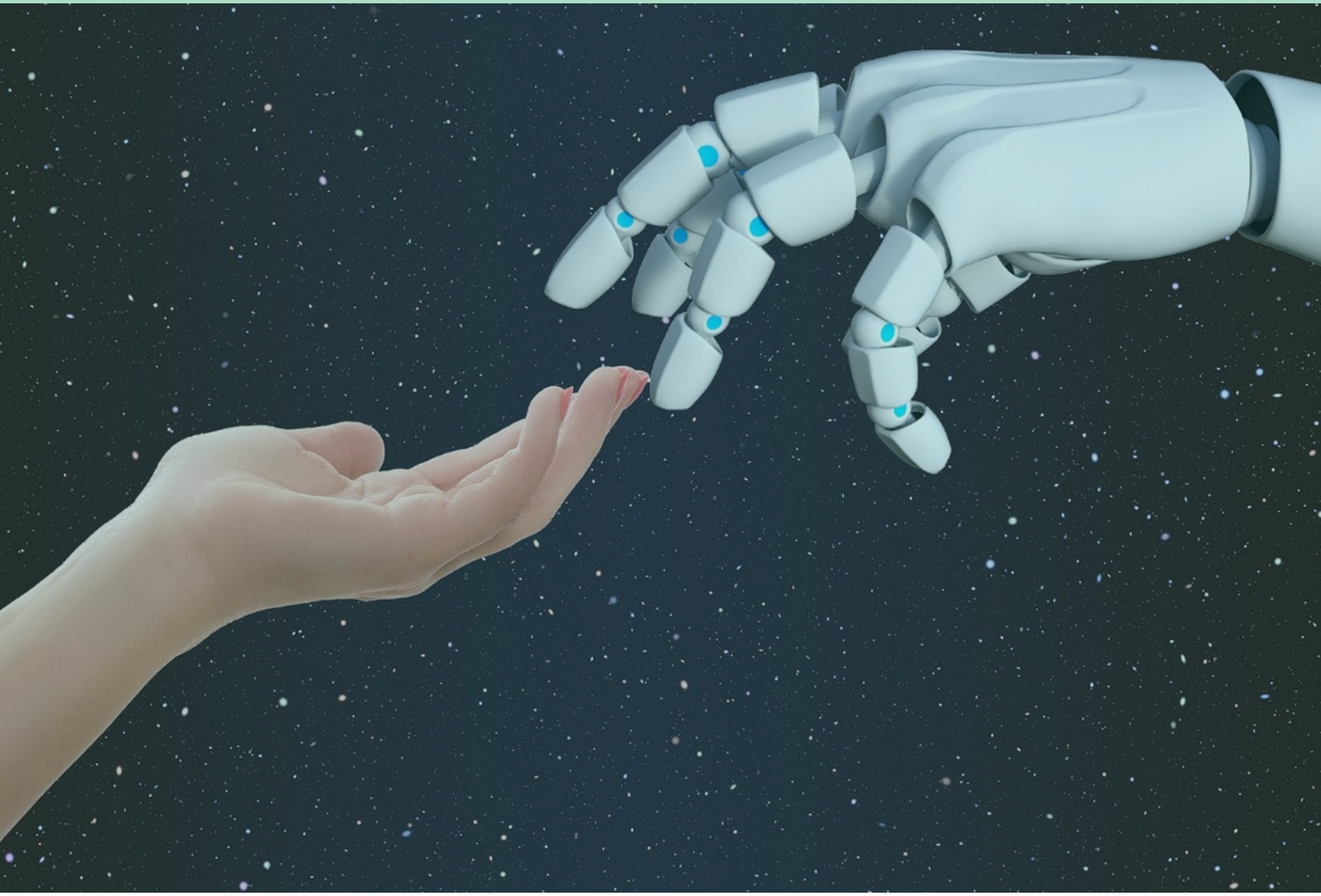
# TECHNOLOGY SCAN: HUMAN & MACHINE COLLABORATION



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## METHODOLOGY

**1. Dataset used for the report**

The patent dataset was retrieved on 17 May 2019 and comprises worldwide patent applications relating to human and machine collaboration technologies published in 2009-2018.

Relevant business information, market data, and national policies that are available from commercial databases or on the web are also used to support the findings of the report.

**2. Counting the number of inventions**

This report counts the number of inventions by the number of unique patent families. Counting individual patent applications will result in double counting as each patent family may contain several patent publications if the applicant files the same invention for patent protection in multiple destinations. As a patent family is a group of patent applications relating to the same invention, analyses based on counting one invention per unique patent family can reflect innovation activity more accurately.

