From the point of view of L4.0, the most interesting are transport robots and robots for material handling and loading of pallets (AGV, LGV, SGV), as well as other mobile robots, etc. For purpose of this article selected IR, that can or have been used in logistics systems, are chosen and evaluated in terms of their potential inclusion among the solutions focused around I4.0 and L4.0. This evaluation is carried out as a result of a search for robots, that they arouse the greatest interest from the point of view of L4.0. Next, the solutions will be evaluated as a result of using a tool used to assess the innovativeness of solutions.

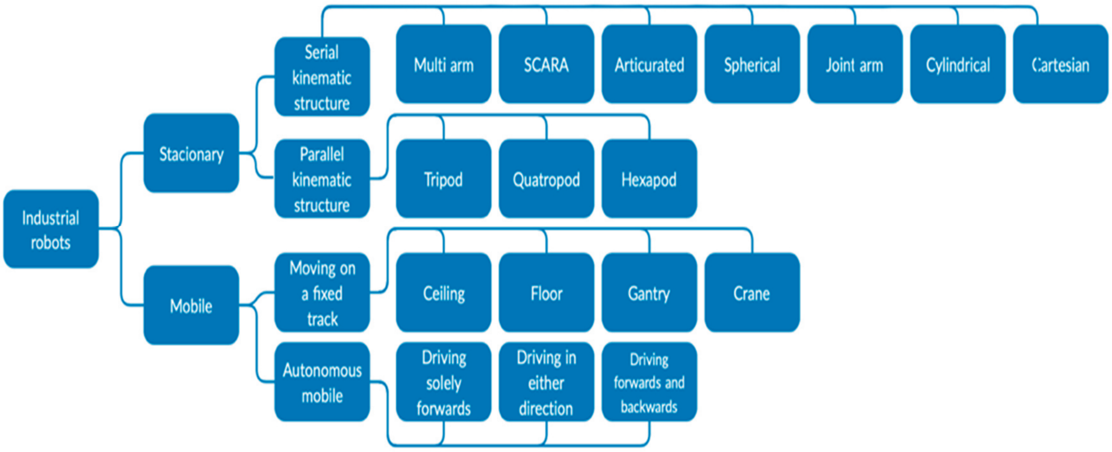


Figure 1 Classification of IR [8]

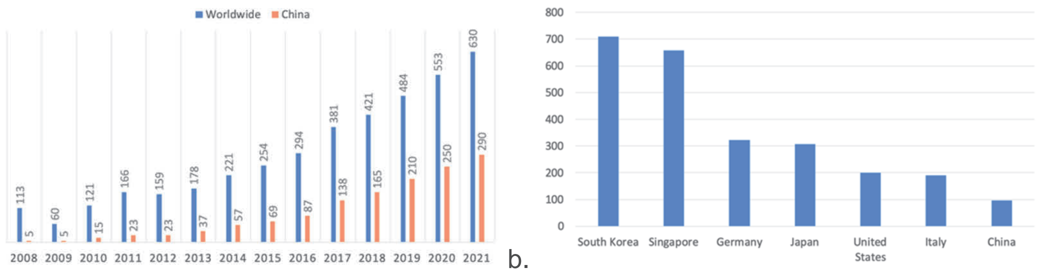
a.  b.

Figure 2a Growth of IR worldwide and on China sample - estimated annual supplies of IR between 2008 and 2021, **2b** Robots density (in thousands) in 2018; a. and b. based on [12]

4. MACHINE EVALUATION MODEL IN THE CONTEXT OF L4.0

This section presents the tool for assessing the innovativeness level of the discussed solutions in relation to L4.0. It is the tool redefined after [11,15], where: $\boldsymbol{A}$ - a set of numbers of presented and assessed solutions, $\boldsymbol{A} = \{0, \dots, a, \dots, A\}$, $\boldsymbol{S}$ - a binary set explained by its elements, $\boldsymbol{S} = \{0,1\}$, where $s = 0$ if the solution in question existed before or during 2011 and $s = 1$ otherwise, $\boldsymbol{P}$ - a binary set that explains whether a chosen solution has been implemented, $\boldsymbol{P} = \{0,1\}$, $p = 0$ if the solution in question was not implemented before, during or after 2011, $p = 1$ otherwise. The Cartesian product shall then be appointed as in equation (1), the elements of which are transformed into the set $\boldsymbol{I}$ as it is given in equations (2) and (3). The $i(a,s,p)$ is binary parameter which takes value 1 for solutions that existed after 2011 and are fully implemented.

