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ORIGINAL PAPER

DESCRIBING THE TECHNOLOGICAL SCOPE OF INDUSTRY 4.0 – A REVIEW OF SURVEY PUBLICATIONS

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ABSTRACT. **Background:** The paper addresses common difficulties of understanding the scope and the underlying technologies of “Industry 4.0”. Existing definitions comprise a variety of technologies and applications, processes as well as business models. Their difficult differentiation has led to a complicated understanding of the topic altogether.
Therefore, this study aims at a structuring of the scope of “Industry 4.0” using the average importance of its underlying technologies, as it is represented in 38 survey publications dedicated on Industry 4.0.
Methods: Based on a review of existing survey literature on Industry 4.0, relevant technologies are identified. Next, these technologies are recapped in five technology areas. Furthermore, all technologies are assessed according to their relevance to Industry 4.0 using citation indices of the respective publication. Finally, two-dimensional figures are used to present an overview structure of all cited technologies, their structural connections and their relevance. In summary, a structuring of “Industry 4.0” through the cited technologies and their evolution over the years 2013 until 2016 is displayed to facilitate the understanding of significant research trends and promising application areas within “Industry 4.0”.
Conclusion: Compared to existing reviews and empirical approaches on the topic, this paper focusses on a review of survey literature specifically dedicated to an understanding of the concept of Industry 4.0. The results allow an overview of the respective relevance of technologies within the comprehensive scope of the topic. It shows the most often used technologies (web services with a relative importance of 3.46/5) as well as the evolvement of the importance of each technology within the period of 2013-2016.

Key words: Industry 4.0, Technology Management, Technology Scouting, Advanced Manufacturing, Smart Factory.

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INTRODUCTION

The term ‘Industry 4.0’ refers to an expected upcoming fourth industrial revolution [Kagermann 2013] due to systematical deployment of Cyber-Physical Systems (CPS), advanced information analytics, networked machines that will be able to perform more efficiently, collaboratively and resiliently [Lee 2015].

Industry 4.0 and the innovations that are incorporated are currently under investigation by numerous research institutes as well as by companies [Yin 2017] and even country’s industrial strategies [Santos 2017]. However, the interpretation of the term is very different [Pantförder 2014]. Various definitions and interpretations have emerged for the Industry 4.0 concept. Up to now, a generally accepted understanding of the term does not exist [Hermann 2016, Bischoff 2015, Heng 2014]. In addition, many different technologies, functionalities and application examples are publicly assigned to it without using defined assessment criteria. Some authors even

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mention a dilution of the Industry 4.0 concept [Hermann 2016, Bauernhansl 2014].

BACKGROUND

The term "Industry 4.0" itself was first presented in 2011 to a broader public [Kagermann and Lukas 2011]. With the implementation recommendations for the future project Industry 4.0 [Kagermann 2013] and the subsequent development of the platform Industry 4.0 [Plattform Industrie 4.0 2018], the activities received an additional boost. This was further strengthened by first implementation examples and promotion activities at the national and international level. The development of industrial production, similar to the Industry 4.0 strategy, has also been advanced beyond the German-speaking countries in countries such as the USA, China, Japan, France and at the EU level [Zhong 2017].

With Industry 4.0 many different objectives are closely linked within the framework of the formulated "dual strategy" [Kagermann 2013]. On the one hand, innovative products and product-oriented services are to be developed in order to positioning the domestic industry as the leading provider of networked intelligent products [Schmidt 2015]. On the other hand, the strategy pursues that companies integrate these innovative Industry 4.0 technologies into their value-added processes at the same time and thus create a leading market for the industrial use of the new solutions [Kusiak 2018], [Monostori 2014]. The recommendations for action of the research team distinguish three main areas [Kagermann 2013]:

– Horizontal integration via value-added networks
– Consistency of engineering across the entire value chain
– Vertical integration and networked production systems.

Because of the development, completely new business models are expected on the product and production side. This is made possible by price declines in the area of industrial hardware and software – cobots, mobile devices and wearables, ID tags and transponders, as well as sensors and storage space. In addition, the Internet is widely used as a data exchange platform in the B2C and B2B area and is expected to merge with an Internet of Things and an Internet of Services. However, the truly relevant increases in productivity will only succeed if the use of technology is reflected in more effective and efficient production processes.

SCIENTIFIC AIM AND NOVELTY

The aim of this paper is to support a grounded common understanding of the relative importance of technologies within the scope of Industry 4.0 for both, the scientific community and industry. Therefore, a sound approach was quested to determine which technologies are considered to be at the core of the concept or rather within the surroundings.