**3. Formulation of search strings**

To ensure optimal recall and accuracy of the data sets retrieved, the search strings used in this study were formulated by incorporating keywords (and their variants), as well as relevant patent classification codes and indexes, e.g. International Patent Classification (IPC) and Cooperative Patent Classification (CPC).

**4. Grouping of technology domains**

Grouping of individual patent documents into the respective technology domains was carried out based on patent classifications codes, text-mining and semantic analysis of the patent specifications in particular claims, titles, abstracts, as well as a manual review of the individual patent applications.

**5. Growth rate calculation**

Annual growth rate refers to the average annual growth and was derived by using the best-fit exponential line method for the set of data, $y = a*e^{bx}$, where b is the growth rate.

# CONTENTS

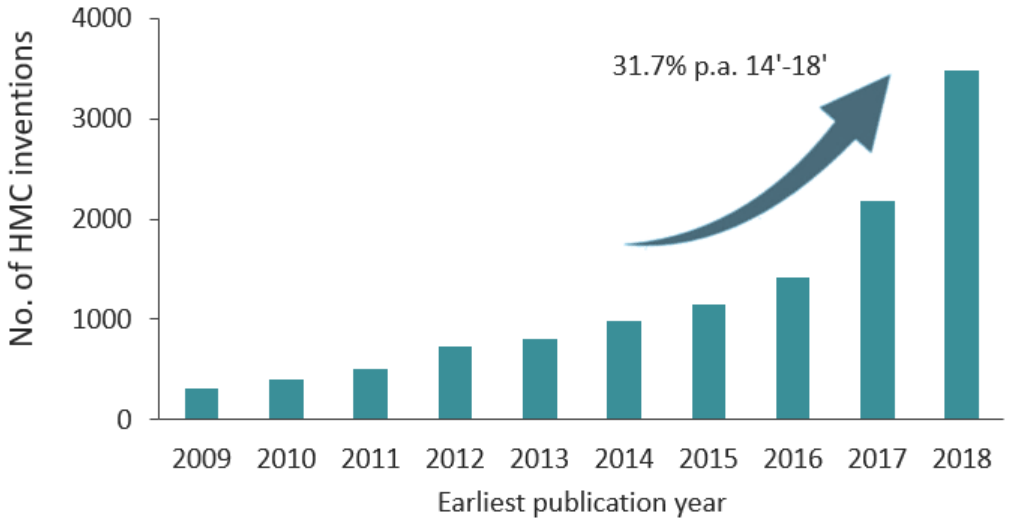
# INTRODUCTION

Programmable robots are playing an increasingly important role in the advancement of industrial automation – assisting mankind with a range of simple and complex operations, including hazardous tasks and operations that demand high precision. The rapid development of artificial intelligence (AI) technologies has also pushed the frontiers of robotics. Hence, it is not surprising that both machines and robots can now sense and recognize the environment, scour the internet to answer a myriad of questions, learn from their mistakes, and even beat humans in games like Jeopardy! and Go[1-2]. As AI technologies progress towards performing more "human" tasks, the fear that we will eventually be displaced by machines seemed legitimate at first, but that notion has since been brought into question.

Recent research gives an optimistic perspective suggesting that, instead of displacing employees, the most likely impact of AI lies in augmenting human capabilities, enabling people and machines to work collaboratively[3]. This paradigm shift is evident in organisations that have ventured into human–machine collaborations (HMC), re-imagining how humans and machines can augment one another through collaborative intelligence.

This report examines the state-of-the art of HMC by studying worldwide HMC-related patent applications published from 2009 to 2018. Our comprehensive trend analysis focuses on four domains, namely: ***Mechanical***, ***Linguistic***, ***Emotional*** and ***Digital Trust***. In addition to providing an overview of the innovation trends of HMC technologies, this report also elaborates on the technology trends relating to specific areas such as machine-to-machine collaboration and swarm intelligence.

