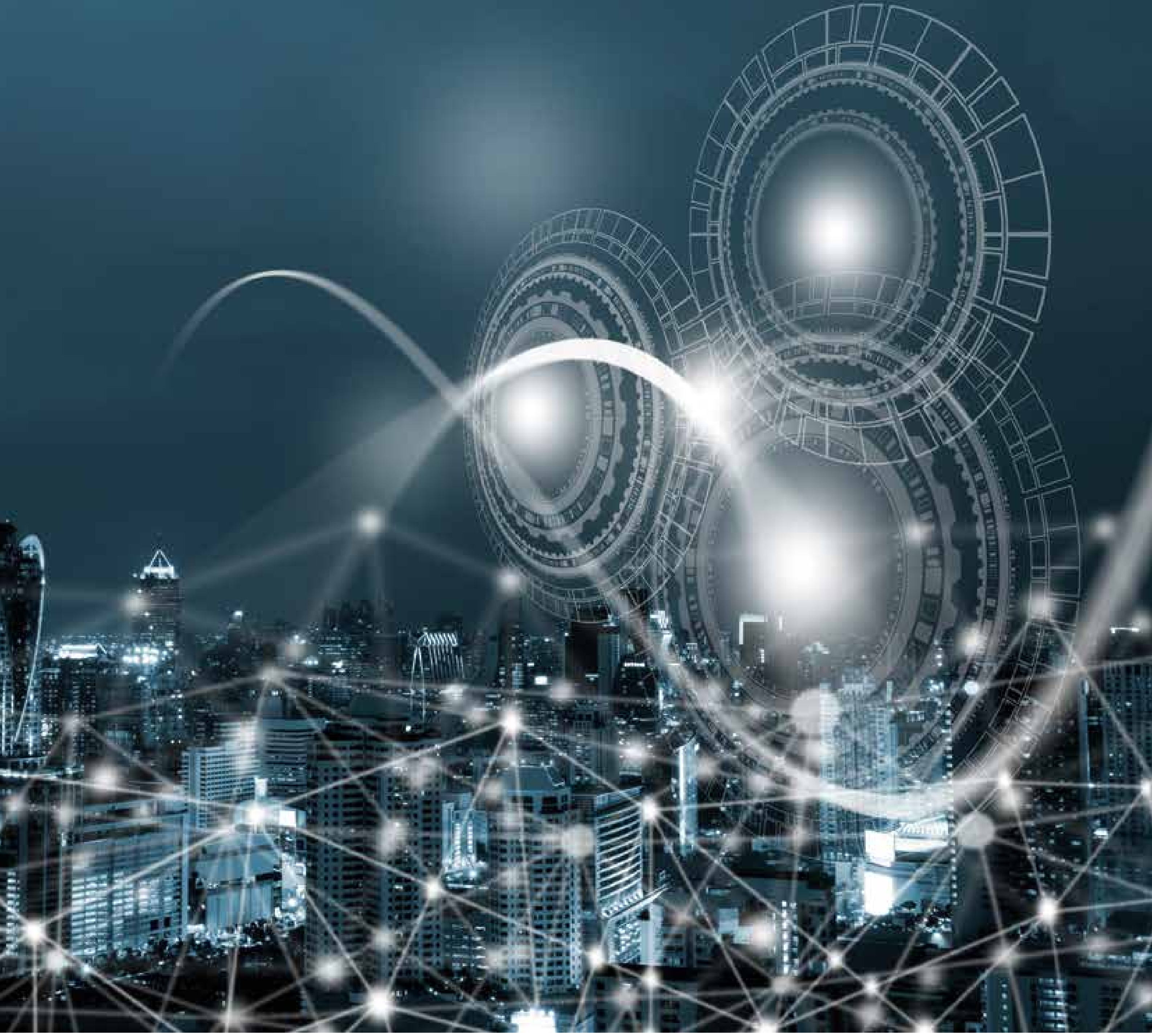
Europäisches Patentamt
European Patent Office
Office européen des brevets

Patents and the Fourth Industrial Revolution

The inventions behind digital transformation | December 2017



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Foreword

Dear readers,

A new era of technological development characterised by digital transformation is rapidly gathering momentum – one which is frequently referred to as the Fourth Industrial Revolution (4IR), or, in some regions, as Industry 4.0. The consensus on 4IR is still forming but the fact that it is referred to as a 'revolution' implies that its impact is expected to be far-reaching. Businesses, industry, analysts, policy makers and many others are starting to discuss in greater detail its characteristics and the challenges and opportunities the revolution presents. As an organisation at the forefront of technology, the EPO has the tools and skills to support this dialogue with a clear picture of evolving trends: the EPO is one of the leading suppliers of patent information, and the solid data that we hold can help us to reliably identify and follow developments as we head into this period of great change.

Our ESPACENET database, for example, provides free access online to a wealth of more than 100 million patent documents containing data about inventions and technological advances from around the world. And with PATSTAT, we have put one of the most advanced statistical tools for analysing technology trends in patents at the disposition of the public. Paired with the expertise of our patent examiners, these tools are a reliable resource for conducting meaningful studies on the emergence of technology trends and their development over time and economic regions.

We have employed our data and skills to produce this publication, the EPO's first landscaping study related to patents and 4IR technologies. The study provides a picture of the dynamics of 4IR technologies as reflected in patent applications and clearly demonstrates that 4IR innovation is accelerating faster than other fields. It is also becoming more interdisciplinary, as the changes we are witnessing are driven by connected objects, data and software.

The EPO is alert to the effects of 4IR technologies and their implications for both its own work and the needs of users of the patent system. For years now, we have been applying a stable, rigorous and transparent examination practice regarding patents for computer-implemented inventions. The EPO is therefore well prepared to address the patentability of 4IR inventions under the applicable European patent law, and to create the necessary legal certainty for innovating businesses in the sector.

The findings confirm Europe's strong position as a hub for the technologies driving this evolution. Since the mid-1990s, Europe, alongside the USA and Japan, has been one of the main innovation centres for 4IR technologies, and European inventors were responsible for almost 30% of all 4IR patent applications filed with the EPO up to 2016. This confirms the findings of the wider analysis of the EPO's annual patent statistics in recent years, namely that the European economy can rely on a broad and evenly spread technology portfolio to secure its competitiveness. In relation to 4IR technologies, the study draws an encouraging picture of Europe's innovative strength in a game-changing domain.

Benoît Battistelli,
President, European Patent Office

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List of abbreviations

4G	Fourth generation of mobile networks
4IR	Fourth Industrial Revolution
5G	Fifth generation of mobile networks
AI	Artificial intelligence
CII	Computer-implemented inventions
CPC	Cooperative Patent Classification
CPS	Cyber-physical systems
EPC	European Patent Convention
EPO	European Patent Office
GPRS	General Packet Radio Service
GPS	Global Positioning System
ICT	Information and communication technology
IoT	Internet of Things
IP	Internet Protocol
JRC	Joint Research Centre of the European Commission
M2M	Machine-to-machine
NUTS 2	Nomenclature of territorial units for statistics - Level 2
OECD	Organisation for Economic Co-operation and Development
PATSTAT	EPO Worldwide Patent Statistical Database
PCT	Patent Cooperation Treaty
R&D	Research and development
SMEs	Small and medium-sized enterprises

List of countries

AT	Austria
AU	Australia
BE	Belgium
CA	Canada
CH	Switzerland
CN	People's Republic of China
CZ	Czech Republic
DE	Germany
DK	Denmark
ES	Spain
FI	Finland
FR	France
GB	United Kingdom
HU	Hungary
IE	Ireland
IL	Israel
IN	India
IT	Italy
JP	Japan
KR	Republic of Korea
NL	Netherlands
NO	Norway
PL	Poland
RO	Romania
RU	Russian Federation
SE	Sweden
SG	Singapore
TR	Turkey
TW	Taiwan
US	United States of America

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Executive summary

Aim of the study

The massive deployment of the Internet of Things (IoT) is about to entice a Fourth Industrial Revolution (4IR). By 2025, it is estimated that 26-30 billion of devices in the home and workplace will be equipped with sensors, processors and embedded software, and connected to the Internet of Things (IoT). These objects can operate autonomously based on the data that they collect or exchange with each other. Once combined with other technologies, such as cloud computing and artificial intelligence , they enable the automation of entire business processes, including repetitive intellectual tasks previously performed by human beings. Autonomous objects are already transforming a large variety of sectors, from manufacturing and agriculture to health and transportation. However, the deepest changes are yet to come.

This study draws on the latest available patent information to analyse the innovation trends to analyse the innovation trends that signal the advent of the the Fourth Industrial Revolution. All European patent applications related to 4IR have been identified up to 2016.

These 4IR inventions have been further classified into three main sectors, each of which is subdivided into several technology fields:

- **Core technologies** (*Hardware, Software* and *Connectivity*) that make it possible to transform any object into a smart device connected via the internet.

- **Enabling technologies** (*Analytics, Security, Artificial intelligence, Position determination, Power supply, 3D systems, User interfaces*) that are used in combination with connected objects.

- **Application domains** (*Home, Personal, Enterprise, Manufacturing, Infrastructure, Vehicles*) where the potential of connected objects can be exploited.

About patents and patent information

Patents are exclusive rights for inventions that are new and inventive. High-quality patents are assets for inventors because they can help attract investment, secure licensing deals and provide market exclusivity. Patents are not secret. In exchange for these exclusive rights, all patent applications are published, revealing the technical details of the inventions in them.

Patent databases therefore contain the latest technical information, much of which cannot be found in any other source, which anyone can use for their own research purposes. The EPO's free Espacenet database contains more than 100 million documents from over 100 countries, and comes with a machine translation tool in 32 languages.

This patent information provides early indications of the technological developments that are bound to transform the economy. It reveals how innovation is driving the Fourth Industrial Revolution.

