IMSS '19

SAKARYA UNIVERSITY
İSKENDERUN TECHNICAL UNIVERSITY
YALOVA UNIVERSITY

10th International Symposium on Intelligent Manufacturing and Service Systems

Industry 4.0/5.0: Future Minds
and Future Society

9-11 September 2019 | Sakarya / Turkey

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Keynote Speakers

Andrew Kusiak
Keynote: Service Manufacturing: Basic Concepts and Technologies
Professor, Industrial and Systems Engineering
Additional Titles: Professor, College of Nursing Affiliate, University of Iowa

Zekai Şen
Keynote: Natural Intelligence vs. Artificial Intelligence

Professor, Earth Sciences and Water Resources, Istanbul Medipol University

Maged Dessouky
Keynote: An Online Cost Allocation Model for Horizontal Supply Chains
Professor and Chair, Daniel J. Epstein Department of Industrial and Systems Engineering Affiliate, University of Southern California

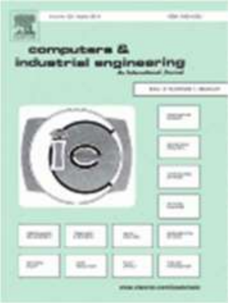
Ercan Öztemel
Keynote: Understanding Digital Transformation

Professor, Marmara University, Faculty of Engineering / Department of Industrial Engineering

Chen Chun-Hsien
Keynote: Informatics-Enabled Human-Centric Product Design in the Era of Industry 4.0
Assoc Prof Chen Chun-Hsien’s areas of expertise are Industrial/Product Design, Knowledge Engineering, and Decision Support Systems.

Alper Gerçek
Invited Speaker
Industry 4.0 Digital Transformation Guide for SMEs

Publications



Computers & Industrial Engineering
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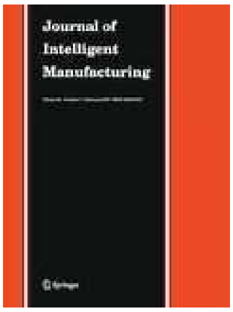
(Scopus)



Journal of Intelligent Manufacturing
(SCI-Expanded)

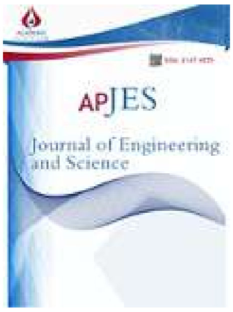
International Journal of Hybrid Intelligent
Systems
(Scopus)

Advanced Engineering Informatics
(SCI-Expanded)

Periodicals of Engineering and Natural
Sciences (Scopus)

Journal of Information Assurance and
Security
(E-SCI)

Sakarya University Journal of Science
(TR-Dizin)



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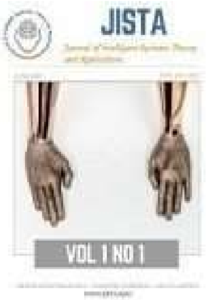
Journal of Network and Innovative Computing



Journal of Intelligent Systems: Theory and Applications

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- Modeling, Simulation and Optimization
- New Product Development
- System Design, Planning and Control
- Quality Control and Management
- Supply Chain Management
- Logistics, Material Handling
- Sustainability and Techonogy Management
- Advanced Production and Technology Management
- Computer and Intelligence in Manufacturing and Production Systems
- Additive Manufacturing
- Industrial Robotics

Production Systems

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- Chemical Process
- Food Processing
- Production Services
- Production Planning
- Operations Management
-

Healthcare

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- Healthcare Operation Research
- Artificial Intelligence in Medicine
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- Distance Healtcare
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- Clinical Decision Support System

Defence

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- Unmanned & Intelligent Systems

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- Electromagnetic Industry

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- Freeway Management
- Transit Management
- Incident Management
- Emergency Management
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- Traveler Information
- Information Management
- Crash Prevention and Safety
- Intermodal Freight
- Driver Asistance Systems
- Collision Notification Systems

Smart Cities, Digital Goverment & Digital Nations

- Smart Parking
- Traffic Flow Analytics
- Intelligent Buildings and Urban Spaces
- Distributed Energy
- Governance
- Trapped in The Digital Divide
- Technologies of Citizenship