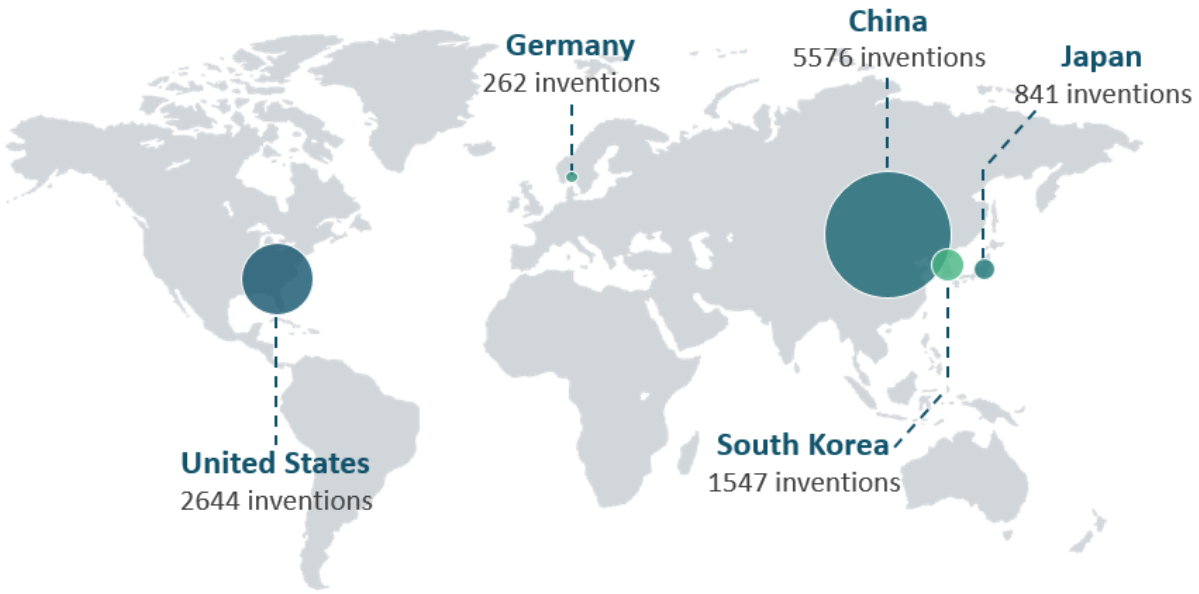
# WORLDWIDE PUBLICATION TREND OF HMC-RELATED INVENTIONS




As industries embrace both AI and robotic technologies, HMC innovations have emerged as a promising area of development. The growing relevance and importance of HMC innovations were apparent in a recent survey by Forbes Insights which revealed that 80 percent of surveyed executives recognize the demand for HMC in their organizations[4].

According to a Gartner report, the cooperation between humans and intelligent machines is forecasted to generate $2.9 trillion in business value by 2021[5]. The potential of this booming market is underpinned by intensive HMC innovations, manifesting in more than 12,000 inventions published worldwide in the last ten years, with an average growth rate of 32% per annum. HMC-related innovations appear to have received a dramatic boost in the past five years. Given the growing emphasis on HMC across various industries, the growth of HMC innovations is expected to accelerate further, impacting our work and everyday life like never before.

## TOP 5 APPLICANT ORIGINS




Applicant origin approximated by 1st priority country

China and the US are the most active countries in HMC innovations, accounting for more than 46% and 22% of the global HMC-related inventions, respectively. China and the US have distinguished themselves as the two most innovative countries in AI technologies[6]; their strong AI innovation has been the cornerstone of the advancement of HMC. Apart from China and the US, HMC innovations are also prominent in countries like South Korea, Japan and Germany, which are also leading countries in developing AI technologies[6].

Both China and the US have unveiled national strategic initiatives in AI, which include HMC. In China, the "New Generation Artificial Intelligence Development Plan"[7] highlights human-machine hybrid intelligence and swarm intelligence as key technologies for further development in both fundamental research and technical applications. In the US, a series of policies have been released by the US government. In the "*National Artificial Intelligence Research and Development Strategic Plan*" in 2016 and its updated version recently released in June 2019, one of the key strategies is to develop effective methods for human-AI collaboration[8].

There are 15 HMC inventions by Singapore local applicants published in the period of 2009-2018. While the number is relatively modest, it is interesting to note that the HMC-related innovations are predominantly in the area of medical applications, such as collaborative surgical robots and AI-assisted diagnosis methods. The gradual increase in the patenting activity of HMC-related innovations in Singapore in recent years underscores the consistent attention given to the healthcare needs of Singapore.