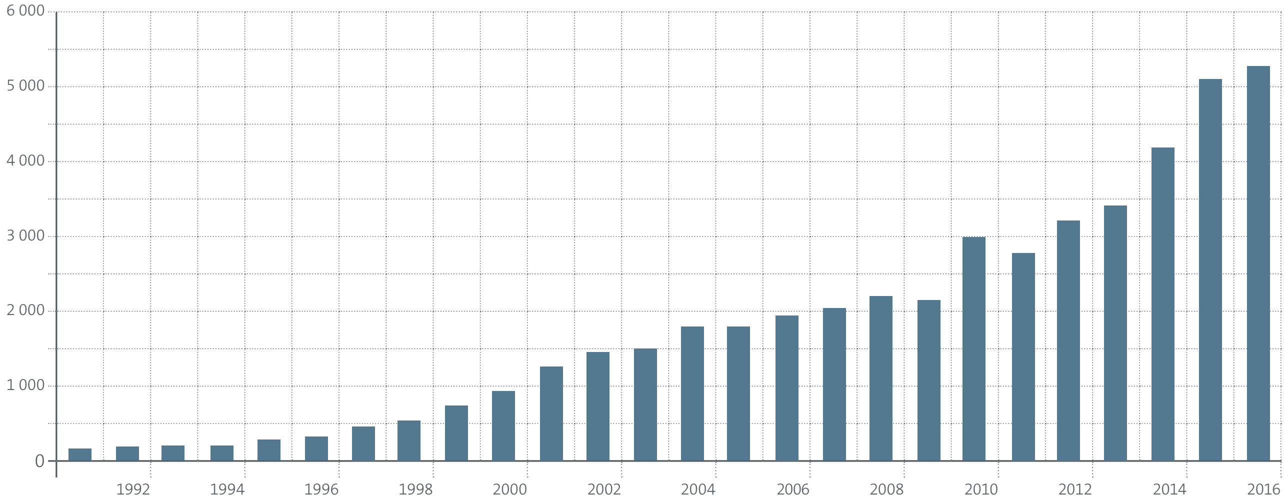
Main findings

4IR innovation is taking off

- More than 5 000 patent applications for inventions relating to autonomous objects were filed at the EPO in 2016 alone and in the last three years, the rate of growth for 4IR patent applications was 54%. This far outpaces the overall growth of patent applications in the last three years of 7.65%.

- *Connectivity* and the application domains *Personal* and *Enterprise* have attracted the largest numbers of such patent applications so far, while the fastest-growing fields are *3D systems, Artificial intelligence* and *User interfaces*.

4IR patent applications at the EPO 1991-2016



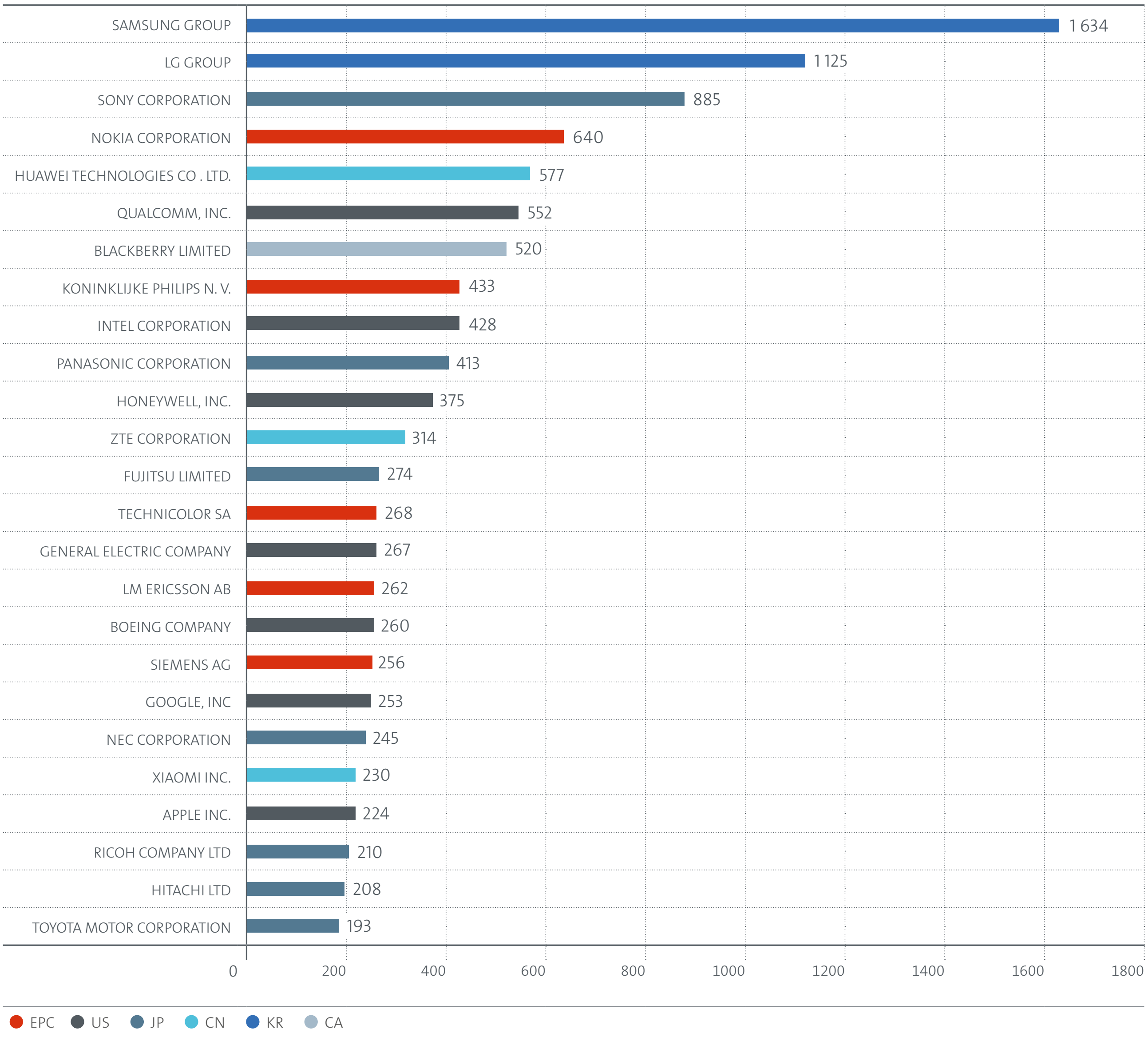
Source: European Patent Office

Top 4IR applicants active in different industries

- Twenty-five companies, most of them with a strong focus on information and communication technologies (ICT), accounted for about half of all 4IR patent applications at the EPO between 2011 and 2016.

- Innovation in core technologies is mainly led by a limited number of large companies focused on information and communication technology (ICT). Inventions in enabling technologies and application domains are less concentrated, and the top applicants in these sectors originate from a larger variety of industries.

Top 25 4IR applicants at the EPO 2011-2016



Source: European Patent Office

Europe, the USA and Japan are the established leaders, but China and Korea are rapidly catching up

– Europe (EPC), the USA (US) and Japan (JP) started developing 4IR technologies in the mid-1990s, and they were still the main innovation centres in 2016. The top European, US and Japanese applicants include large companies from various industry sectors, with strong patent positions in application domains and enabling technology fields.

– 4IR innovation started ten years later in the Republic of Korea (KR) and the People's Republic of China (CN), but has been increasing at a faster rate than in other regions. In Korea, more than 90% of 4IR applications come from Samsung and LG, both of which have developed strong patent portfolios in diverse 4IR technology fields. Nearly 70% of Chinese patent applications originate from two companies (Huawei and ZTE) that are more specialised in core technologies.

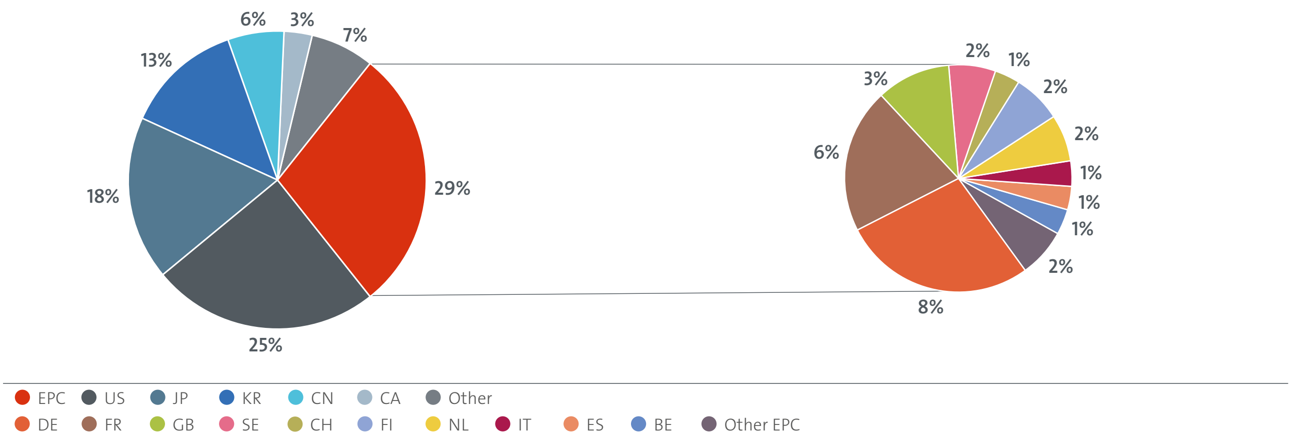
In Europe, Germany and France are ahead

– Within Europe, Germany (DE) and France (FR) are foremost in 4IR innovation. Germany stands out in the application domains of *Vehicles, Infrastructure* and *Manufacturing*, while France leads in enabling technologies such as *Artificial intelligence, Security, User interfaces* and *3D systems*.

– The United Kingdom (GB) and other European countries such as Sweden (SE), Switzerland (CH), Finland (FI) and the Netherlands (NL) also show inventive activity.

– 4IR research in Europe is subject to a marked regional concentration. The inventive profiles of the top two EU regions for 4IR innovations (the greater Paris area, followed by the greater Munich area) reflect the complementary strengths of France and Germany.

Geographic origins of 4IR inventions 2011-2016



Source: European Patent Office

Introduction

This study by the European Patent Office (EPO) is intended to provide users of the European patent system and the broader public with information about a major technology trend that is being observed across a whole range of technical fields. Known as the Fourth Industrial Revolution[1] (4IR), this trend is primarily driven by the emergence of the Internet of Things (IoT). It also encompasses a number of other technologies, such as cloud computing and artificial intelligence, that make it possible to fully exploit the potential of smart connected objects in nearly all sectors of the economy.