Digital Transformation

- Internet of Things
- Big Data
- Augmented Reality
- Cyber-Physical Systems
- 3D Printing
- Smart Factories
- Cloud Computing
- Data Science

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- Türkay Dereli (Iskenderun Technical University Rector)

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- Ajith Abraham
- Andrew Kusiak
- Chen Chun-Hsien
- Maged Dessouky
- Zekai Şen
- Ercan Öztemel

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- Zekai Şen

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- Yakup Kara
- Yılmaz Uyaroğlu
- Zerrin Aladağ

Symposium Agenda

September 9, 2019 Monday

08:30 – 9:00	Registration
09:00 – 10:00	Opening Ceremony and Speeches
10:00 – 10:30	**Keynote Speaker:** Prof. Dr. Zekai Şen **Natural Intelligence vs. Artificial Intelligence**
10:30 – 11:00	**Keynote Speaker:** Prof. Dr. Andrew Kusiak **Service Manufacturing: Basic Concepts and Technologies**
11:00 - 11:15	Coffee Break
11:15 – 12:30	Panel **İmalat Sanayiinde Yapay Zeka Uygulamaları (Artificial Intelligence Applications in Manufacturing Industry)** Moderator: Prof. Dr. Ercan Öztemel Prof. Dr. Zekai Şen, Prof. Dr. Türkay Dereli, Prof. Dr. Bülent Eker
12:30 – 13:30	Lunch
13:30 – 14:00	**Keynote Speaker:** Prof. Dr. Ercan Öztemel **Understanding Digital Transformation and comparing Industry 4.0 with Society 5.0**
14:00 – 14:30	**Keynote Speaker:** Prof. Dr. Maged Dessouky **An Online Cost Allocation Model for Horizontal Supply Chains**
14:30 – 16:00	Parallel Session 1
16:00 – 16:15	Coffee Break
16:15 – 17:45	Parallel Session 2
19:00 –	Gala Dinner

September 10, 2019 Tuesday

08:30 – 9:00	Registration
09:00 – 09:30	Keynote Speaker: Assoc. Prof. Dr. Chen Chun-Hsien Informatics-Enabled Human-Centric Product Design in the Era of Industry 4.0
09:30 – 11:00	Parallel Session 3
11:00 – 11:15	Coffee Break
11:15 – 12:45	Parallel Session 4
12:45 – 14:00	Lunch
14:00 – 14:30	**Invited Speaker:** Alper Gerçek **Industry 4.0 Digital Transformation Guide for SMEs**
14:30 – 16:00	Parallel Session 5
16:00 – 16:15	Coffee Break
16:15 – 17:30	Parallel Session 6
18:00 – 19:00	Panel **Industry 4.0/5.0: Future Minds and Future Society** **Moderator:** Prof. Dr. Türkay Dereli Prof. Dr. Ercan Öztemel, Prof. Dr. Andrew Kusiak, Prof. Dr. Maged Dessouky, Prof. Dr. Zekai Şen, Assoc. Prof. Dr. Chen Chun-Hsien
19:00	Closing Ceremony Plates **Closing Speech:** Prof. Dr. Harun Taşkın

September 11, 2019 Wednesday

08:30	**Departure from** Sakarya University Campus
	Lake Golcuk: Breakfast and short walk
	Lake Abant: Hiking and sightseeing by the lake, picnic
17:00	**Departure:** Lake Abant
19:00	**Arrival** to SAU campus

Symposium Scientific Programme

First Day	**September 9, 2019 Monday**
TIME	
08:30 – 9:00	Registration
09:00 – 10:00	Opening Ceremony and Speeches
10:00 – 10:30	Keynote Speaker: Prof. Dr. Zekai Şen **Natural Intelligence vs. Artificial Intelligence**
10:30 – 11:00	Keynote Speaker: Prof. Dr. Andrew Kusiak **Service Manufacturing: Basic Concepts and Technologies**
11:00 - 11:15	*Coffee Break - I*
11:15 – 12:30	Panel: **İmalat Sanayiinde Yapay Zeka Uygulamaları** (Artificial Intelligence Applications in Manufacturing Industry) Moderator:Prof. Dr. Ercan Öztemel Prof. Dr. Bülent Eker Prof. Dr. Zekai Şen Prof. Dr. Türkay Dereli
12:30 – 13:30	*Lunch* *Sakarya University Dining Hall*
13:30 – 14:00	Keynote Speaker: Prof. Dr. Ercan Öztemel **Understanding Digital Transformation and Comparing Industry 4.0 with Society 5.0**
14:00 – 14:30	Keynote Speaker: Prof. Dr. Maged Dessouky **An Online Cost Allocation Model for Horizontal Supply Chains**