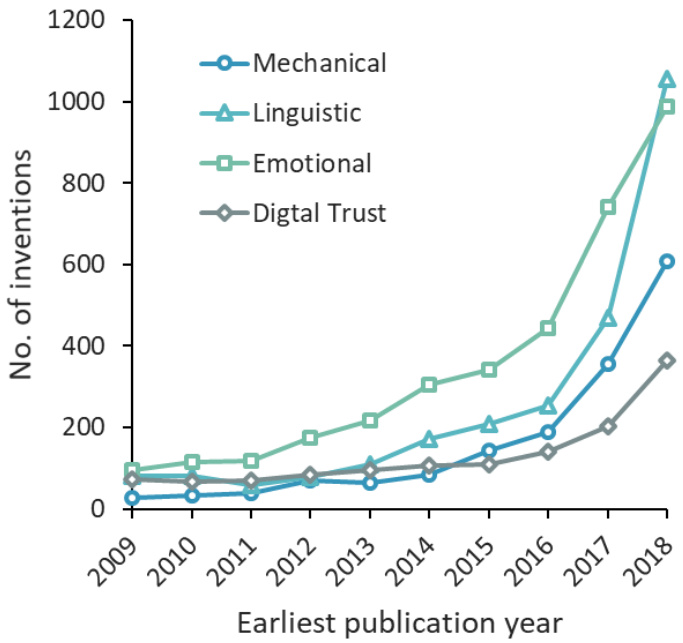
## HMC TECHNOLOGY DOMAINS

**Mechanical** **1618** inventions, **48.6%↑**
Mechanical-collaboration refers to the physical interactions between machine and human or mutual assistance in a shared workspace. Inventions in this domain include collaborative robot, or cobots, soft-robots that are designed with elastic or flexible materials, as well as innovations relating to the safety control or damage prevention in a human-machine co-working environment.

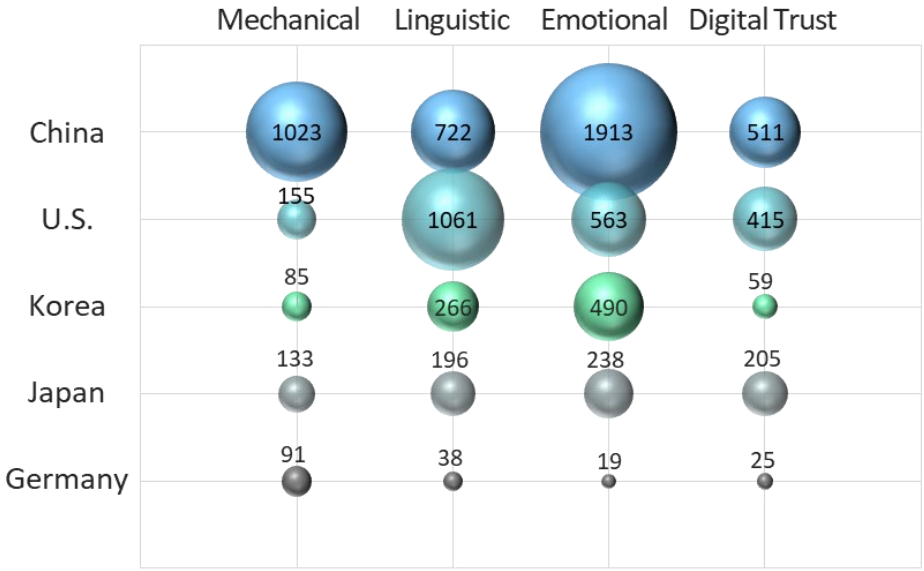
**Linguistic** **2575** inventions, **44.4%↑**
Linguistic-collaboration refers to speech-based information exchange between human and machine. Inventions in this domain include chatbots, conversational AI, virtual assistants and virtual agents.

**Emotional** **3536** inventions, **31.3%↑**
Emotional-collaboration refers to how a machine detects and understands human emotions (emotive), how the machine can have and express its internal processed emotions (affective), and the cognition capability to do both (cognitive). Inventions in this domain include human emotion recognition based on facial expressions or speech semantics, psychological or educational social bots, and artificial emotion generation or expressions.

**Digital Trust** **1318** inventions, **30.6%↑**
Digital Trust relates to technologies that aim to enhance the degree to which humans can trust the actions and decisions made by AI, and to ensure that machines make non-biased and moral decisions. Inventions in this domain include explainable AI, AI reasoning based on knowledge-graph representation, AI ethics and machine morality.




In this report, HMC-related innovations have been categorised into four HMC domains, viz. ***Mechanical***, ***Linguistic***, ***Emotional*** and ***Digital Trust***. Amongst the four domains, the bulk of HMC innovation is focussed on the *Emotional* domain which has more than 3,500 inventions published in the last decade and accounting for nearly 30% of overall HMC innovations. Interestingly, the number of published inventions in the *Linguistic* domain reached a record high of 1,057 in 2018, surpassing that of the *Emotional* domain. In terms of the total innovation volume, the focus on HMC innovations in the *Mechanical* and *Digital Trust* domains is less pronounced, with each domain accumulating less than 2,000 inventions in the past decade.




## *MECHANICAL*

China is the most dominant player in the HMC *Mechanical* domain, contributing over 60% of overall innovation in the domain. China is not only the biggest market for industry robots but also the largest robot supplier in the world. In addition, China is also increasingly adopting advanced robotic technologies as the World's factory seeks to improve the productivity of its manufacturing sector[9]. As the robotic industry in China continues to make major breakthroughs, the substantial number of innovations relating to the design of collaborative robots (cobot) suggests that it is an emerging innovation area. While Germany only ranks fifth amongst the countries on overall HMC innovations, a substantial proportion of its HMC innovations is in the *Mechanical* domain. This also correlates with Germany being the largest manufacturing economy in Europe[10].