The Fourth Industrial Revolution

The term "industrial revolution" reflects the pervasiveness and the disruptive potential of the latest technological developments. While previous industrial revolutions have led to the increasing automation of repetitive *physical* work, 4IR goes much further: it leads to the large-scale automation of entire groups of tasks, including repetitive *intellectual* tasks previously performed by human beings. 4IR can significantly enhance the efficiency and flexibility of production processes and augment the value of products and services (MGI, 2015; European Commission, 2015). The transition towards "smart" factories operating autonomously has already been recognised as an important challenge by industry and policy-makers in Europe[2] and beyond. Likewise, the deployment of connected objects in transport (autonomous vehicles), energy (smart grids), cities, healthcare and agriculture profoundly changes the way these sectors are organised.

Like previous industrial revolutions, 4IR raises major economic and social issues (OECD, 2017; European Commission, 2015). Increasing the automation of routine intellectual tasks changes the nature of human work, and hence the balance of the labour market. It obliges companies to rethink their business models and to adapt to new forms of competition. Besides investing in the training of the 4IR workforce, policy-makers face the challenge of supporting and regulating new digital infrastructures and of creating appropriate legal frameworks to safeguard competition, cybersecurity and consumer rights in the digital age.

Aim of the study

The study focuses on the technologies underpinning these transformations and on the way in which they will shape tomorrow's economy. Aimed at decision-makers in both the public and private sectors, it looks at the high-tech drivers and innovation trends behind 4IR and draws on the latest information available in patent documents and the technical expertise of the EPO's patent examiners.

4IR is primarily driven by scientific progress, and therefore by patented inventions. Companies and inventors make use of the temporary exclusivity conferred by patent rights to market their innovations and, in doing so, to recoup their R&D investments. They also increasingly employ patents as leverage in order to exploit their products, whether through licensing contracts or by setting up R&D co-operations. The EPO is responsible for granting patents which can be validated in up to 40 European countries. As one of the world's main providers of patent information, it is therefore uniquely placed to observe the early emergence of these technologies and to follow their development over time. The analyses presented in the study are a result of this monitoring.

One of the aims of the study is hence to share the EPO's understanding of the scope and dynamics of 4IR. It identifies the different technology building blocks concerned and shows how these technologies are increasingly being integrated into a wide range of business applications, offering new opportunities for innovation and value creation based on data and software.

1 Fourth Industrial Revolution is the term used by Klaus Schwab, founder and Executive Chairman of the World Economic Forum, in his recent book on this subject (Schwab, 2017).

2 See e.g. "Industry 4.0" (Germany), "Nouvelle France Industrielle" (France), "Fabricca Intelligente" (Italy), "Industria Conectada 4.0" (Spain), "Made Different" (Belgium), "Prumysl 4.0" (Czech Republic), "Smart Industry" (Slovakia), "Production 2014" (Sweden), "MADE" (Denmark), "Produktion der Zukunft" (Austria) and "Smart Industry" (The Netherlands).

The study also aims to statistically analyse recent trends in 4IR innovation, by systematically mapping the building blocks of 4IR to European patent applications. The resulting patent statistics provide advanced indicators of technical progress and future market trends. They are also valuable for assessing the performance and specialisation profiles of the companies and countries involved.

Focussing on patent applications filed with the EPO makes it possible to produce up-to-date statistics, including unpublished patent documents filed in 2016 and only available in the EPO's internal database. Since all European patent applications are classified by the EPO's patent examiners, they can also be mapped to the different 4IR technology fields with a high degree of certainty.

Outline of the study

Chapter 1 introduces the main technology building blocks of 4IR and shows how combining them can open up new possibilities for value creation and innovation. Chapter 2 sets out the methodology used in the study to identify and map inventions into the different technology fields underpinning 4IR, while Chapter 3 presents the main trends. Chapter 4 discusses the continued integration of the different technologies into a variety of new market applications. Chapter 5 focuses on the top patent applicants involved in 4IR. Chapter 6 analyses the global origins of 4IR inventions filed at the EPO, while Chapter 7 looks more closely at European countries. The study also contains four case studies, two of which are dedicated to selected 4IR technologies (additive manufacturing and smart sensors) and two to specific application fields (smart manufacturing and smart health).

BOX 1

Patents support innovation, competition and knowledge transfer

Patents are exclusive rights that can only be granted for inventions that are new and inventive. High-quality patents are assets which can help attract investment, secure licensing deals and provide market exclusivity. Inventors pay annual fees to maintain those patents that are of commercial value to them; the rest lapse, leaving the technical information in them free for everyone to use. A patent can be maintained for a maximum of twenty years.

In exchange for these exclusive rights, all patent applications are published, revealing the technical details of the inventions in them. Patent databases therefore contain a wealth of technical information, much of which cannot be found in any other source, which anyone can use for their own research purposes. The EPO's free Espacenet database contains more than 100 million documents from over 100 countries, and comes with a machine translation tool in 32 languages. Most of the patent documents in Espacenet are not in force, so the inventions are free to use.

1. The building blocks of the Fourth Industrial Revolution

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The term Fourth Industrial Revolution (4IR) is used in this study to denote the full integration of information and communication technologies (ICT) in the context of manufacturing and application areas such as personal, home, vehicle, enterprise and infrastructure. It is, however, more than a mere continuation or even acceleration of the development of ICT.

In contrast with the early days of digitisation, the truly disruptive nature of 4IR originates in the combined use of a wide range of new technologies in a large variety of sectors of the economy. These include digitisation and highly effective connectivity, but also technologies such as cloud computing and artificial intelligence that have permitted the development of interconnected smart objects operating autonomously.

The purpose of this chapter is to introduce these technologies and to present the way in which, once combined, they can revolutionise a variety of domains.

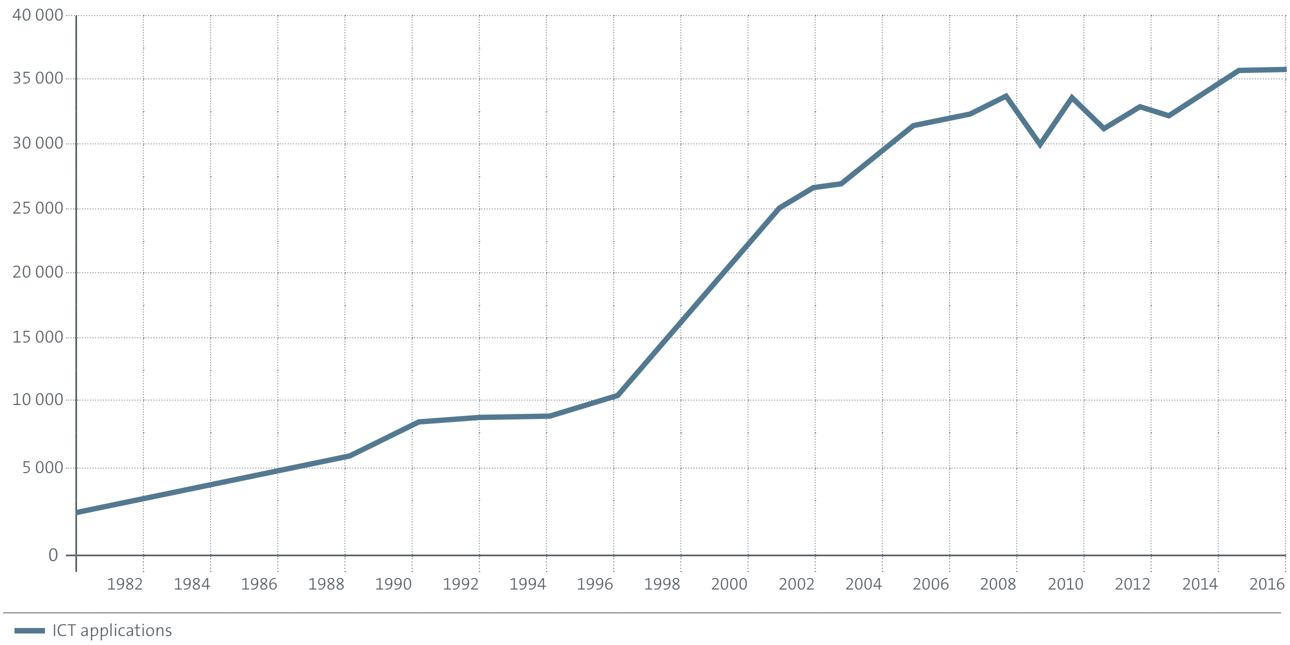
1.1 Connected smart objects

Information and communication technologies have been major drivers of innovation since the early 1980, as illustrated by the growing number of patent applications in ICT during this period (Figure 1.1). These innovations led to the presence of a computer and internet access in just about every home and workplace, and later on to the integration of computers into mobile communication devices. 4IR opens a new cycle of innovation, in which every object will be equipped with computing capabilities and connected to a communication network.

Recent technical progress in the cost-effectiveness and size of processors plays an important role in this development, by allowing for the integration of chips with networking capabilities into everyday objects. From 2002 to 2015, the size of transistors (the elementary component of electronic circuits) decreased from 180 nanometres to less than 20 nanometres (Condliffe 2016; Sutherland 2013). As a result, a single chip may be ten times more powerful than ten years ago, with up to several billions of integrated transistors. Conversely, smaller chips can be used to perform standard functions at a lower cost for consumers and in wider categories of objects.

Figure 1.1

Patent applications in ICT at the EPO



Source: European Patent Office. Based on a classification of ICT patent applications developed by the OECD (Inaba and Squicciarini, 2017).

The potential for new connected objects goes well beyond devices traditionally connected to the internet such as laptops or smartphones. It includes all objects and sensors that may gather data in the home and workplace – or more diverse domains such as agriculture and traffic management – and communicate with one another. Analysts estimate that the number of such connected devices will increase by about 15-20% annually over the next few years, reaching 26-30 billion by 2025 (MGI, 2016). Thanks to embedded electronics, sensors, software and network connectivity, these devices will be able to collect and exchange data without any involvement by human beings.