Industry 4.0/5.0: Future Minds and Future Society
9-11 September 2019
Sakarya University - Sakarya/Turkey

	Prof. Dr. Nevzat Kor Hall	**Prof. Dr. Fuat Sezgin Hall**	**Prof. Dr. Gültekin Yıldız Hall**	**Hall 4**	**Hall 6**	**Hall 7**
Parallel Session 1	**Defence-1** **(Chair: Prof. Dr. B. GÜLTEKIN ÇETINER)**	**Smart Cities, Digital Goverment&Nations-1** **(Chair: Assoc. Prof. Dr. ZEHRA KAMIŞLI ÖZTÜRK)**	**Logistics, Material Handling** **(Chair: Assoc. Prof. Dr. TARIK KÜÇÜKDENIZ)**	**Data Science** **(Chair: Assist. Prof. Dr. ONUR DOĞAN)**	**Big Data-1** **(Chair: Assist. Prof. Dr.TÜLAY KORKUSUZ POLAT)**	**Modeling, Simulation and Optimization-1** **(Chair: Assist. Prof. Dr.SEHER ARSLANKAYA)**
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	238 - Marmara Credit Loops: A Blockchain Solution To Nonredemption Problem I... B. GÜLTEKIN ÇETINER	108 - Improving Production Line Performance Via Simulation Approach: An Appl... SINEM BÜYÜKSAATÇI KIRIŞ	106 - A New Fuzzy C-Means And Ahp-Based Three-Phased Approach For Multiple C... FATIH YIĞIT	202 - Clustering Universities In Turkey According To Their Relevance To Indu... ÖZGE VAR	67 - A Comprehensive Energy Supply Forecasting Model: Comparison Between Tu... OMER ALGORABI	86 - A Decision Model Proposal For School Selection Problem Under Hesitant ... AYLIN ADEM
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Second Day	**September 10, 2019 Tuesday**					
08:30 – 9:00	Registration					
09:00 – 09:30	Keynote Speaker: Assoc. Prof. Dr. Chen Chun-Hsien **Informatics-Enabled Human-Centric Product Design in the Era of Industry 4.0**					
	Prof. Dr. Nevzat Kor Hall	**Prof. Dr. Fuat Sezgin Hall**	**Prof. Dr. Gültekin Yıldız Hall**	**Hall 4**	**Hall 6**	**Hall 7**
Parallel Session 3	**3D Printing (Chair: Assoc. Prof. Dr. IHSAN HAKAN SELVI)**	**Production Systems-1 (Chair: Assoc. Prof. Dr.SEMRA BORAN)**	**Comp. and Intell. in Man. and Prod. Sys. -2 (Chair: Prof. Dr. ALI RIZA YILDIZ)**	**Electromagnetic Industry (Chair: Dr.İBRAHİM BAHADIR BAŞYİĞİT)**	**Big Data-3 (Chair: Assoc. Prof. Dr.RECEP YILMAZ)**	**Modeling, Simulation and Optimization-3 (Chair: Assist. Prof. Dr.TİJEN ÖVER ÖZÇELİK)**
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Collaborative Robots Between Industry 4.0 And the Platform Economy: Where Next for Cobots?

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KEYWORDS – Collaborative Robots, Cobots, Human-machine interaction, Industry 4.0, Platform Economy, Industrial Ergonomics, Innovation management

ABSTRACT

The market for collaborative robots (cobots) is rapidly rising around the world. Cobots form an important element of new paradigms of Industry 4.0 and Smart and Additive Manufacturing. This article places collaborative robots in the trending framework of Industry 4.0 and discusses collaborative robots in relation to new ways of human-machine interaction in the Industry 4.0 era. It describes the origin, development and status of the market for collaborative robots – providing a rising field with an overview surprisingly lacking from academic literature. Using the burgeoning academic literature on cobots as a starting point, the article discusses the frontiers of cobot uptake along three main dimensions. The first dimension relates to economics and includes the value proposition of cobots supporting agile manufacturing and mass customization. We place the business models of cobots within wider changes to the industrial business environment with the emergence of the Platform Economy and value cocreation in platform ecosystems. The second dimension relates to social aspects, ie. human-machine interface and collaboration. This include issues such as organizational health and safety, industrial economics, and trust. The third dimension relate to possible new technological developments within the field of collaborative robotics.