Upon analysis of the top applicants in the *Mechanical* domain, as well as the attributes of the inventions, we note that institutes of higher learning (IHLs), such as the Harbin Institute of Technology and Shanghai Jiao Tong University, primarily focus on fundamental research. Conversely, multinational companies (MNCs) such as Fanuc, Kuka and ABB, which are well-established manufacturers of industrial robots, tend to protect HMC products or solutions that are ready for commercialisation. Some of the cobots already available in the global market include Fanuc's CR series[11], Kuka's LBR iisy and LBR iiwa[12], and ABB's Yumi[13].

While it is anticipated that the cobot market alone will reach US$ 5 billion by 2023 at a remarkable growth rate of around 64% p.a. [14], the relative sizes of the patent portfolios of leading robot suppliers in the *Mechanical* domain show there is no clear winner with a dominant patent portfolio. These observations point to both substantial industry demand and encouraging market prospects for HMC innovations in the *Mechanical* domain as well as R&D opportunities in this area yet to be explored.

| Mechanical | Linguistic | Emotional | Digital Trust |
|---|---|---|---|
| Fanuc [53] | Microsoft [127] | IBM [120] | IBM [61] |
| Kuka [32] | IBM [114] | Samsung [63] | NEC [45] |
| Harbin Inst of Tech [26] | Google [71] | Beijing Guangnian Wuxian [46] | Microsoft [30] |
| ABB [24] | Baidu [42] | ETRI, KR [42] | Siemens [17] |
| Shanghai Jiao Tong Univ [22] | Apple [40] | Nanjing Univ Post & Tel [38] | Zhejiang Univ [16] |
| Soft Robotics [17] | Samsung [36] | SONY [33] | Hitachi [14] |
| Harvard College [16] | Tencent [34] | Southeast Univ [29] | State Grid Corp [13] |
| Seiko Epson [16] | Beijing Guangnian Wuxian [33] | Baidu [28] | Fujitsu [13] |
| SIASUN Robot [16] | Nuance Communications [28] | Hefei Univ of Tech [27] | NTT [12] |
| South China Univ Tech [16] | Arria Data2text [23] | NEC [26] | FTI Consulting [12] |

The number in the parentheses represents the number of published inventions owned by the applicant.

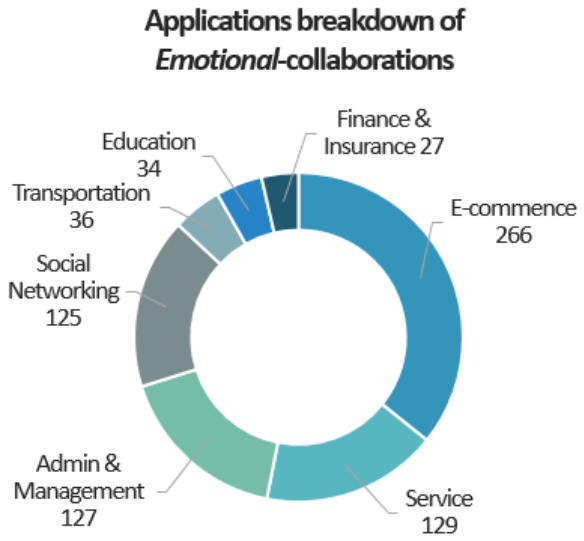
## *LINGUISTIC*

Clearly, when it comes to the *Linguistic* domain, the emphasis placed on this domain by the Chinese is contrary to that of the US, where the *Linguistic* domain clearly overshadows the other domains. This is the case globally as well. Apart from the global adoption and widespread use of the English language, the prominence of the *Linguistic* domain (second only to the *Emotional* domain) can be attributed to the intensive innovations from big MNCs such as Microsoft, IBM and Google, with 70+ to 120+ published inventions, respectively.

In the recent years, innovative companies have made remarkable progress in the communication skills of robots by employing well-established capabilities in machine learning and natural language processing (NLP); take for example, the Google Assistant[15]. From a commercial standpoint, enterprises such as insurance companies, healthcare providers and other business operators are increasingly using chatbots and AI-based call centres to enhance their customer support services and improve client engagement, even generating data through social media platforms to further drive their businesses. These human-machine collaborations integrate the powerful storage and computing capacity of machines with the logic, empathy and flexibility of human beings, effectively improving the quality of service and efficiency of the customer support staff. According to a recent market report, the global AI-based call centre market is expected to grow from US$ 800 million in 2019 to US$ 2,800 million by 2024[16]. This rapid growth trajectory is indicative of the imminent tension and fierce competition in this field. Given the large patent portfolios and thus the strong technology ring-fencing of the MNCs in the *Linguistic* domain, it is likely that smaller companies or new entrants will face challenges in innovation and growth in this area. On the other hand, the intensive competition would accelerate the development and maturity of NLP products and services, providing more affordable choices for companies looking to deploy chatbots or virtual assistants to elevate their business potential.