The Internet of Things (IoT) is the network formed by these billions of interconnected objects. Smart clothes, buildings, vehicles, implants, machines and robots, all equipped with sensors and endowed with their own internet address, will contribute to the increase in data traffic in future years (Figure 1.2). According to Cisco (2017), global IP traffic will grow three-fold from 2016 to 2021, reaching 278.1 exabytes per month in 2021. Smartphones, connected TVs, and PCs will represent 40% of all networked devices and generate 88% of global IP traffic. Machine-to-machine (M2M) communication modules will directly account for only 5% of global Internet Protocol (IP) traffic, as they mainly generate small and intermittent data transfers. However, they are expected to represent more than half of all networked devices.

The 5th generation (5G) of mobile networks will provide the communication infrastructure for these developments. 5G will allow data transmission rates of up to ten gigabits per second for users, as compared with up to 1 gigabit per second for 4G. The 5G networks will be built around a combination of standards, designed to support a variety of applications of the IoT such as connected wearables, augmented reality and immersive gaming (see Table 1.1 for other applications). In addition to providing faster speeds, they are expected to support massive and ultra-reliable device-to-device communications, such as the simultaneous connections of several hundreds of thousands of wireless sensors, with low energy consumption and reduced network latency.

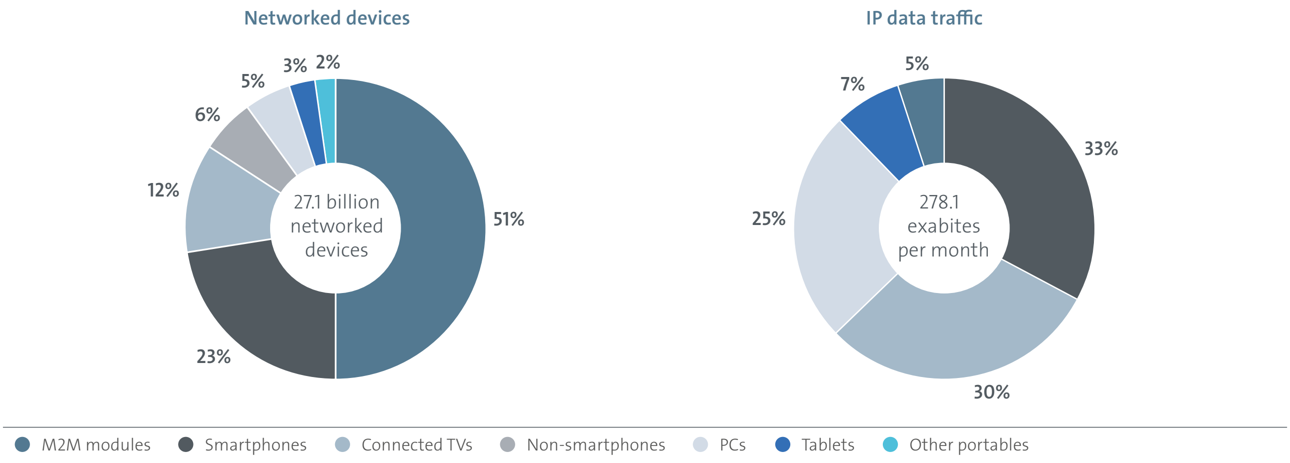
1.2 Data-driven value creation

The main feature of intelligent, connected devices is that they have the autonomy to decide how to act or react, based on information that they have collected or received from other devices. To understand their full potential, however, it is also necessary to take into account additional developments driven by other enabling technologies.

The availability and interaction of massive data sets (big data). Sensors and connected objects are primarily valuable as a source of accurate information. Their variety and ubiquity

Figure 1.2

Expected impact of connected objects on internet data traffic in 2021



Source: CISCO; European Patent Office

make it possible to collect data of virtually any type and origin (from the traffic conditions in which a vehicle finds itself to the physiological state of a patient) on an unprecedented scale. Besides accuracy, technology plays a critical role in ensuring the secure use of these data which, once aggregated into “big data”, provide the raw material of the 4IR applications.

New forms of distributed computing and data storage (cloud computing). Increases in the ability to store enormous quantities of data, managed reliably and safely over networks in the cloud, are also a key enabling element. Cloud computing offers the capability to store and process huge amounts of data on networks of remote servers located in multiple data centres. It effectively works as a utility for easily-scalable data services for all types of companies and organisations, using shared resources to achieve economies of scale and making data-accessing mechanisms more efficient and reliable.

The emergence of powerful data analytics. Progress in data analytics is in turn of fundamental importance to extract value from data. Analyses have long been performed by people supported by computers. However, the development of powerful diagnostic systems, including the performance of human-like cognitive functions by artificial intelligence (AI), is set to change this pattern. These tools can process vast amounts of data, and detect and interpret patterns that were previously impossible to calculate, identify, or even imagine. By making the interpretation of such patterns meaningful for machines as well as for humans, they enable machine prediction, diagnosis, modelling and risk analysis. AI is an essential element for enabling effective use of larger data volumes which can no longer be dealt with manually, and where the algorithms can no longer be efficiently reprogrammed by hand.

The realisation of physical or simulated 3D systems. Using large data sets, these systems make the results of complex models humanly viewable. Together with new interfaces to display such information, they enable applications based on virtual reality in a wide range of situations, from gaming to remote surgery, as well as the flexible design and production of any type of object through additive manufacturing.

These additional technologies play a critical role in enabling the full exploitation of the information collected by connected objects. Combined in the IoT, they displace the focus of value creation and innovation from traditional engineering towards the automated regulation of any type of system through the collection and analysis of data.

Examples of the wide variety of potential applications are provided in Table 1.1. They range from the remote monitoring of treatments for patients to the automated organisation of factories, logistical chains and fleets of vehicles, and are

Table 1.1

Some applications of the Internet of Things

Setting	Examples
Human	Devices (wearable and ingestible) to monitor and maintain human health and wellness, disease management, increased fitness, remote health monitoring, telehealth systems
Agriculture	Prescriptive farming, regionally pooled data analysis, predictive maintenance, real-time monitoring, predictive treatment of cattle
Home	Home controllers and security systems, smart energy (thermostats and HVAC), smart lighting, home automation
Retail environments	Self-checkout, in-store offers, inventory optimisation, food traceability, omni-channel operations, digital signage, in-store consumer digital offers, vending machines, near-field communication payment/shopping
Offices	Energy management and security in office buildings, improved productivity, including for mobile employees, production and asset management, staff identification
Factories and worksites	Operating efficiencies, optimising equipment use and inventory, predictive maintenance, health and safety
Cities	Adaptive traffic control, smart grids, smart meters, environmental monitoring, resource and waste management, parking solutions, public infrastructure asset control, public safety and emergency response
Transport	Connected navigation, real-time routing, shipment tracking, autonomous vehicles and flight navigation, transport sharing, asset and fleet management, freight monitoring, automated public transport, marine and coastal surveillance
Vehicles	Condition-based maintenance, usage-based design, pre-sale analytics, e-Call, connected vehicles
Finance	Remote asset security, insurance telematics, smart ATMs, bank digital signage, risk assessment in house and health insurances

Source: McKinsey (2015); European Commission; European Patent Office expected to have an important economic impact. In a study published in 2015, the McKinsey Global Institute concludes that the different applications of the IoT could generate between USD 3.9 and USD 11.1 trillion a year in economic value by 2025 – of which USD 1.2–3.7 trillion in factories, USD 930 billion–1.7 trillion in cities and USD 170 billion–1.6 trillion in human health and fitness. In the European Union alone, the market value of the IoT is expected to exceed one trillion euros in 2020 (European Commission, 2015).

1.3 Software-driven innovation

An important implication of 4IR is that innovation in the enhancement of products and processes is increasingly taking place in the virtual layer of software, rather than in any hardware components. In doing so it amplifies a general trend that is already well advanced. In recent years, growth in the ICT sector has largely been driven by software production and services, accounting for more than 80% of total ICT value added (OECD, 2017), and a similar trend has started in other sectors.

A large proportion of current inventions are therefore based on software implementation. Within the context of the European Patent Convention (Box 1), these inventions are known as computer-implemented inventions (CII). The element in the technology which is new and inventive is actually a changed computerised algorithm or control mechanism which is responsible for bringing about an improved technical effect. Besides representing the bulk of patent applications in ICT at the EPO, these computer-implemented inventions account for a large part of technological developments in many other areas. Prominent examples, representing two of the biggest European markets, are *Automotive and Medical technologies*, where the share of CII in all patent applications has reached the 50% mark in recent years.[3]

4IR technologies are likewise systematically based on CII. In addition – and more importantly- they offer additional ways of replacing hardware innovation by further moving the functionalities of inventions from mechanical or electrical parts into the digital world. This feature is already familiar in computers and mobile devices, which consumers can update, upgrade or equip with new applications without having to buy a new device. With the generalisation of the IoT, the same pattern is set to apply to all sorts of hardware, including vehicles and factories. A digital user interface for any connected device can be put into a tablet or smartphone application, enabling remote operation and eliminating the need for direct controls in the product itself.

One important consequence of this transition towards software-driven inventions is that it reduces the physical complexity of products, such as the number of physical components (for instance dials and buttons), or the production steps needed to build and assemble them. Until recently, industry has for instance used advanced machines run by standard software, and productivity gains were achieved through improving the hardware. However, this pattern is already evolving: machines are becoming more standardised, and advanced software is increasingly being used to enhance their performance. As a result, improvements to software are becoming the main source for increasing productivity, and even in the manufacturing sector, the focus of innovation is rapidly moving from hardware (e.g. vehicle, machine) to software. In this new context, the role of the manufacturer is changing from exclusive hardware producer to hardware and software producer.

3 This estimate is based on the analysis of large representative samples of patent applications in *Automotive* and *Medical technologies*.

BOX 1

Computer-implemented inventions (CII) at the EPO

Computer-implemented inventions are treated differently by patent offices in different regions of the world. In Europe, Article 52 of the European Patent Convention (EPC) excludes computer programs “as such” from patent protection. This exclusion does not mean that all inventions involving software are excluded from patenting; what it does mean is that tighter scrutiny of the technical character of these inventions is required.

Over the years, the case law of the EPO boards of appeal has clarified the implications of Article 52 EPC, establishing a stable and predictable framework for the patentability of computer-implemented inventions.