Together these dimensions represent a state-of-the-art overview of the field of cobots and its next frontiers. By providing this overview and coupling technology, social interaction with humans and business model- and market insights related to collaborative robots the article makes unique contributions to a surprisingly under-studied field.

1 INTRODUCTION

Collaborative robots or “cobots” marks a departure from traditional industrial robots which functions separated from its human co-workers. Cobots, on the other hand, are intended for direct interaction with human workers, handling shared payload, and without the need for conventional safety cages or similar protective measures [1, 2].

Robots and especially cobots have had a tremendous evolution the last ten years [3]. In the words of Korn et al., *“robots have long left the cages of industrial settings: They work together with humans – collaboratively*” [4]. This collaboration leverages the strength and endurance of robots with the flexibility and decision making of humans [5]. The majority of cobots are lightweight and possible to move between places, i.e. they are in the passive sense mobile [6].

The uses of cobots is supported by the current trend of automation and data exchange in manufacturing technology, the so-called Industry 4.0. At the core of Industry 4.0 is the aim of achieving efficiency, cost reduction, increased productivity, and increased flexibility through integrated automation systems [7]. Manufacturing companies engage in more flexible production processes with mass customization and small batch sizes. Automation is an answer to some of these demands, but traditional robotics do not always provide suitable solutions [8].

Flexibility and changeability of assembly processes require a close linkage between the worker and the automated assembly system. Combining the advantages of robots with the advantages of human workers through direct human-robot cooperation is only now beginning to be realized in industry [3]. Collaborative robotics has now become one of the fastest-growing sectors of the robotics market [9]; cobot technology can be a game changer and the dominant robot technology in the decades to come [8]. This article provides a literature-based state-of-the-art overview of current frontiers of collaborative robotics along three main dimensions: Economics, social dimensions, and technology.

2 METHODOLOGY

The main source of information for this article is the international academic publication database Web of Science. A literature search has been performed in the database for “collaborative robot*” or “cobot” to appear either in the title of publications or as keyword. The literature search provided a total of 706 articles on cobots by May 2019.

In Figure 1, we have outlined the growing amount of publications on cobot technology available in Web of Science. Trend curve clearly reveals that in years 2015-2018 we have moved to growth phase according to the Web of Science database. In incubation phase there were about less than 20 annual hits, but in 2018 data shows more than 7 times higher volume.