## *EMOTIONAL*

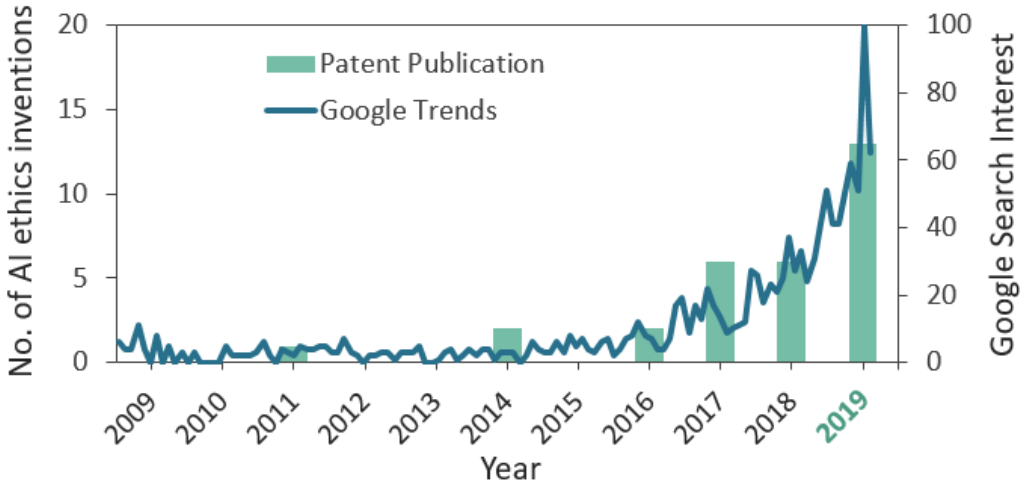
Innovations in *Emotional*-collaborations are receiving intense focus among major countries. As developments in the emotional-collaboration capabilities make headway, it is poised to improve the human-machine interaction experience and make a broad spectrum of applications possible, from E-commerce, services in hotels, tourism and property sectors, administration and management, to social networking, transportation and education. Taking the transportation sector as an example, at the Consumer Electronics Show (CES) 2019, Kia Motors introduced its Real-time Emotion Adaptive Driving System, or R.E.A.D., which can monitor facial expressions of passengers and track biomarkers in real time for signs of stress[17]. In the service and education sectors, there is increasing usage of interactive robots to educate children and serve the needs of the elderly, people suffering from Alzheimer's and other disabilities. The value of such entertainment & social robots is estimated to reach US$ 2 billion by 2025, implying there is a market for innovations in this domain[18].