There have already been approaches to analyze publications on Industry 4.0 in order to identify:

– Frequently used words and sentiments [Yilmaz 2017]
– Major concepts and key techniques [Zhong 2017]
– Key aspects in terms of meanings and the implications of the Industry 4.0 concept [Pereira 2015],
– Design principles [Hermann 2016],
– Smart products [Schmidt 2015],
– Modeling [Wortmann 2017] and
– Implications for mobile supply chain management (mSCM) [Barata 2018].

All authors employed textual analysis or a mapping study [Wortmann 2017] on a part of the existing literature, focusing on selected scientific papers or Twitter feeds [Yilmaz 2017]. Though some of the results have some overlapping, none of the approaches shows the relative importance of technologies within Industry 4.0.

To achieve this aim, an empirical analysis of existing survey literature was chosen in order to identify which 'Industry 4.0 technologies' are of central and marginal importance. The result of this work is a graphical representation, which shows the technologies relevant to the industrial revolution based on surveys and their scientific citations.

RESEARCH PROCESS AND RESEARCH METHOD

In principle, all information sources can be used for researching technology information. In early technology phases, implicit sources of information about contacts are used, since often there are not enough independent written sources. In order to fill the gaps in the information as reliably as possible despite this state of affairs, interviews with experts from the respective field are usually used. However, the technologies in the context of Industry 4.0 seem to have passed through the very early stages. There are already a large number of written, explicit data sources that can be accessed. The fact that so many publications exist on this topic makes it possible to rely exclusively on such explicit data sources as a sound information base.

With regard to the evaluation of Industry 4.0 technologies, this makes it possible to carry out an assessment based on many different authors' opinions. This avoids overweighting of a few, subjective expert opinions. For this reason, the use of implicit sources of information is dispensed with, and only a search of explicit sources is carried out.

With regard to the assessment of Industry 4.0 technologies, a further aspect has to be considered. The publications used must deal with Industry 4.0 as a whole as far as possible in order to identify differences in the importance of individual technologies for Industry 4.0. If studies are included in the assessment, which consider the partial aspects of Industry 4.0, the technologies of this partial view are given greater attention than they are in the overall context of Industry 4.0.

In order to perform an efficient technology evaluation, a high degree of detailing of the research is only to be applied where it is also necessary. The different detail levels range from coarse technology fields down to the application level and are shown in Figure 1. The technology assessment is carried out on the level of superior technologies, which provides a good, still manageable overview about Industry 4.0. Further detailed information about individual technologies or application cases related to the superior technologies can be collected where it is necessary.

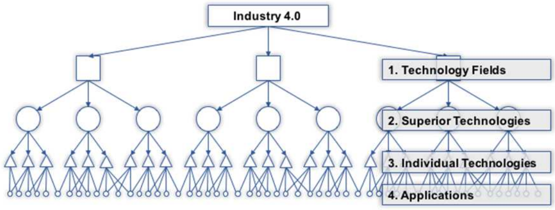

Fig. 1. Scope of technology evaluation

To determine the importance of a technology in the context of Industry 4.0 an approach is chosen which first assesses the importance of a technology within individual publications, and then aggregates the overall importance of technology in the overall context of Industry 4.0 through evaluation of a broad range of publications. This approach is chosen, since the meanings of the Industry 4.0 technologies are determined based on a large number of different publications. The results are more scientifically sound as if they were based on a survey of fewer experts. The evaluation of a technology within Industry 4.0 takes place in three steps, which are described in detail below:

- Assessment of the importance of technologies within individual publications. The evaluation scale is shown in table 1.
- Evaluation of the importance of each publication.
- Aggregation of the importance of a technology within individual publications and the importance of these publications on the overall importance of the technology in the context of Industry 4.0.

Table 1. Assessment scale for the importance of technology within a publication

		Importance	Frequency
Technology is not mentioned within the publication. Technology has no importance for Industry 4.0.	0	low	low
Technology is mentioned in the publication, but only very rarely. Technology has very little importance for Industry 4.0.	1		
Technology is mentioned within the publication with low frequency. Technology has little importance for Industry 4.0.	2		
Technology is mentioned in the publication with medium frequency. Technology has medium importance for Industry 4.0.	3		
Technology is mentioned frequently within the publication. Technology has a great importance for Industry 4.0.	4		
Technology is mentioned very frequently within the publication. Technology has greatest importance for Industry 4.0.	5	high	high

IMPORTANCE OF A TECHNOLOGY WITHIN A PUBLICATION

Publications are scored for mentioning of technologies and comments about their importance for Industry 4.0. Based on the criteria shown in table 1 the importance of each technology is subsequently rated on a scale from zero (no mentioning) to five (frequent mentioning with remarks about their importance for Industry 4.0). To keep track of the importance values a table is created. A new column is added for each inspected publication. If new technologies are mentioned, another row is added. After reviewing all publications, the technology table shows first all technologies related to Industry 4.0 and second the importance of each technology for the topic.