$$i(a,s,p) \colon \boldsymbol{A} \times \boldsymbol{S} \times \boldsymbol{P} \rightarrow \{0,1\}, \tag{1}$$

$$\boldsymbol{I} = \{i(1,0,0), \dots, i(a,s,p), \dots, i(A,S,P)\}, a \in \boldsymbol{A},\ s \in \boldsymbol{S},\ p \in \boldsymbol{P}, \tag{2}$$

$$i(a,s,p) = \begin{cases} 0 \colon \exists s = 0\ \wedge\ \exists p = 0 \vee p = 1 \\ \quad 1 \colon \exists s = 1\ \wedge\ \exists p = 1 \end{cases} \tag{3}$$

The $\bar{\imath}$ parameter quantifies solutions which determines the number of potentially innovative solutions:

$$\bar{\imath} = \sum_{a \in \boldsymbol{A}} \sum_{s \in \boldsymbol{S}} \sum_{p \in \boldsymbol{P}} i(a,s,p). \tag{4}$$

If the condition (5) is met, then solutions from set $\boldsymbol{A}$ (taken together) are not considered to be innovative. In other case solutions from set $\boldsymbol{A}$ can be considered as innovative, where: $card(\boldsymbol{A})$ - cardinality of a set $\boldsymbol{A}$:

$$\exists(\bar{\imath}/card(\boldsymbol{A})) \leq 0.50. \tag{5}$$

Table 2 List of devices

Device/robot	Type of a robot	Release	a	s	p	$i(a,s,p)$
Vecna RL350, Vecna RC500 [16]	Autonomous robotic vehicle (ARV)	2017	1	1	1	1
Kiva [17,18,19, 20]	AGV, LGV, ARV	2006	2	0	1	0
Aurora CEITruck [20, 21]	AGV, LGV, ARV	2007	3	0	1	0
Butlers [22]	AGV	2018	4	1	1	1
CarryPick KMP600 [17]	AGV	2012	5	1	1	1
BinGo [23]	AGV	2016	6	1	1	1
KUKA mobile platform (KMP) 1500 [24]	AGV	2017	7	1	1	1
Baxter [25]	packaging robot	2011	8	1	1	1
Roberta [25]	6-axesrobot	2015	9	1	1	1
SERVUS ARC3 [26, 27, 28]	transport robot	2013 [29]	10	1	1	1
Agile1500 [30, 31, 32]	AGV	2017	11	1	1	1
Aethon TUG - AMR [33, 34, 35]	AGV	2013 [34]	12	1	1	1
MiR100, MiR200, MiR500 [35, 36, 37]	AGV	2016	13	1	1	1
LD-60, LD-90 [38, 39] LD-130CT [35]	LGV, ARV	2017 [38]	14	1	1	1
SEIT100, SEIT500 [35]	LGV	2017	15	1	1	1
OTTO 100, OTTO 1500 [35, 40, 41]	LGV, ARV	2018 [40, 41]	16	1	1	1
Elettric80 Giraffe	pallet lift truck	2009 [42]	17	0	1	0
Robotino Basic (Premium) Edition [43]	AMR, AGV	2016 [43]	18	1	1	1

5. SPECIFICATION OF SELECTED INDUSTRIAL ROBOTS

Selected IR in applications for L4.0 are presented in **Table 2**. In the same table, the data necessary for the use of the described model are presented.

6. CONCLUSION

Based on information given in **Table 1**, it can be stated that more than 83 % ($\bar{\imath}/card(\boldsymbol{A}) = 0.83$) of presented devices and solutions were released after the Hannover Fair of Industrial Technologies which took place in 2011. This might mean that the idea of I4.0 utmost significantly contributes to the innovation of robotic products in the sphere of L4.0. It can be stated that the innovativeness level of solutions suggested as belonging to L4.0 in the context of I4.0 is about 83 %, therefore it is very satisfactory. The article indicates that IR used in L4.0 are characterized by a high level of innovation. The authors are aware of the fact that the analysis of the years of origin, practical application and maturity of solutions are too general assumptions, therefore it is worth undertaking analyses concerning technological, organizational and financial issues of solutions in the context of their location in logistics systems. In the model, it is worth considering the aspects of its maturity and customer satisfaction [44] and routing in transport processes [45]. This constitutes further research work.

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