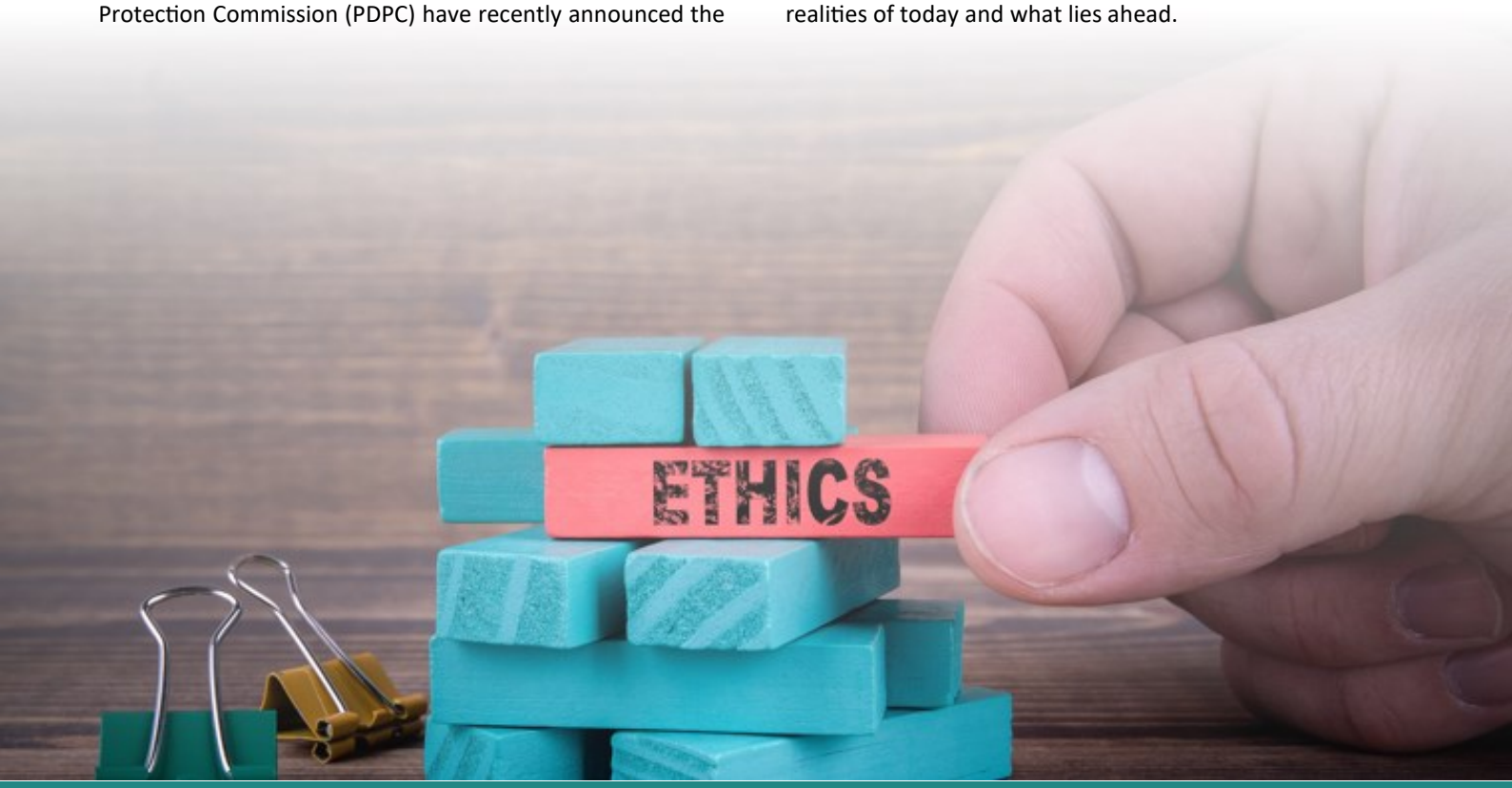

## *DIGITAL TRUST*

As AI applications become more complex and prevalent in our everyday lives, there are growing concerns about how much we can really trust a machine's decisions, especially in critical areas such as autonomous driving, healthcare, criminal justice and the hiring process. One key area of focus in *Digital Trust* is building transparency and explainability into AI models to clearly explain and identify the logic behind predictions from the machine learning "black-box". As a result, around half of the inventions in the *Digital Trust* domain relate to explainable AI (XAI). Another innovation focus in this domain relates to communication between human and intelligent machines, such as those that seek to understand how the machine communicates its intentions and reasoning processes to the human, and how humans can query and interact with the robot's plan.

While the trust (or lack thereof) in digital technologies spans across technical, ethical and moral aspects, AI ethics as a whole remains a largely unexplored area, with only approximately 30 inventions registered during 2009-2019. The published inventions mainly focus on the supervision of AI applications to ensure that unwanted outcomes — such as discrimination, violence or racism — are detected and eliminated to prevent harm. Despite having only a small number of related inventions, AI ethics have been gaining fast traction in most recent years. In particular, the newly published inventions relating to ethical AI in the first five months of 2019 have already exceeded the total number for 2018. The growths of the related patent publications have also corroborated well with the fast growing interest in the public as evidenced by the increasing occurrence of related keywords in Google search. This high interest in AI ethics and the relatively small number of inventions suggests a strong potential for future growth and expansion in this area.




Besides technical efforts, building trust between human and intelligent machines requires the participation of other social disciplines such as philosophy, ethics, and law. Policymakers are committed to building mutual trust between governments and enterprises by setting guidelines for cooperation and mutual respect between countries, and shaping the future of AI technologies. In May 2018, the European Union implemented the General Data Protection Regulation to protect data privacy. Later in June, Singapore also announced her initiatives on AI governance and ethics, forming an advisory council on the ethical use of AI and data. This year in Singapore, the Infocomm Media Development Authority (IMDA) and the Personal Data Protection Commission (PDPC) have recently announced the first comprehensive Trusted Data Sharing Framework to facilitate trusted data sharing between organisations[19]. In Europe, "Ethics Guidelines for Trustworthy AI" was published by the EU commission to fight against biased algorithms[20], and the UK government proposed a new framework for Internet regulations in order to avoid harmful content on websites and social media[21]. Nevertheless, despite the well-meaning efforts of policymakers and innovations from enterprises to build digital trust, the battle to prevent the abuse of AI is an uphill task that demands a concerted effort from various stakeholders. Google, for example, cancelled its AI ethics board just one week after forming it[22], implying that there's a big gap between the realities of today and what lies ahead.