IMPORTANCE OF EACH PUBLICATION

The relevance of the publications is included in the assessment of the importance of Industry 4.0 in order to give recognized sources of information a higher weighting than rather unknown ones. This prevents the fact that rather exotic opinions, which are not shared by the majority, do not feed into the meaning of a technology as generally accepted and correct opinions. Based on a broad public opinion, the results may be based on their general validity rather than on the opinion of individual persons or selected persons.

To ensure that the evaluation of the relevance of publications is not influenced by the opinion of a person or a small group of persons, it must be based on purely objective criteria. As a common measure of the importance of a source, its citation frequency has proven its worth. This is based on the assumption that highly cited publications have a high scientific qualification [Albers and Gassmann 2005]. As a source for the determination of the citation number per publication used so-called citation databases, which contain information about how often and where a publication was cited. There are different citation databases, which are free or accessible by means of licenses. Table 2 presents an overview of the citation databases considered.

Table 2. Possible citation databases to determine the citation frequency of the publications used

Citation database	Accessibility	Thematic focus
Google Scholar	Free accesible	General
Web of Science	License required	General
Microsoft Academics	Free accesible	General
CiteSeer	Free accesible	Computer Science
Scopus	License required	General, but only journal papers on Elsevier

Google Scholar, Web of Science and Microsoft Academics have been used as sources of data for the citation based technology ranking. Most of the included publications are listed on Google Scholar. For this reason, the rates of citation are primarily taken there. If a publication is not listed on Google Scholar, the numbers from one of the other two databases are used.

The number of citations is then used to classify the meanings of a publication on a scale of one to five (similar to the meanings of the technologies within a publication). The classification of the technologies is based on Table 3.

Table 3. Rating scale for the meaning of a publication

Number of citations on Google Scholar (or Web of Science, or Microsoft Academics)	Importance
no citations	1
< 5 citations	2
< 10 citations	3
< 100 citations	4
> 100 citations	5

This makes an objective assessment of the importance of the sources used. This method nevertheless has a disadvantage. Citations arise from the fact that publications are read by other authors and refer to them in their own publications. Until these citing publications are written and published, some time passes by. Therefore, new sources tend to have fewer citations than older ones. This can in principle be taken into account in the classification of meaning based on the assessment scale. However, the consideration of the temporal development of citation based on facts is complicated and therefore difficult to implement. This assessment method does not take into account the temporal development of the publications' citations.

AGGREGATION OF THE IMPORTANCE VALUES

First, the values for the meaning of the publications are supplemented in the technology table. This value is then multiplied by the importance of the technologies within this publication and recorded in a further line. If these values are added line by line across all publications (columns), values are obtained that reflect the importance of the technologies in the context of Industry 4.0. If these values are then divided by the sum of the meanings of the publications, they are scaled down to a scale of zero to five. The calculation of the importance of a technology X over all studies in the context of Industry 4.0 can be calculated using the following formula:

$$B_x = \frac{\sum_y (B_{xy} \cdot P_y)}{\sum_y P_y}$$

B_x - importance of technology x in the context of Industry 4.0

B_{xy}- importance of technology x in publication y

P_y - importance of publication y

CATEGORIZATION INTO TECHNOLOGY FIELDS

The categorization of the technologies into technology fields takes place according to the criterion of the function or the application area, but not with the characteristics of material, product and production technology. Instead, five technology fields are defined as expressions, each combining technologies of similar functions, objectives or areas of application.

The five technology fields used in this work are:

- Communication technologies
- Embedded systems
- Human-machine interface
- Software and systems engineering
- Smart Factory

They reflect a subset of the different technology fields used in other publications. The basis for this elaboration is the overview of the technology fields according to Bischoff [Bischoff 2015]. Their overview also contains the first four technology fields. In addition, they introduce "sensors", "actuators" and "standards and standardization" as further technology fields. Standards and standardization are not understood as technologies in this work, which is why this technology field is not adopted. The technology fields of sensors and actuators are not treated as separate technology fields. Instead, they are integrated into the "embedded systems" technology field. This is also reflected in the Industry 4.0 technology fields according to Bauer [Bauer 2014] as well as Emmrich [Emmrich 2015]. Both of them also introduce a "Smart Factory" technology field, which has also been included in this paper and represents the fifth and final technology field.