Like all other inventions, in order to be patentable, computer-implemented inventions must meet the fundamental legal requirements of novelty, inventive step and industrial application. In addition, it must be established that they have a technical character that distinguishes them from computer programs “as such”. In other words, they must solve a technical problem in a novel and non-obvious manner.

The normal physical effects of the execution of a program, e.g. electrical currents, are not in themselves sufficient to lend a computer program technical character, and a further technical effect is needed. The further technical effect may result, for example. from the control of an industrial process or the working of a piece of machinery, or from the internal functioning of the computer itself (e.g. memory organisation, program execution control) under the influence of the computer program.

The EPC thus enables the EPO to grant patents for inventions in many fields of technology in which computer programs make a technical contribution. Such fields include medical devices, the automotive sector, aerospace, industrial control, communication/media technology, including automated natural language translation, voice recognition and video compression, and also the computer/processor itself.

2. Methodology

2. Methodology

4IR is driven by inventions, most of which are patented, in new technological fields. Patent offices are therefore in a position to observe the emergence of these technologies at an early stage, and to monitor their development over time. In order to perform rigorous assessments of patent applications, patent examiners must develop and maintain significant expertise in the related technology fields. For the purpose of this study, the EPO has used this expertise to develop a cartography covering all related technologies in order to map the patented inventions underpinning 4IR.

2.1 Cartography of 4IR inventions

This cartography aims to identify all patent applications that are directly related to the building blocks of 4IR. It is based on a rigorous selection of inventions that combine features of computing, connectivity, data exchange and smart devices. These 4IR inventions are further divided between three main sectors, namely "core technologies", "enabling technologies" and "application domains", each of which is subdivided into several technology fields.

The first sector, *core technologies*, corresponds to the basic building blocks upon which the technologies of 4IR are built. It consists of inventions that directly contribute to the three established ICT fields inherited from the previous industrial revolution: *Hardware, Software* and *Connectivity*. The table gives a short definition of these core technology fields.

Table 2.1

Overview of core technology fields

Field	Definition	Example
Hardware	Basic hardware technologies	Sensors, advanced memories, processors, adaptive displays
Software	Basic software technologies	Intelligent cloud storage and computing structures, adaptive databases, mobile operating systems, virtualisation
Connectivity	Basic connectivity systems	Network protocols for massively connected devices, adaptive wireless data systems

The second sector captures *enabling technologies* that build upon and complement the core technologies. These enabling technologies can be used for multiple applications. They have been subdivided into seven technology fields.

Table 2.2

Overview of enabling technology fields

Field	Definition	Example
Analytics	Enabling the interpretation of information	Diagnostic systems for massive data
User interfaces	Enabling the display and input of information	Virtual reality, information display in eyewear
Three-dimensional support systems	Enabling the realisation of physical or simulated 3D systems	3D printers and scanners for parts manufacture, automated 3D design and simulation
Artificial intelligence	Enabling machine understanding	Machine learning, neural networks
Position determination	Enabling the determination of the position of objects	Enhanced GPS, device to device relative and absolute positioning
Power supply	Enabling intelligent power handling	Situation-aware charging systems, shared power transmission objectives
Security	Enabling the security of data or physical objects	Adaptive security systems, intelligent safety systems

The third sector, *application domains*, encompasses the final applications of 4IR technologies in various parts of the economy. It has been divided into six different technology fields.

Table 2.3

Overview of technology fields in application domains

Field	Definition	Example
Personal	Applications pertaining to the individual	Personal health monitoring devices, smart wearables, entertainment devices
Home	Applications for the home environment	Smart homes, alarm systems, intelligent lighting and heating, consumer robotics
Vehicles	Applications for moving vehicles	Autonomous driving, vehicle fleet navigation devices
Enterprise	Applications for business enterprise	Intelligent retail and healthcare systems, autonomous office systems, smart offices, agriculture
Manufacture	Applications for industrial manufacture	Smart factories, intelligent robotics, energy saving
Infra-structure	Applications for infrastructure	Intelligent energy distribution networks, intelligent transport networks, intelligent lighting and heating systems

Using the above cartography, 48 069 published and unpublished patent applications relevant for 4IR and filed at the EPO before 2017 were identified. The cartography enables them to be systematically classified in 4IR technology fields. *Application domains* capture the largest proportion of 4IR inventions, with a total number of 33 929 patent applications, representing 70.6% of all 4IR inventions. About half of all 4IR inventions (24 836 patent applications) are in turn related to core technologies. A smaller proportion of 34.5% of inventions (16 575) are related to enabling technologies. As indicated in Box 2, 4IR inventions can be relevant to one or more technology fields, within one or more technology sectors. If an invention combined features of several 4IR technologies, forming a bridge technology between different 4IR building blocks, the related patent application was classified accordingly in all relevant technology fields, resulting in overlaps in the numbers at field and sector level.

BOX 2

Identifying and mapping 4IR patent applications

The cartography of 4IR technologies was created in three steps.

Step 1: Mapping the cartography to the patent classification scheme

The cartography has been assembled from the intellectual input of patent examiners at the EPO. Patent classification experts from all technical areas were asked to indicate in which field ranges of the Cooperative Patent Classification (CPC) scheme they would assign 4IR inventions, and to which field(s) of the cartography these ranges should be attributed. The resulting concordance table contains around 320 CPC field ranges in all technical areas with their respective 4IR technology fields (see Annex, Figure 1). The cartography has been verified by applying *ad hoc* queries against the EPO's full-text patent database and analysing the results using text mining techniques. Anomalies identified have been re-assessed by classification experts and corrected/amended where necessary.

Examples

A61B5/68 - A61B5/6802	Wearable sensors	Personal, Connectivity
B60D1/01 - B60D1/075	Types of traction couplings	Vehicles

Step 2: Identifying 4IR patent applications

On all published and unpublished patent documents in the identified CPC ranges, a full-text search query was applied to identify documents related to the 4IR definition with the highest degree of certainty placed on true positives. As a general restriction, all documents must contain the concept of data exchange. In addition, further subqueries were defined to include the concepts of communication (e.g. internet, mobile, wireless, etc.), computing (e.g. big data, cloud, artificial intelligence, etc.) and devices (e.g. sensor networks, Internet of Things, smart homes, etc.).

Step 3: Classifying patent applications to the cartography fields

All CPC codes assigned to each identified 4IR patent application during the patenting process together with the CPC codes of documents cited as prior were extracted and combined. The unique CPC classes for each patent application were then mapped to the respective fields of the cartography using the concordance table from step 1. The combination of the cartography fields defined the characteristic 4IR technology fields of the patent application.

Example

- *CPC codes assigned to patent application or cited documents:* A61B5/68, B60D1/075
- *Corresponding CPC field ranges in 4IR cartography:* A61B5/68 - A61B5/6802, B60D1/01 - B60D1/075
- *Cartography fields mapped to patent application:* Personal, Connectivity, Vehicles

For the purposes of this study, the statistics on 4IR patent applications have been based on a simple count method, reflecting the number of inventions assigned to a particular field or sector of the cartography, independently of whether some of these inventions are also classified in other fields or sectors. For example, an invention assigned to two fields of the same sector is counted as a single invention at sector level and as one invention in each of the technology fields. Accordingly, an invention assigned to two fields in two different sectors would be counted as one invention in each of the two technology sectors and as one invention in each of the technology fields.

2.2 Focus on European patent applications

The patent analysis described in the following chapters is based on all European patent applications filed at the EPO in the period 1978-2016. This approach has several advantages. First, it makes it possible to report the most recent patent statistics for the European market, including unpublished patent documents filed in 2016 and only available in the EPO's internal databases. Second, it creates a homogeneous population of patent applications which can be directly compared with one another. Indeed, these applications have been filed with the same patent office and seek protection in the same geographical market (Europe), and have all been classified by EPO patent examiners.

This approach avoids the national biases that usually arise when comparing patent applications across different national patent offices. One further advantage of focusing on EPO patent applications is that one patent application in most cases can be considered as representing one technical invention.

However, care needs to be taken when comparing patent applications originating from within Europe with those from outside. While European applicants are targeting their home market when filing a patent application with the EPO, non-European applicants are targeting a foreign market. Nevertheless, comparisons are still justified and informative, since even European patent applicants use the EPO only if they are targeting a market that goes beyond their national one. Otherwise they would file a patent application with their national patent office only.

The reference year used for all statistics is either the filing year of the European patent application (for applications filed direct with the EPO (Article 75 EPC)) or the year of entry into the European phase (for international (PCT) patent applications (Article 158(2) and Rule 107 EPC)). This is in line with the EPO's official reporting method for annual statistics.

Where necessary, the dataset was further enriched with bibliographic patent data from PATSTAT, the EPO's worldwide patent statistical database, as well as from internal databases, providing additional information, for example about the names and addresses of applicants and inventors. Applicant names have been harmonised to enable the analysis of top applicants presented in chapter 5. The harmonisation process was carried out for patent applications filed with the EPO in the period 2011-2016 and was based on the method used for the EPO's annual report and statistics. When creating statistics based on origin of inventor or applicant, the existence of multiple inventors or applicants is accounted for in this study by applying what is known as the fractional counting method. This method divides patent applications into as many fractions as inventors or applicants and assigns to each of them their respective share.