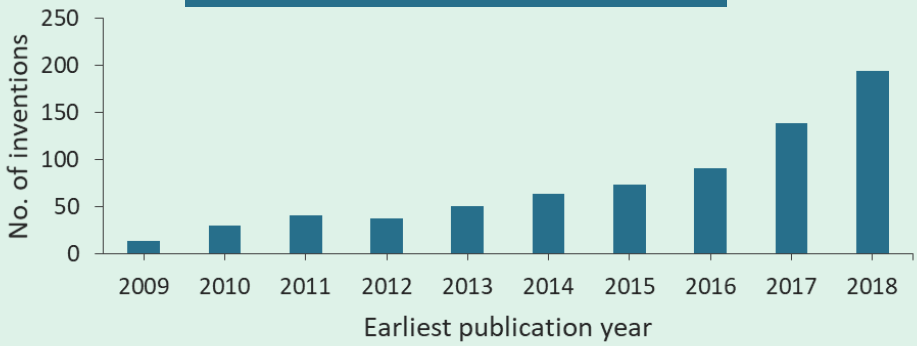
## ***Spotlight**: Machine-to-Machine (M2M) collaboration and Swarm Intelligence*

Human and machine collaborations are not limited to interactions between one machine and an individual human *per se*. When multiple machines work together establishing machine-to-machine (M2M) collaborations, they can better service and help humans. One of the major developments is **swarm intelligence**, an emerging area in AI based on the study of decentralised, self-organised systems that can move quickly in a coordinated matter to perform a common goal, which has been traditionally studied in nature.

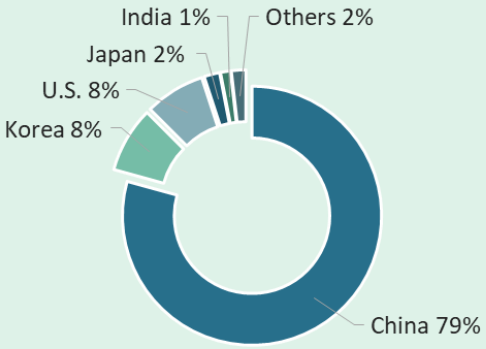
Compared with the four HMC domains, swarm intelligence is much less explored, with less than 800 inventions recorded during 2009-2018. Nevertheless, the upward trend in patent publications demonstrates a growing innovation interest in swarm intelligence. Chinese applicants have filed the most inventions in this area, accounting for nearly 80% of the global swarm-intelligence-related inventions. These inventions relate mainly to the control and navigation of multiple robots for specific tasks, such as cleaning, inspection or delivery, as well as the utilisation of swarm intelligence for scheduling optimisation or industrial fault detection.

Active applicants in swarm intelligence are IHLs from China and Korea. In particular, the lack of companies with large technology portfolios further illustrate the nascence of this area and the space for further R&D.

**Worldwide patent publication trend**




**Country of Origin**




**Top applicants & No. of inventions**

| |
|---|
| Zhejiang Univ [36] |
| Shenzhen Inst Adv Tech, CAS [16] |
| ETRI, KR [14] |
| Institute of Automation, CAS [12] |
| Southeast Univ [11] |
| Univ Shanghai Sci Tech [11] |
| Nanjing Univ Post & Tel [11] |
| Hangzhou Dianzi Univ [10] |
| Harbin Eng Univ [9] |
| Hohai Univ [9] |

## CONCLUSION

This report provides an overview of HMC-related technologies based on the worldwide patents published in the past decade. Increasing innovation and a booming global market suggest a growing focus on HMC innovations and great potential for commercial applications in future, with an increasing emphasis on the social and ethical aspects of advanced robotics and AI technologies. At the domain level, innovations in *Mechanical*-collaboration are expected to maintain the fastest growth rate with continued capacity for further development, in contrast to the *Linguistic* domain which is a relatively congested area experiencing fierce market competition. In the *Emotional* domain, emotion recognition has been intensively studied, while machine emotion synthesis and expression are still a fertile area for future innovation. With regards to *Digital Trust*, both technical innovations and social supervisions are receiving greater interest and activity but much work remains to be done in reconciling the technical, ethical and moral aspects to set the parameters for market adoption. Swarm intelligence, in building of M2M collaboration, is also seen as an upcoming area with strong R&D opportunities. Overall, while there is increasingly widespread adoption of AI in most areas of industry, the unknowns and need for further study in the various aspects of HMC mean that we are still some way from the deployment of AI solutions in critical and high-risk applications.

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