INDUSTRY 4.0 TECHNOLOGY COSMOS

After the technology assessment and their categorization into technology fields, the third step towards the implicit description of the Industry 4.0 concept is the classification of technologies in the context of Industry 4.0. This is to be done by means of a two-dimensional graphical representation, from which the structuring and the importance of the technologies in the context of Industry 4.0 emerge at a glance. The development of this Industry 4.0 technology cosmos is explained more detailed in the following section.

A two-dimensional diagram similar to the monitoring radar is selected from technology forecasting. In this representation, several information about the respective technologies can be displayed simultaneously. In addition to the importance of the technologies in the context of industry 4.0, this includes both the affiliation to the technology fields and the thematic proximity to other technologies.

In principle, the diagram is circular. In the center, industry 4.0 is a fixed point and the umbrella term for technological change, which takes place in industrial production. The individual technologies that contribute to this change are arranged as circular areas. This is done by means of a distance and an angle specification, which are assigned to each technology. This assignment is not arbitrary, but based on the previously described information, which should be included in the diagram. The distances to the center are calculated based on the meanings of the technologies. The importance of the technologies is also reflected by the area of the individual circles. This means that technologies with a great importance appear to be larger and closer to the center than unimportant technologies. The general Industry 4.0 technology cosmos is shown in Fig. 2.

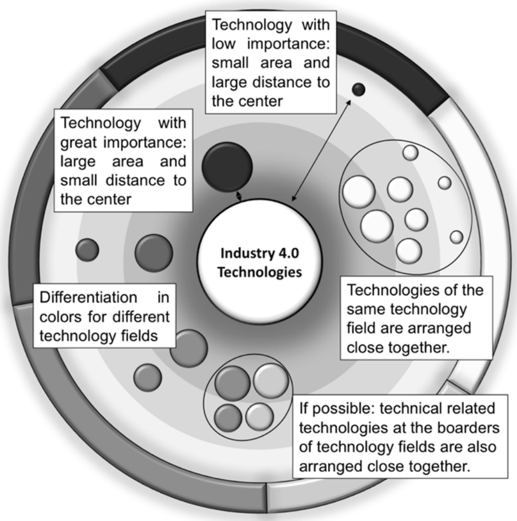

Fig. 2. General Industry 4.0 technology cosmos with guidelines for creation

The distance of a technology to the center of the diagram is determined based on the meanings from the technology evaluation table. However, these values cannot be taken directly as a distance, since technologies with a great importance are further removed from the center than unimportant technologies. In order to arrange important technologies close to the Industry 4.0 concept, the meaning values must therefore be converted into distance values with a function. The simplest possibility would be to choose a linear relationship between the mean value and the distance value. However, this has the disadvantage that unimportant technologies have very large distances to the center and many empty surfaces are formed around them. At the same time, the important technologies close to the center would overlap because of the small size available at small radii. This would lead to a confusing and diffuse presentation. In order to obtain a compact and at the same time clear overview, the meaning values must therefore be converted into radius values with a function which increases the distances between large meanings and reduces the distances between small meanings. The function used for this work is shown below.

$$A_x = a + \frac{b}{(c - B_x)^4}$$

A_x distance of technology x to the center of the diagram
B_x importance of technology x
a,b,c,d parameters for the calibration

The angle at which a technology is placed in this cosmos is determined by the following priorities. First, technologies of a technology field are arranged in the same area of the technology cosmos. The angles of the individual technologies are selected in such a way that the technologies do not overlap as much as possible. If spaces remain to move the technologies, secondly, it can be tried to arrange thematically related technologies close together. This is first done within the technology fields. Subsequently, it is also attempted to arrange thematically related technologies as close as possible to one another beyond the boundaries of the technology fields. These steps are carried out in an iterative process, in which the scaling of the area contents and the distances to the center are always adapted in order to obtain a clear overview as far as possible. For the sake of clarity, the technologies of different technology fields are also differentiated from one another in color.

The technology cosmos allows the technological side of Industry 4.0 to be surveyed in a presentation. The differentiation of colors also enables the structuring of the Industry 4.0 concept to be quickly captured in different technology fields. From the size of the circular areas and the proximity to the center, the importance of the individual technologies visually emerges and helps to differentiate what is indeed central and what is rather incidental.

RESULTS

The importance of the technologies was evaluated as an average over the years 2013 to 2016 and for the years 2013 to 2015 separately to identify changes over the time. The calculated values are based on an evaluation of 38 publications. Table 5 shows how the publications are composed over the years and the number of citations.