3. Innovation trends

3. Innovation trends

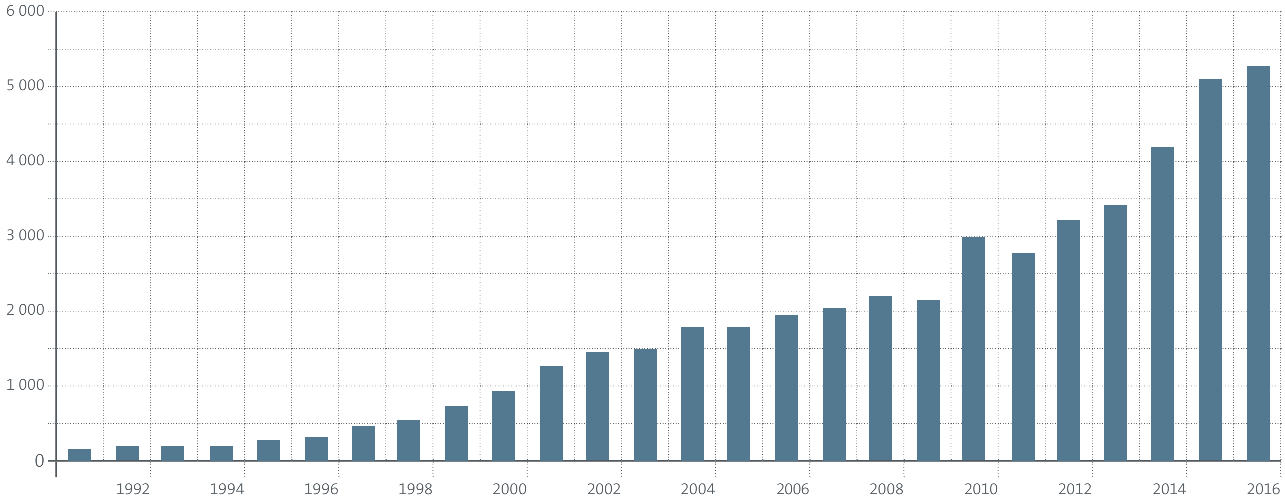
Using the cartography of 4IR technologies described in chapter 2, a total of 48 069 published and unpublished 4IR patent applications were identified as having been filed at the EPO between 1978 and 2016. This chapter looks at trends in these inventions over the last four decades and across different technology fields and sectors.

3.1 4IR inventions at the EPO

Although the term Fourth Industrial Revolution is relatively new, the technological developments which led to this term first appeared nearly 40 years ago (Figure 3.1). Initially, the number of patent applications in 4IR technologies was very low, and only began to rise steeply in the mid-1990s, increasing from around 300 in 1995 to 944 in 2000. In the years that followed, that growth continued, with numbers reaching more than 5 000 in 2015 and 2016 (Figure 3.1). As a result, there were almost twice as many 4IR patent applications in 2016 than there were in 2011.

Figure 3.1

4IR patent applications at the EPO 1991-2016

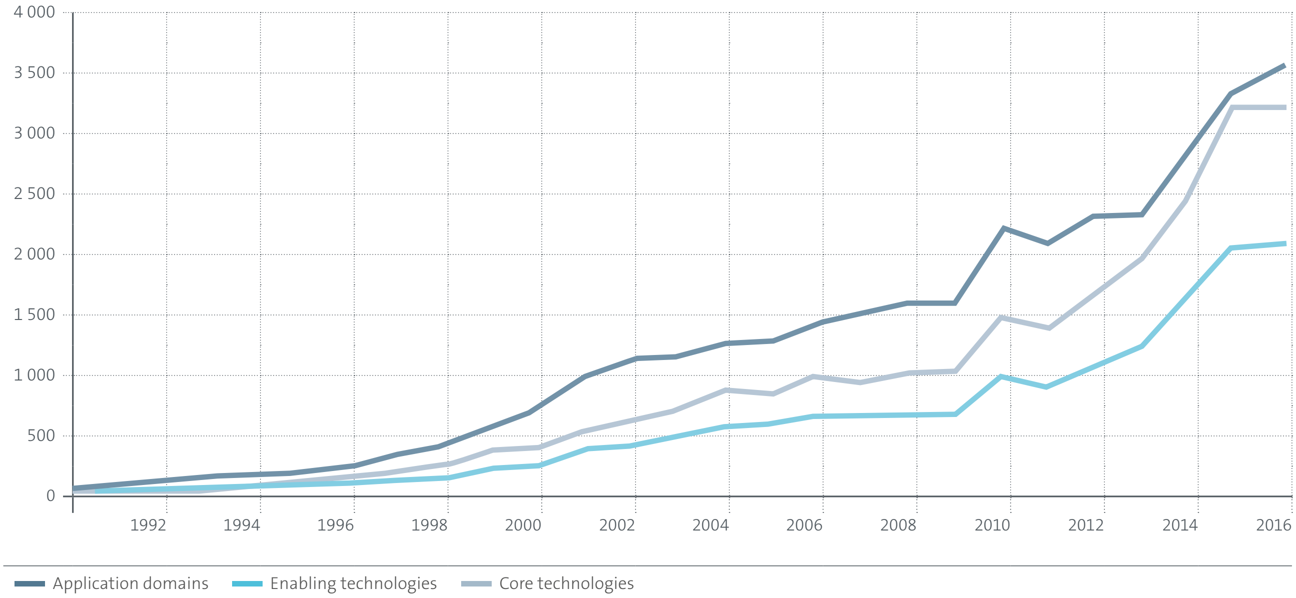


Source: European Patent Office

This rapid rise in 4IR inventions occurred across all three main sectors of the cartography (Figure 3.2). However, the actual number of inventions differs from sector to sector. Application domains and core technologies capture a larger share of inventions, with the number of inventions relating to enabling technologies being significantly smaller. In recent years, the number of inventions involving core technologies has been increasing at a faster rate, almost catching up with application domains.

Figure 3.2

Trends in patent applications by sector 1990-2016



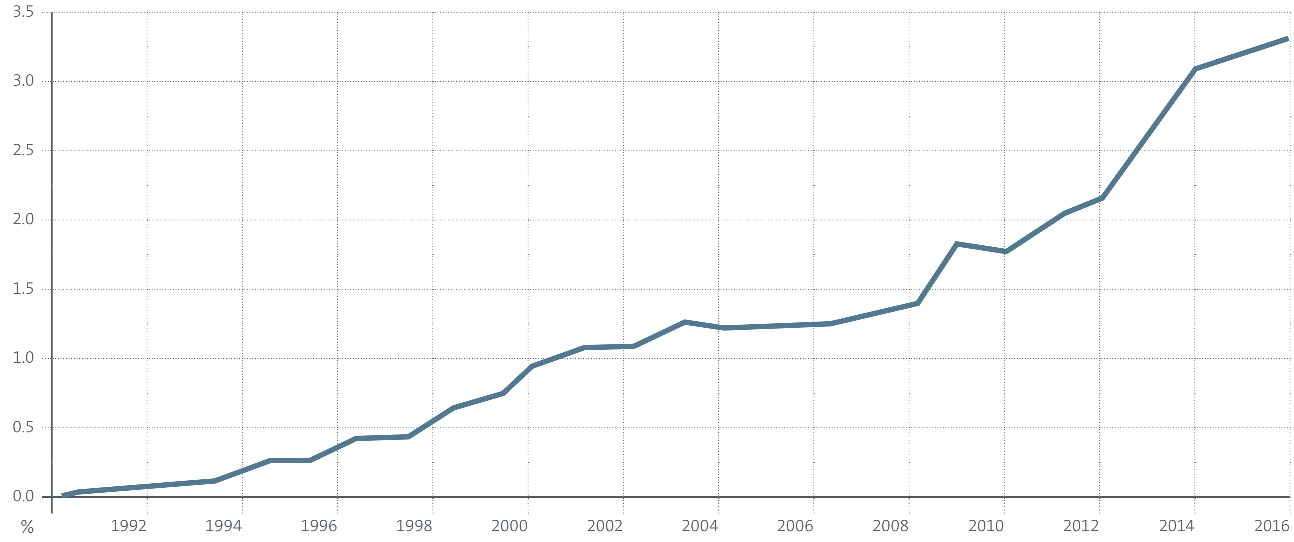
Source: European Patent Office

Despite this rate of growth, inventions relating to 4IR patents still represent a modest share of all incoming applications at the EPO – about 3.3% of all European patent applications in 2016. However, this share has risen significantly in recent years. In the 1990s, 4IR patent applications represented less than 1.0% of all patent applications at the EPO (Figure 3.3). After a short period of relative stagnation between 2004 and 2008, it more than doubled between 2009 and 2016, as a result of the rapid acceleration in 4IR applications over this period. This means that over these seven years, 4IR technologies experienced a much faster development compared with other technology fields.

Technical maturity is often assessed using the concept of the "technological life cycle", which starts with the emergence of a new technology, followed by a growth phase, a maturity phase and, finally, a saturation phase. Figure 3.1 suggests that 4IR technologies have already passed the "emerging" stage, a period with a relatively low number of patentable inventions, and are now maturing into the growth phase. With the development of new applications around the turn of the century, early 4IR technologies have been integrated into new products and business processes in various sectors. A further acceleration in inventive activity and market penetration can be expected in the next few years, before the speed of technological development reaches an inflection point on the way to technological maturity.

Figure 3.3

4IR patent applications as a share of total applications at the EPO 1990-2016



Source: European Patent Office

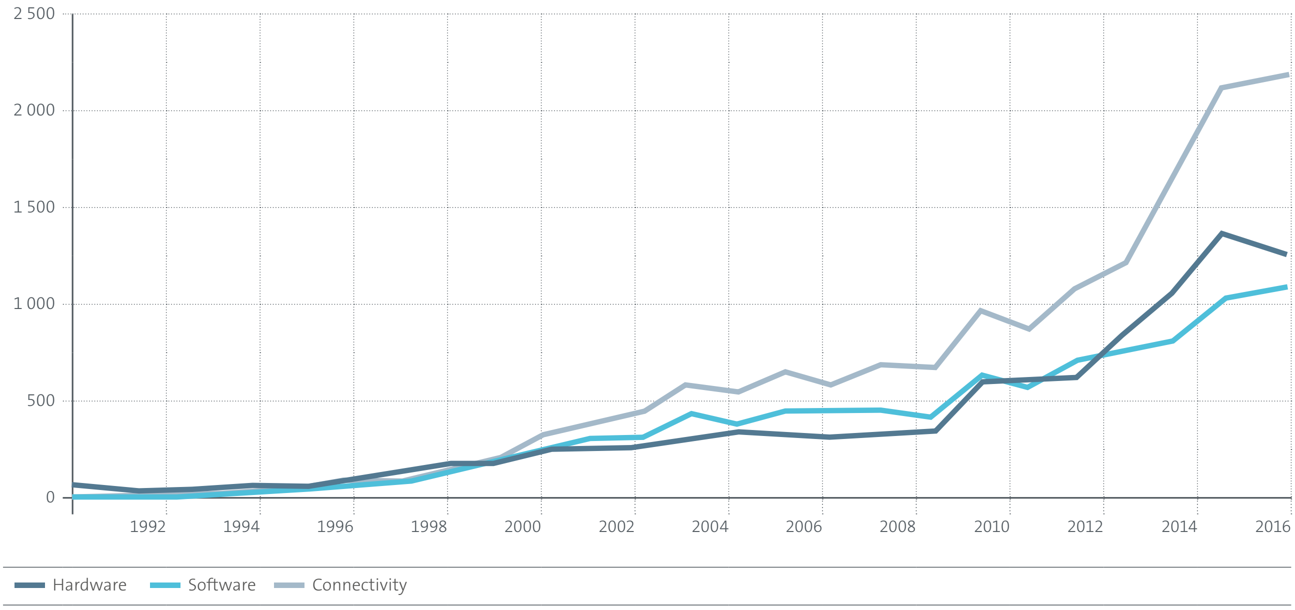
3.2 Trends in the core technologies sector

Figure 3.4 shows the trends in inventions in each of the three core technology sector fields. Between 1978 and 2016, 15 775 patents were filed with the EPO in *Connectivity*, making it the largest of the three. This is followed by *Hardware* and *Software*, with 10 390 and 9 910 applications respectively over the same period. All three fields saw very low patent application numbers prior to the mid-1990s, but have experienced a fast and continuous growth since then. The growth rate has been fastest in *Connectivity*, resulting in an ever-widening gap with respect to the other two sectors since 2000.