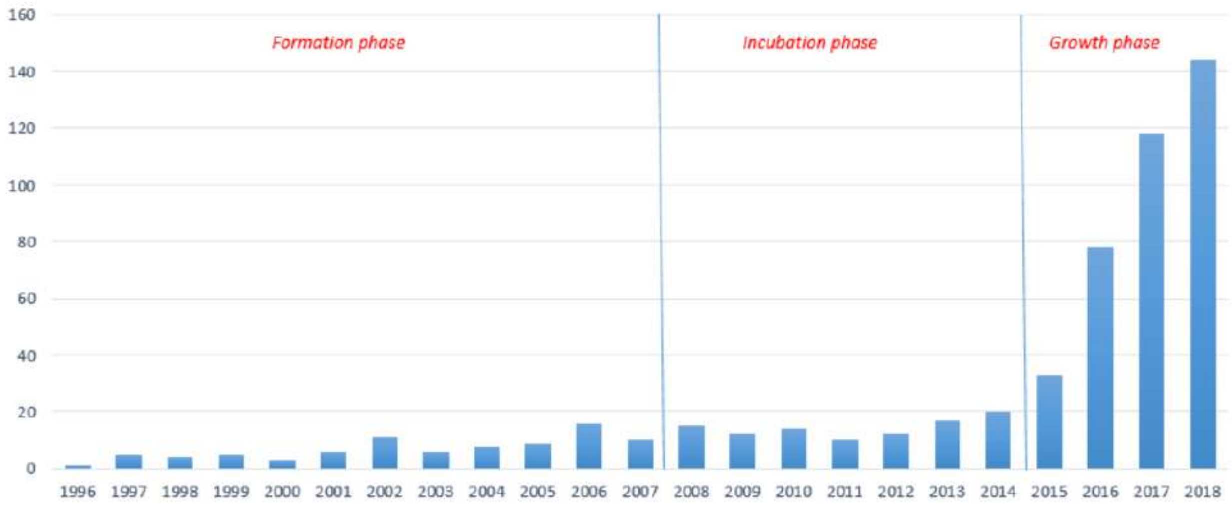

Figure 1: Cobot articles indexed in Web of Science, by year

3 FRONTIERS OF COBOT DEVELOPMENT

3.1 Economic frontier: The business proposition of cobots

3.1.1 Cobot market development

The global market value of cobots is still relatively minor with an estimated turnover of less than $600 million in 2018 [10]. Behind his number is a strong growth, however, with almost 50% growth rate compared to 2018. Cobots are particularly starting to make an impact in the automotive industry, which is the largest market sector for industrial robots [2]. Forecasts for the annual revenues of collaborative robots are highly optimistic, from global revenues of $7.6bn in 2027 [10] to the even more optimistic $9.2bn by 2025 [11]. Danish company Universal Robots sold the world's first commercial collaborative robot in December 2008. The company experienced a 72% growth rate in 2017 and company expects to sustain 50-70% growth year-on-year for at least another five years [12]. It remains the largest player in the market with a market share of more than 50 pct. of the global market. In 2018, the company also celebrated the sale of its 25,000th cobot.

Until relatively recently, the supply of cobots were limited to a handful of suppliers, but during the past few years major industrial players such as ABB, Robert Bosch and manufacturer of industrial robots KUKA have all joined the market for collaborative robots [2]. As the market worldwide market expands, both market fragmentation and market selection mechanisms may come in play.

3.1.2 Value proposition of cobot introduction

Around the world, factories and assembly lines are moving from traditional configurations to comply with changes in manufacturing industry, which is shifting from mass production to mass customization and towards agile manufacturing-paradigms [13, 14].

Agile manufacturing systems must be flexible, open, scalable and re-configurable. Industrial automation is capable of maintaining high efficiency and repeatability for mass production. However, it lacks flexibility to deal with uncertainties Industrial automation and classical robotic work cells lacks versality and flexibility, and high change-over times makes it difficult to adapt to dynamic environments or to efficiently produce small-batch production [14, 7]. A comparison between traditional industrial robots and cobots can be seen in table 1 below.

Table 1 Comparison between traditional industrial robots and collaborative robots [7]

Traditional industrial robots	**Collaborative industrial robots**
Fixed installation	Flexibly relocated
Repeatable tasks, rarely changed	Frequent task changes
Lead-through and off-line programming	On-line programming (lead-through walk-through and Pbd), supported by off-line programming and multi-modal interaction
Rarely interaction with the worker, only during programming	Frequent interaction with the worker, force/precision assistance
Worker and robot are separated through fence	Sharing workspace
Cannot interact with people safely	Safe interaction with
Profitable only with medium to large lot size	Profitable even at single lot production
Small or big or very fast	Small, slow and easy to use and easy to move

Increasing the ability to respond rapidly to changing customer/market needs and strengthening manufacturer's ability to provide customization and low volume production are therefore important elements of the value proposition of cobots [2]. They may be particularly ideal for manufacturers with more variants and smaller lot sizes [5], and for manufacturing SMEs lacking the operational capacity to invest and benefit from large industrial robots. In the sense, cobots are also seen as a 'gateway' into factory automation [15].

While cobots are more flexible and cheaper than traditional industrial robots, customers still need to be able to justify their investment. Especially smaller SMEs could find themselves with challenges in looking for new tasks for cobots, if original plans are altered as documented in [16].

The case study exemplifies how, despite the optimistic market forecasts, proving the value of cobot introduction can still be needed.