Table 4. Composition of the publications and their share in the determination of the overall importance

	Number of publications	Split by number of citations					Sum of the importance values of the publications	Share of the total importance
		0	<5	<10	<100	>100		
total	38	13	7	13	2	3	89	100%
2013	10	3	2	3	0	2	26	29.2%
2014	13	2	4	4	2	1	35	39.3%
2015	13	6	1	6	0	0	26	29.2%
2016	2	2	0	0	0	0	2	2.2%

It is possible to deduce the weighting of the individual years in determining the overall average. The years 2013 to 2015 each account for about one-third of the weighting of the overall average. Even though the publications from 2014 represent a slightly higher proportion, it can nevertheless be assumed that the results reflect a balanced picture of Industry 4.0 over the past few years. From 2016 only two studies were used, which is why their influence is rather marginal at 2%. This is also because these publications do not yet have any citations since they are still very young. However, there is no reason not to include them in the evaluation.

Each technology has been evaluated from zero to five within the studies. Together with the meanings of the individual publications, they were used to determine mean values for each individual technology over the period from 2013 to 2016.

The results are shown in Table 4. The technologies with the greatest significance for Industry 4.0 reach values of more than three. Partially, a technology is not mentioned in some publications at all and is therefore rated as zero. The zeros significantly reduce the average. This means that no values are reached in the upper range of the scale (four to five). A meaning of 3.46, like that of the web services, is therefore not to be estimated as medium-moderate, but as extremely high.

Table 5. Meaning values of the individual technologies on average over the years 2013 to 2016.

		Importance
Communication technologies	Machine-to-Machine communication	3.26
	Wireless technologies	3.02
	IT security	2.91
	Wireline high-performance networks	2.04
	Intelligent communication protocols	1.48
	Industrial Ethernet	0.79
Embedded systems	Sensors	3.26
	Microcontroller	3.01
	Auto-ID technologies	2.04
	Actuators	1.29
	Positioning systems	0.92
	Energy harvesting	0.18
Human-machine interaction	Mobile assistance systems	3.10
	Virtual reality/ Augmented reality	2.55
	Context-based information presentation	1.96
	Intuitive operation elements	1.61
	Voice control	1.24
	Gesture control	1.08
Software/systems engineering	Cloud computing	3.09
	Big data	2.85
	Real-time data	2.71
	Social technologies	1.66
	Simulation	1.43
	Machine learning	0.99
	Semantic technologies	0.37
	Middleware	0.19
Smart factory	Autonomous and decentral control	3.13
	Innovative robotics	2.49
	Plug and produce	2.42
	Smart machines	2.28
	Smart products	1.85
	Additive manufacturing	1.30
	Industrial smart grids	1.04

At this point, only the most important technologies, with a value of more than three, will be highlighted. They have in common that they enable enormous improvements in industrial production. Web services (3.46) and cloud computing (3.09) revolutionize the IT systems in the production networks. They simplify data exchange between different applications and enable real-time optimization across entire sites. Wireless communication technologies (3.02) are the basic prerequisite for integrating mobile objects such as vehicles, tools or products into the comprehensive data exchange. Another revolutionary innovation is the autonomous and decentralized control (3.13) of the machines and plants. A prerequisite for this is that machines can exchange via M2M communication (3.26). The ability to make their own decisions are obtained by their own computing power in the form of microcontrollers (3.01). The basis for all decisions is a variety of different information, which is partly gained by sensors (3.26). To enable people to make the best decisions in this highly complex production environment, they need support in the form of mobile assistance systems (3.10).

Thus, all the necessary values for the creation of the technology cosmos were available. Based on these average importance values over the years 2013 to 2016, the parameters for the creation of the technology cosmos were determined. The resulting Industry 4.0 technology cosmos is shown in figure 3.