Most recently, between 2011 and 2016, innovation in *Hardware* has been increasing as fast as in *Connectivity* and much faster than in *Software*. This reflects recent developments in IoT technologies. The current focus is on connecting as many “smart things” as possible that can collect data, take decisions autonomously and communicate with each other, while at the same time improving the network infrastructure for mass data transfer. A consequent acceleration in the development of downstream basic software technology in order to solve connectivity and hardware-related problems and improve the functionality of 4IR systems is likely to follow.

Figure 3.4

Patent applications in core technologies 1990-2016



Source: European Patent Office

3.3 Trends in the enabling technologies sector

The number of inventions in the seven fields of the enabling technologies sector has followed a consistent upward trend during the period under analysis, although the absolute numbers of inventions vary considerably from field to field (Figure 3.5). *Security* is in the lead, followed closely by *Analytics*. Since 2011, growth has significantly sped up in both these fields, resulting in an increasing gap in numbers of patent applications compared with the other fields and reaching 739 patent applications in *Security* and 654 in *Analytics* in 2016. It is not surprising that developments in these two fields run in parallel. *Analytics* comprises mainly inventions which deal with diagnostic systems for large data sets, which are often personal or critical to the function of systems. Access to this information therefore needs to be protected by means of heightened security measures at database, software and device level, so that data analytics applications can develop their full business potential.

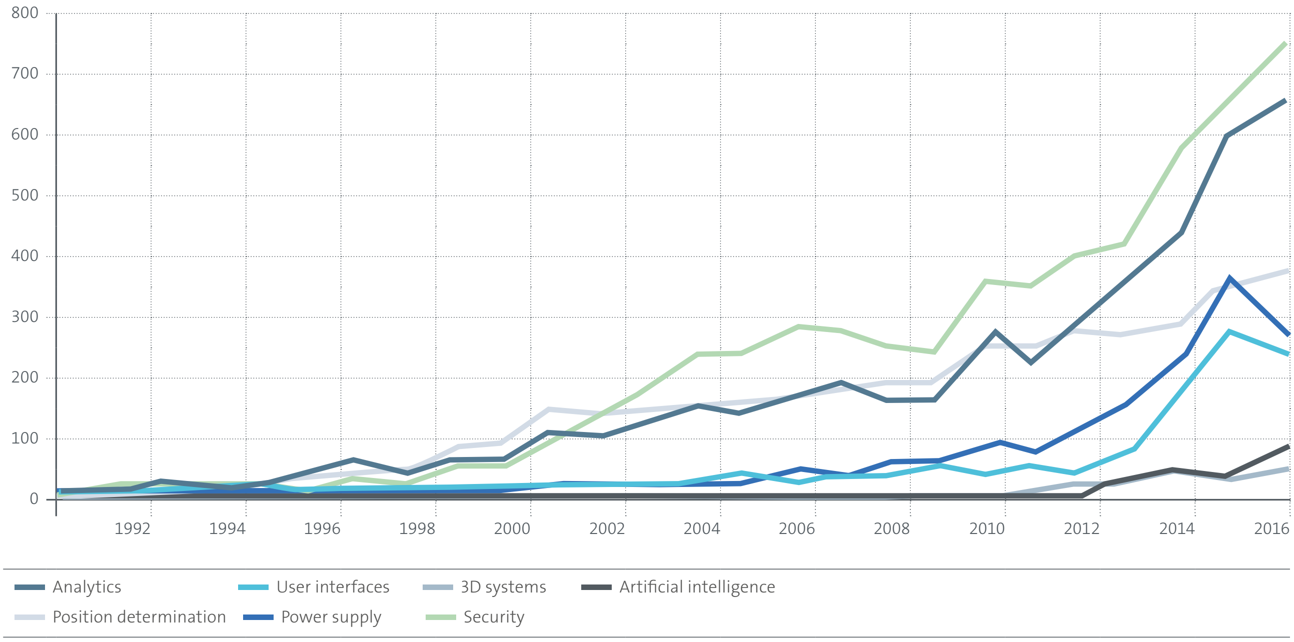
Inventions relating to *Position determination* form the third largest field in the enabling technologies sector, with a total of 367 patent applications over the whole period. This field has shown consistent but linear growth over the years. *Position determination* reached its technological maturity more than a decade ago, so more recent inventions relate to the use of basic technologies such as GPS in new applications.

Even though applications in *Power supply* and *User interfaces* achieved similar levels in 2016, with 286 and 248 filings respectively, they have followed a different development trend. Due to developments in virtual and augmented reality, applications in *User interfaces* took off in 2012, experiencing one of the highest growth rates (43%) of all 4IR fields since 2011. The exponential increase in *Power supply* started much earlier. One of the main limiting factors of IoT applications is the need for a sufficient and independent power supply, so solutions in this field are critical for future expansion.

Artificial intelligence (83 patent applications in 2016) and *3D systems* (44) are the smallest and most recent fields in the enabling technologies sector. However, they have also been the fastest-growing 4IR fields, with average annual growth rates of 43% (*Artificial intelligence*) and 56% (*3D systems*) between 2011 and 2016. There are still unresolved technical obstacles, such as providing the computing capacity that AI calculations require, that need to be overcome before AI can achieve its full potential. *3D systems* (see the case study on additive manufacturing) have also not yet reached technological maturity. However, these fields are expected to see rapid growth in the next few years.

Figure 3.5

Patent applications in enabling technologies 1990-2016



Source: European Patent Office

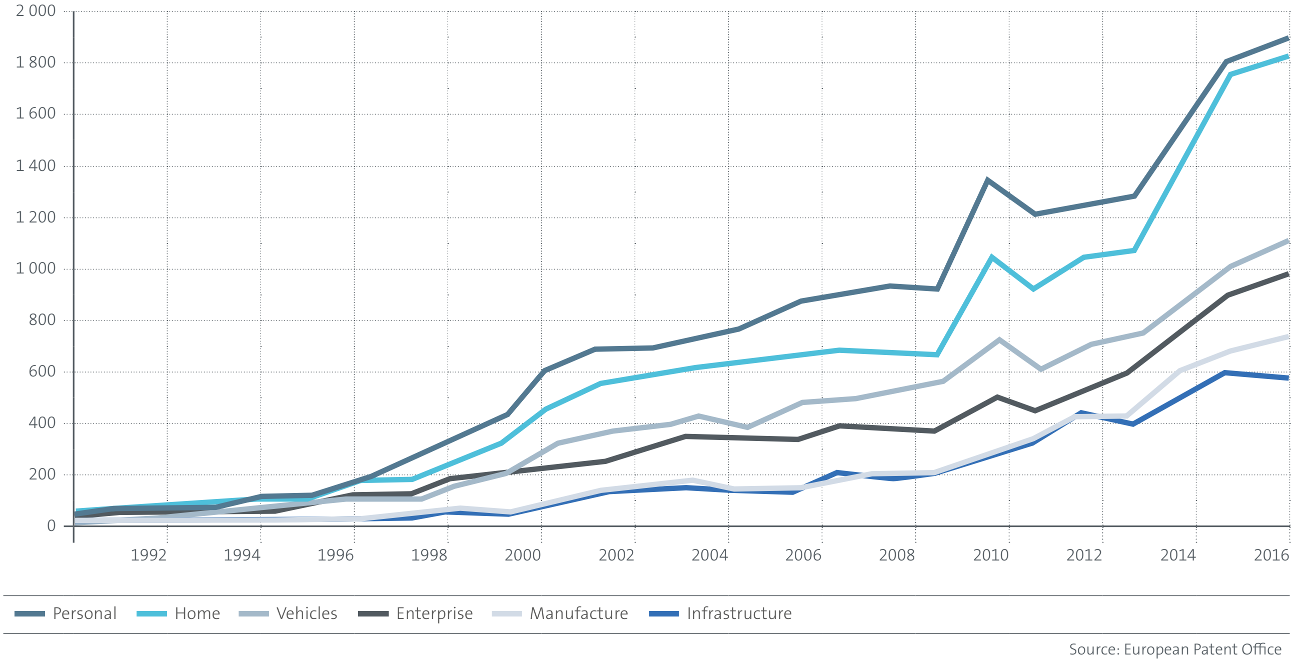
3.4 Trends in the application domains sector

The six fields of the application domains sector similarly show homogenous time trends, but the total volumes of inventions differ (Figure 3.6). After an initial growth jump in the second half of the 1990s, all fields have seen a sharp rise over the last six years. The total number of patent applications in the period 1978-2016 ranged from 4 713 in *Infrastructure* (inventions related to energy and transport) to 19 186 in *Personal* (inventions in wearable devices). *Enterprise* (agricultural, healthcare, retail and payment applications) has the second-highest number of patent applications, and has been closing the gap on inventions in *Personal* over the last two years. There were more than 1 800 patent applications in each of these two fields in 2016.

Inventions in *Vehicles* (includes autonomous driving technologies) and *Home* come next, with 1 104 and 967 patent applications respectively in 2016. *Manufacture* was the second smallest field in 2016, with 728 applications, followed by *Infrastructure* with 579.