3.1.3 Manufacturing locations

One main driver of political backing of Industry 4.0-initiatives, e.g. in Germany and the United States, has been to ensure continued competitiveness of industries in high-cost manufacturing environments. Increased uptake of robotics and automation may, according to this narrative, help 'bring manufacturing back' [17, 18]. This conclusion have also been highlighted by firms [16], suggesting the need to remain competitive with outsourced competitors as key for cobot investments.

As the geography of global manufacturing may shift with geopolitical trends, this could also have significant effects on the development of the cobot market, and this is an important driver of the future cobot business.

3.1.4 Business models of cobot manufacturers: Towards platform economy?

In recent years the global market leader Universal Robots have moved towards platforms business models. CTO and co-founder Esben Østergaard has envisioned the development as a 'dating service for problems and solutions' [19], and how the company wants to underpin their customers' ability to customise their own solutions. This arguably mirrors the agile value proposition of cobots well. Business models of industrial robots today tend to be rather traditional, and Landscheidt et al. argues that business model change is necessary rather than just possible [20]. The selection of optimal business models will be a natural frontier among cobot manufacturers, as the market expands.

3.2 Social frontiers: Human-machine interactions

3.2.1 Human-machine interactions

Drawing on [21], the ways human operators and cobots interact can be defined as *collaboration scenarios*. Each scenario involves at least one human operator and at least one cobot sharing the same workspace in order to perform manufacturing process(es) on work piece(s). Several definitions exist in literature distinguishing collaboration from cooperation or interaction. For example, Bendel (2018) noes that cooperation robots work with people step by step for a common goal, while collaborative robots work with people hand in hand on a common task [6]. With a more lenient definition corresponding to the definition of cobot manufacturers, any robot operating alongside a human without a fence can be characterized as a collaborative robot [21].

Four distinct collaborative scenarios can be defined:

- *Independent*: Operator and cobot work on separate work pieces, independently, for their individual manufacturing processes. The collaborative element constitutes the shared workspace without cages or fences.
- *Simultaneous*: Operator and cobot operate on separate manufacturing processes at the same work piece at the same time. There is no time or task dependency between them, but concurrently operating on the same work piece minimises transit time, improves productivity and space utilisation.
- *Sequential*: Operator and cobot perform sequential manufacturing processes on the same work piece. There are time dependencies between the processes of the operator and the cobot; often with the cobot assigned to handle tedious processes to improve the operator's working condition.
- *Supportive*: Operator and cobot work on the same process on the same work piece interactively. There is dependencies between the actions, as one cannot perform the task without the other.

At present stage most cobots deployed in industrial settings relate to the ‘independent’ or the ‘simultaneous’ collaboration scenario. Most cutting-edge research, on the other hand, falls under the categories of ‘sequential’ or ‘supportive’. These demands more sophisticated systems and solutions. As the degree of collaboration increases such as in the latter two scenarios, cobots need to have semantic understandings of the task goal and the actions and intents of its human co-workers, and the human needs to able to communicate with the cobot in intuitive ways.

3.2.2 Safety

Safety remain a fundamental prerequisite in designing collaborative workplaces where humans work alongside robots [7]. After a series of unfortunate robot-related events, guidelines for robot safety began to emerge in the mid-1980s [15]. Interest in the topic has ebbed and flowed, but in general research has focused on maintaining operator safety by separating active machinery and robots from the workforce. Even recent books on occupational health and safety has preventing interaction between human and robot as the main point concerning industrial robots [22].

However, robot safety standards are now updated to address new co-working scenarios [7]. The international ISO-standard identifies four collaborative modes: i. *Safety-rated monitoring stop (SMS), ii. Hand guiding (HG), iii. Speed and separation monitoring (SSM), and iv. Power and force limiting (PFL).* As collaborative robotics progresses, research on safety issues within each of these four collaborative modes must simultaneously progress. Safety requirements should not be a hindrance to cobot performance, but rather performance should be optimized subject to the constraint of safety, while safety solutions must also takes needs of vulnerable users into account and acknowledge different skills and capabilities [7].

3.2.3 Ergonomics

Ergonomic concerns is a main driver for the introduction of cobots, as more than 30% of European manufacturing workers are affected by lower back pain [23, 24]. Significant amount of research relates to the possibility of cobots to reduce work-related muscuskeletal disorders (MSDs) as well as stress and fatigue of operators. This represent a rapid and dynamic evolvement in the field of ergonomics, but also an important frontier for further cobot development.