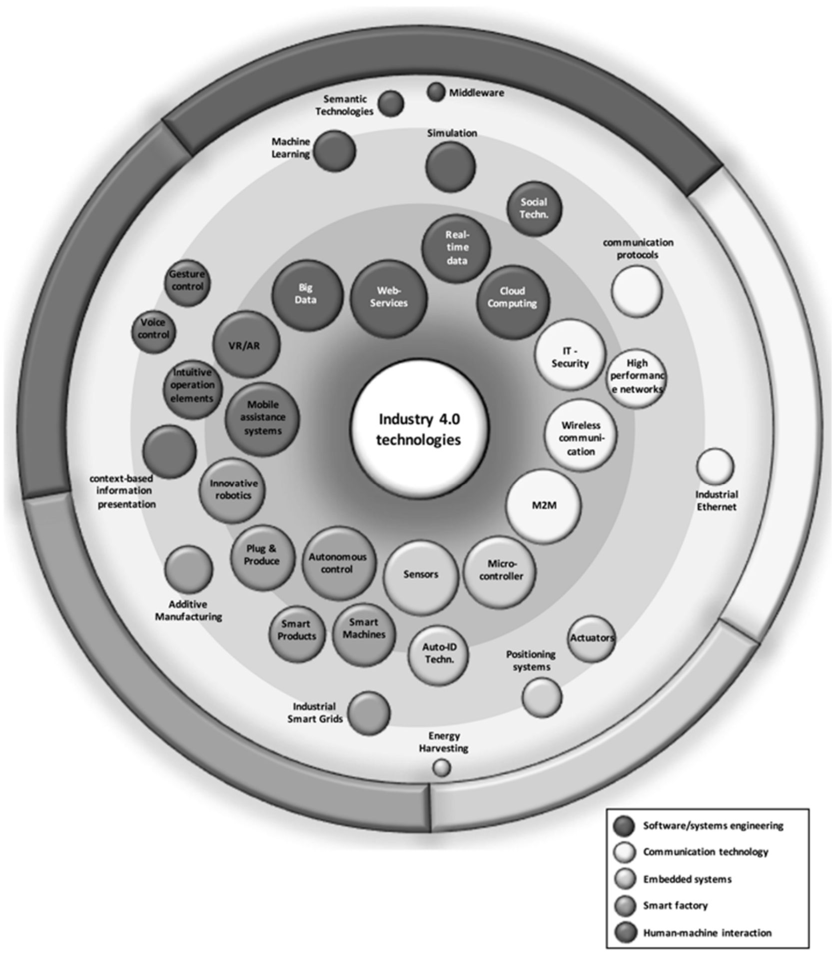

Fig. 3. Industry 4.0 technology cosmos based on the average importance over the years 2013 to 2016

CHANGES IN RELATIVE IMPORTANCE BETWEEN 2013-2015

What does not appear from the presentation of the technology cosmos in the preceding chapter in addition to all aspects included, are temporal changes in the importance of the individual technologies. Therefore, a further presentation of the Industry 4.0 technology cosmos was created. In addition to presenting the average since 2013, this represents the changes during this period.

These three representations were subsequently superimposed in a representation, so that temporal changes of the meanings emerge from a representation. In order to maintain comparability, the exact formula for determining the distances to the center was used every time. The distance to the center therefore offers a possibility to recognize directly whether a technology gained importance over time (moved closer to the center) or lost (moved to the outside). For reasons of clarity, the circular areas had to be reduced compared to the general presentation (average over the years 2013 to 2016). In order to maintain the comparability, the circles were scaled down by the same factor for each of the three years. The angle values for the technologies were also slightly changed for the sake of clarity, compared to the general cosmos. However, the angular values have been changed for the same amount every three years, so that a technology is always at exactly one angle and moves only in the radial direction inwards or outwards. The result is shown in figure 4.