3.2.4 Human factors and human-centered design

An emerging, but still scarce amount of literature relates to human-centered design in intelligent manufacturing systems [25]. As cobots perform more of the repetitive and physically demanding tasks, the tasks for human workers will change. New tasks will be more complex, and workers will be responsible for an increased number of hetereogenous processes which they have to keep track of in order to perform correct interventions. As new tasks also increasingly involve interaction with computational devices, factory workers of the future take over jobs, which originally have been engineering tasks [26]. Smart and skilled operators not only collaborates with robots, but is aided by machines, advanced human-machine interaction technologies and adaptive automation [27].

As unique human capabilities play a more significant role for human task design, it will be increasingly important for designing human-robot interaction to reflect not only on the perception of the robot, but also on the perception of the human. Often leaders pay attention to collaboration and knowledge sharing between human beings with different backgrounds, but not to special nature of human-machine interactions. Especially, in innovation ecosystems much attention is often paid to leaders of start-ups and established larger companies, but not too much on digital infrastructures and digital platforms. In the case of entrepreneurship ecosystem, development of inter-firm collaboration and intra-firm collaboration is often organized on the basis of man-man interactions, not on the basis of man-machine interactions. This may be a problematic issue for successful collaboration and it may neglect some main factors. Pacaux-Lemoine et al. notes a list of “hidden assumptions of the magic human” with implications for the system design (adapted in Table 2) [25].

Table 2. Hidden assumptions of the role of humans [adapted from 25]

Role of human	Design implications
The human can be the devil	A human have bounded rationality, forgets things, and makes mistakes The controlled system must be designed to manage this risk.
The human can be the hero	A human can save lives through unexpected, innovative behaviour. The system must be designed to enable humans to integrate unforeseen events.
The human can be the powerless victim	A human may be unable to act despite being sure he/she is right and the automated system wrong. The system must be designed to ensure it can be observed and controlled by the human whenever desired.
The human is legally and socially accountable	If the human is legally and socially accountable, he/she must be allowed to fully control the intelligent system.

For optimising the benefits of collaborative robots, combining the capabilities of humans and robots in an optimal way is essential [28]. This frontier includes optimising the role of both robots and humans. As table 1 clearly indicates, there is a special need to pay more attention to the two-way interactions between humans and machines. This kind of two-way interaction does not happen automatically without planned routines and physio-cognitive ergonomic systems.

3.2.5 Enabling inclusive labour markets

The demographics of labour markets are changing rapidly in many developed countries. In Germany, for example, by 2050 half the population will be older than 50 years. The group of employees below 45 will decrease, while the group of employees above 45 will increase by 25% [29]. Developments that are even more radical are underway in Asian countries like Japan, South Korea, and China [30]. Using collaborative robots to limit e.g. physical loading on the shopfloor, may enable the manufacturing industry to adapt to shifting workforce demographics [29, 31]. With a human-centered design of human-robot collaboration, cobots might also ensure better accessibility to industrial workplaces for people with disabilities [29]. Cobots may therefore be a boon to both shifting and more inclusive labour markets, but these trends can also heavily influence the application and development of cobot technologies.

3.2.6 Trust and social acceptance of robots

From a human perspective, several sources of insecurity affect the acceptance of cobots by its human co-workers [32. For shopfloor workers neither expert nor confident with the use of robots are tasked with working close to such complex systems, it can generate anxiety and fear. Increased operators mental strain has already been reported in collaborative robotic assembly tasks [33]. Insecurity can arise from the complexity of the tool, the fear of losing jobs, the fear of damaging the (perceived costly) robot, and the fear of injury caused by the robot [32]. Qualitative interviews with workers in factories which have implemented cobots show several of these, as workers felt the need to keep an eye on the quality of the cobot's output, and expressed initial fear of being hit by the cobot [16].

As cobot autonomy increases, the already identified concern with cobot predictability may be amplified further. This frontier remain a significant challenge for cobot development.