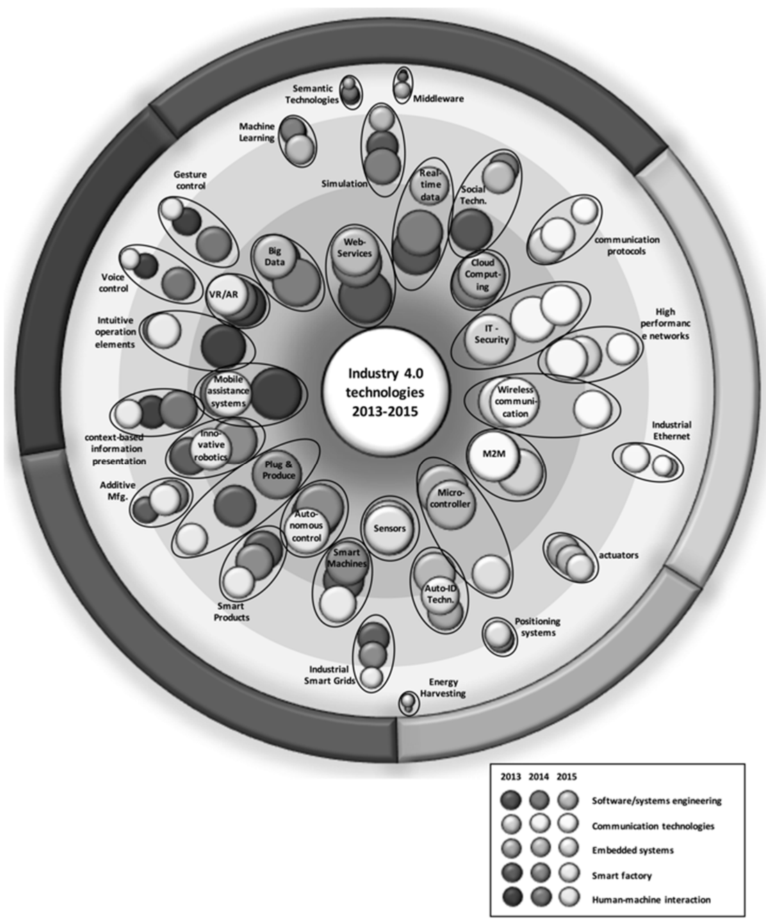

Fig. 4. Trend development of the Industry 4.0 technology cosmos from 2013 to 2015

CONCLUSIONS

The aim of this paper was to support a grounded common understanding of the relative importance of technologies within the scope of Industry 4.0 for both, the scientific community and industry. Compared to existing reviews and empirical approaches on the topic, this paper focusses on a review of survey literature specifically dedicated to an understanding of the concept of Industry 4.0. The results allow an overview of the respective relevance of technologies within the comprehensive scope of the topic. To achieve this aim, an empirical analysis of existing survey literature was chosen in order to identify which 'Industry 4.0 technologies' are of central and marginal importance. The result of this work is a graphical representation, which shows the technologies relevant to the industrial revolution based on surveys and their scientific citations. It shows the most often used technologies (web services with a relative importance of 3.46/5) as well as the evolvement of the importance of each technology within the period of 2013-2016. The graphic representation of the Industry 4.0 technology cosmos also allows an observer to differentiate what is important and what are rather marginal aspects. The method developed, which was used to generate the results, involves many different authors' opinions from research, economics and politics.

However, some of the premises and limits, that the methodology used may have, are not disregarded. The assessment method determines the importance of technologies by combining the frequency and importance of a technology in a study with the importance of the included studies. It is assumed that both the subjective assessment within the studies and the use of citation numbers are appropriate measures for determining the meanings. Both are common tools in the technology assessment, but they have certain limitations or blurring areas.

The evaluation of the technologies within the publications took place subjectively by one person. The fact that the evaluation behavior of this person changes over the large number of publications considered can not be ruled out. An assessment based on hard criteria, such as the counting of the mentions of a technology in the study, is nevertheless not an option, as an evaluation does not allow comparability due to the different sizes of the publications. In addition, statements on the importance of the technologies would be left out. A certain blur in the interpretation of the importance of a technology within the studies is therefore unavoidable. In addition, it can be assumed that it is leveled by the evaluation of several studies. If a technology is rated a little too high and sometimes a little too low, the average is nearly the same. However, some blurring also arises in the interpretation of the technology names. The technologies are not always explicitly mentioned, but are sometimes only circulated in flow text. Partially, the same terms are not meant in different publications. The evaluator must therefore often interpret which technology is meant at this point.

In the determination of the meaning of publications also such blurrings occur, even if the citation frequency is a recognized measure for the meaning of a publication. The citation numbers are partly based on the notoriety of the authors, which has developed through its achievements in the past. These are not necessarily connected with his knowledge of the "new" topic of Industry 4.0. High citation numbers can also occur when a writer represents an exotic opinion that is often compared to other opinions. Both, however, are exceptional cases which, if they exist, are also likely to be subject to an average on the many evaluated publications. The influence of the temporal courses of the citations is therefore more important. Older publications tend to have more citations and are thus ranked higher in comparison to newer publications. This behavior has not been calculated and is therefore a blur.

The assessment in this paper is a snapshot of the current situation. However, the environment of Industry 4.0 is subject to a dynamic change. The meanings of individual technologies are changing and new technologies can be introduced which have not yet been considered in this work.

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More information about the ongoing research project is provided via the website http://www.mycs40.de. Please apologize, that the website is in German language.