3.3 Technological frontiers: Advances in communication and perception

3.3.1 Programming and instruction of collaborative robots

A key challenge for exploiting collaborative robots in a dynamic workflow is instructing and programming the cobot when this functions as an assistant alongside the human worker. Instead of reducing the need for human intervention, the current trend is towards bringing the traditional robot programming from engineers to operators on the shop floor [35]. This has both monetary benefits as it decreases the need for high-wage engineering, but it also allows the operator to channel valuable process knowledge and experience into the instruction.

However, this also requires a need for making the programming of the cobot simple and intuitive. As the CTO of Universal Robots have put it, their mission is put the control of robots back into the hands of the operator, and that ‘If you can work a smartphone, you can program this robot’ [19].

3.3.2 Advanced forms of interaction: Semantic understanding capabilities and cobot anticipation

Key themes in on-going robot and cobot research is the problem of achieving more advanced forms of interactions [36]. Ideally, future cobots can take into account human cues, movements and intentions with the ability to distinguish between work-related intentional and non-intentional human gestures. It is a requirement for natural human-robot collaboration that the robot is endowed with the capability to capture, process, and understand accurately and robustly human requests [37]. This means endowing robots with semantic understanding capabilities, which is a very challenging task, but also a very important one. Research related to human-robot collaboration revolve around enhancing particular enabling functions like visual perception, action recognition, safe on-line motion planning etc., which enables *human awareness* and promotes flexible cobot behaviour [21]. In order to provide optimal physical assistance to humans, it has been argued, cobots also need to be able to predict their intent, future behaviour and movements [36]. Recognising the use of force/pressure sensors in contact to anticipate the movements and objectives of the human partner, represents an alternative approach to the design of human-robot interfaces [38]. Implementation of predictive and adaptive control methodologies is still in a premature state, and it also raises new questions such as whether robot adaptation should be generic or user-specific.

In the context of cobot r/evolution we can expect interactive change impacts, market impact and strategic impacts. All these impacts are connected to each other and there will be needs for so called cube solutions and orchestration inside value networks and broader innovation ecosystems. Applications of cobots will probably include ‘cube solutions’ such as novel design innovations, strategic innovations, incremental innovations and operational innovations [39]. There is need to orchestrate modern production systems in a new way different from Industry 1.0-3.0. The role dynamic capabilities are central in this change process. Four key capabilities are critical: (1) relational capability, (2) sensing capability, (3) absorptive capability, and (4) integrative capability. All of these dynamic capabilities affect stages of the adoptive management innovation process; from initiation through to implementation. In general, there are needs to make sense (understand needed changes) and give sense (implement changes) (see [40]).

4 CONCLUSIONS

The market for collaborative robots (cobots) is rapidly rising around the world. It is a key part of Industry 4.0 impacts whether they are change impacts, strategic impacts or market impacts. Cobots form an important and very challenging element of new paradigms of Industry 4.0 and Smart and Additive Manufacturing. Cobots aid manufacturing plant operators by supplementing the flexibility of humans with the reliability, accuracy and efficiency of robots, and they are central to new ways of human-machine interfaces in manufacturing production with important implications for everything from production economics over health, safety and ergonomics to the future of work. Applications of cobots will include many design innovations, strategic innovations, incremental innovations and operational innovations. There is need to orchestrate production systems in a new way different from Industry 1.0-3.0. There is need for cube solutions to solve complex innovation dilemmas.

In this article we discussed the frontiers of cobot uptake along three main dimensions. The first dimension relates to economics and includes the value proposition of cobots supporting agile manufacturing and mass customization. We place the business models of cobots within wider changes to the industrial business environment with the emergence of the Platform Economy and value cocreation in platform ecosystems. However, cobot manufacturers are still finding their place within these new business paradigms, which is why it is still a frontier. The second dimension relates to social aspects, ie. human-machine interface and collaboration. This include issues such as organizational health and safety, industrial economics, and trust. Within this dimension, there are many frontiers yet to conquer. The third dimension relate to possible new technological developments within the field of collaborative robotics. Here the article provides only a snapshot of the most important frontiers for the near-future, such as i. making the operation of cobots easier for humans, and ii. making cobots better capable of performing tasks autonomous of humans. These developments are highly likely to be explored in parallel. Together these dimensions represent a state-of-the-art overview of the field of cobots and its next frontiers. By providing this overview and coupling technology, social interaction with humans and business model- and market insights related to collaborative robots the article makes unique contributions to a surprisingly under-studied field.

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