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ZAKRES TECHNOLOGICZNY INDUSTRY 4.0. – PRZEGLĄD PUBLIKACJI BADAWCZYCH

STRESZCZENIE. Wstęp: Powszechnie można się spotkać z trudnościami ze zrozumieniem pojęcia Industry 4.0 zarówno pod względem jego zakresu jak i związanych z nim technologii. Istniejące definicje obejmują różne technologie, aplikacje, procesy jak i modele biznesowe. Ich skomplikowane rozgraniczenie prowadzi do trudności ze zrozumieniem całości zagadnienia.
Celem tej pracy jest ustrukturyzowanie zakresu Industry 4.0. poprzez zastosowanie średniej ważności powiązanych technologii w oparciu o 38 prac badawczych poświęconych zagadnieniu Industry 4.0.
Metody: W oparciu o analizę istniejącej literatury naukowej, zidentyfikowano istotne technologie. Następnie, technologie te zostały uporządkowane w pięć obszarów technologicznych. Dodatkowo, wszystkie technologie zostały oszacowane w odniesieniu do ich istotności dla Industry 4.0 w oparciu o wskaźnik cytowalności odpowiedniej publikacji. W kolejnym kroku, dwuwymiarowe dane zostały użyte do zaprezentowania przeglądowej struktury wszystkich cytowanych technologii, ich strukturalnych połączeń i istotności. Następnie zaprezentowano strukturę Industry 4.0 poprzez cytowane technologie i ich ewolucję w latach 2013-2016 w celu ułatwienia zrozumienia istotnych trendów badań jak i obiecujących obszarów aplikacji związanych z Industry 4.0.

Wnioski: W porównaniu do istniejących analiz porównawczych i podejść empirycznych, prezentowana praca skupia się na przeglądzie i analizie literatury z naciskiem na zrozumienie koncepcji Industry 4.0. Wyniki umożliwiają przegląd odpowiednich istotności technologii w obrębie badanego obszaru tematycznego. Prezentuje najczęściej stosowane technologie (usługi sieciowe ze względną ważnością 3,46/5) jak również rozwój istotności każdej z technologii w okresie 2013-16.

Słowa kluczowe: Industry 4.0, zarządzenie technologią, Technology Scouting, Advanced Manufacturing, Smart Factory.

Część tej pracy została zaprezentowana w formie referatu podczas konferencji "24th International Conference on Production Research (ICPR 2017)", która odbywała się w Poznaniu między 30 lipca, a 3 sierpnia 2017 roku.

BESCHREIBUNG DES TECHNOLOGISCHEN ANWENDUNGS-BEREICHS VON INDUSTRIE 4.0 – EIN STUDIEN-LITERATUR-REVIEW

ZUSAMMENFASSUNG. Einleitung: Der Artikel befasst sich mit den Schwierigkeiten des Verständnisses von „Industrie 4.0“, bezogen auf den Anwendungsbereich und die berücksichtigten Technologien. Bestehende Definitionen umfassen eine Vielzahl von Technologien und Anwendungen, Prozessen und Geschäftsmodellen. Die schwierige Abgrenzung führt zu einem komplizierten Verständnis des Gesamtthemas. Ziel dieses Artikels ist es deshalb, den Anwendungsbereich von „Industrie 4.0“ anhand der Relevanz ihrer zugrundeliegenden Technologien aus 38 Umfragepublikationen zu Industrie 4.0 zu strukturieren.
Methoden: Basierend auf einer Analyse bestehender Studien zu Industrie 4.0 werden relevante Technologien identifiziert. Darauf baut eine Zusammenfassung dieser Technologien in fünf Technologiebereiche auf. Die einzelnen Technologien werden nach ihrer Relevanz für Industrie 4.0 anhand der jeweiligen Zitationshäufigkeiten bewertet. Schließlich ermöglicht eine zweidimensionale Übersicht, die zitierten Technologien sowie ihren strukturellen Zusammenhang zu übergeordneten Themen und ihre Relevanz darzustellen. Zusammenfassend wird eine Strukturierung von „Industrie 4.0“ durch die zugrundeliegenden Technologien und deren Entwicklung über die Jahre 2013 bis 2016 vorgestellt, um das Verständnis vielversprechender Forschungstrends und Anwendungsbereiche innerhalb von „Industrie 4.0“ zu erleichtern.
Fazit: Im Vergleich zu bestehenden Reviews und empirischen Ansätzen zu diesem Thema wird in diesem Artikel ein Überblick über bestehende Studien gegeben, die speziell dem Verständnis von Industrie 4.0 gewidmet sind. Die Ergebnisse geben einen Überblick über die jeweilige Relevanz einzelner Technologien innerhalb des umfassenden Themengebiets. Es zeigt die am häufigsten verwendeten Technologien (Web-Services mit einer relativen Bedeutung von 3,46/5) sowie die Entwicklung der Bedeutung jeder Technologie im Zeitraum 2013-2016.

Codewörter: Industrie 4.0., Technologiemanagement, Technologiescouting, Advanced Manufacturing, Smart Factory

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