Figure 3.6

Patent applications in 4IR applications 1990-2016



Source: European Patent Office

Case study: Smart sensors

Sensors are essential components of connected objects, and as such one of the core technologies of the Fourth Industrial Revolution.

The history of sensors goes back as far as 250 years. With the dawn of the industrial age came the use of physical and later also chemical and bio-chemical sensors in a variety of applications. Well-known examples are pressure control in steam engines and temperature control in steel production. Later on, electrical sensors came into use, for example for converting a mechanical pressure signal into an electrical signal. That was followed by the digitisation of analogue electrical sensor information to allow for its subsequent digital processing

The term *smart sensor* first appeared in the technical literature in the early 1980s. It describes the integration of a digital processor and software into a physical sensor to allow local pre-processing of the sensor information and decision-making, e.g. for process control. Since then, smart sensors have become connected: they are able to exchange raw or preprocessed measurement data in a network, and to receive feedback if necessary.

The market potential of sensor-based applications is substantial, as is the kind of information modern sensors can measure. Sensors are not only able to replicate human sensor systems (e.g. temperature, humidity), but also offer a range of advanced sensing applications, such as electric impedance, voltage, magnetic fields, light, chemical or gas concentration, radioactivity and many other measurable conditions. Moreover, smart sensors can determine their own physical location and motion (acceleration, speed and vibration), which are used for object detection and tracking applications.

Due to further progress in miniaturisation, most objects or products can now be equipped with a smart sensor. In the manufacturing process, smart sensors help to monitor, control and improve automated operations, for example by detecting the exact position of products and tools, measuring their dimensions and contours during production, and delivering the products to the customers. Finally, smart sensors enable new valuable features inside physical objects such as cars, aeroplanes or medical devices. Smart sensors enable predictive maintenance of these objects by detecting irregularities in the machine operation and proposing or even arranging a service appointment automatically.

A model for describing smart sensor technology

For ease of understanding, smart sensor systems can be broken down into four technology layers. In current sensors, however, not all of these layers have to be implemented all of the time. Depending on the circumstances, efficiency or other reasons two or more layers can also be combined into one larger layer.

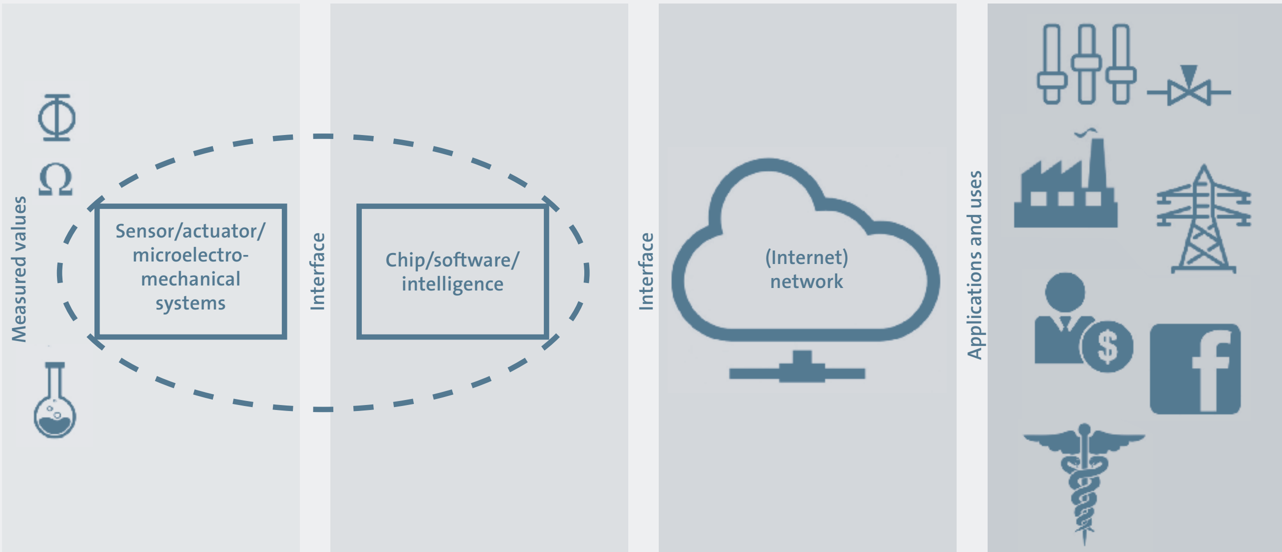
Layer 1 describes the sensor as such and is the basis of every smart sensor technology. It measures physical, chemical and other properties, such as temperature and location, and converts the measured data into digital signals for further processing. With layer 2, sensors become intelligent enough to preprocess and interpret the measured values on their own, e.g. by comparing them with reference values and, based on the interpretation outcome, to take appropriate decisions.

Layer 3 introduces a network interface which allows the sensor to connect to a network such as the internet. In the internet, sensors have their own identity in the form of an Internet Protocol (IP) address. This identity enables reciprocal communication with other sensors, computers, servers or devices in the cloud. Measured values can thus be further processed by any internet-attached device or service.

Layer 4 describes the distinct (business) environments in which smart sensors can be applied: smart grids (e.g. energy production, transmission and consumption), smart cities (e.g. infrastructure or traffic control, logistics), smart manufacturing (e.g. on-demand production of customised products, predictive machine maintenance, inventory management), smart buildings (energy consumption, burglar protection, waste management), smart health (health monitoring and diagnostics, telemedicine) and consumer products (smart phones, autonomous vehicles).

Figure 1

Smart sensor model



Layer 1 Layer 2 Layer 3 Layer 4

Source: European Patent Office

This model of four layers of smart sensors can be further illustrated by the example of a smart grid application, e.g. where the smart grid is an electrical power transmission network. Sensors in the smart grid measure the electrical voltage at specific network nodes of the power transmission network (layer 1). By comparing the actual voltage values with a given desired value, they can determine if the voltage values are within a required range (layer 2). For example, deviations might be induced by variations in the local power production of wind turbines due to changing wind conditions. If so, the voltage information could be sent to centralised control systems (layer 3) which can adjust the energy flow through the smart grid to increase or reduce the voltage in the network (layer 4). Another example, this time in healthcare, is a biosensor integrated into contact lenses. It determines the blood sugar level in tears (layers 1 and 2) and transmits (layer 3) the data to an insulin pump (layer 4) in the diabetes patient's body.

Future trends

In the future, smart sensor applications will be ubiquitous. Incremental improvements to or recombinations of existing technologies, as well as the identification of completely new application environments, will be important drivers of innovation.

Further developments can be expected in all layers of the smart sensor model. Further miniaturisation of sensors, in size and weight, will allow them to be integrated into even the smallest items. Low energy consumption will be a key factor in that respect, requiring the development of new materials and production techniques. Future sensors are also expected to be able to measure new physical, chemical or biological properties. Examples include neural sensors that collect different kinds of brain or physiological signals, which will trigger future applications in the health sector. In the food industry, capacitive sensing of micro-organisms can be used to check food quality and safety, for example by identifying water contamination with bacteria such as *Escherichia coli*.

However, a prerequisite of any smart sensor application is reliable and safe connectivity. Therefore, technological progress in the interoperability of sensors and networks of sensors, and in the availability of a well-functioning wireless communication infrastructure allowing high data transmission rates and real-time communication, will need to continue.

4. Technology convergence

4. Technology convergence

This chapter analyses trends in technological convergence between the different technology building blocks of the Fourth Industrial Revolution. Convergence is defined as the combination of features from different technology fields in one single invention. It is identified through the classification of patent applications in different fields and sectors of the 4IR cartography.

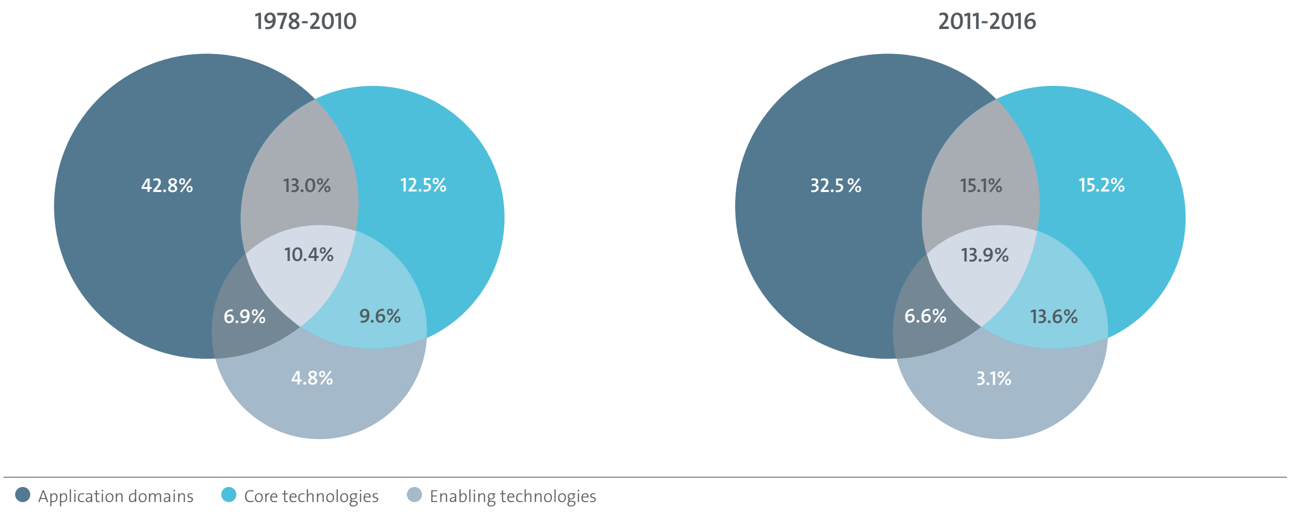
4.1 Aggregate indicators of technology convergence

As indicated in Chapter 2 (Box 2), some inventions are relevant to more than one 4IR technical field, within one or more technology sectors. Where this is the case, the related patent applications are classified in all the applicable technological fields. This multidimensional classification captures integration between the different 4IR technology building blocks.

Figure 4.1 shows the share of patent applications classified in one or more of the three main technology sectors of the cartography, for the two different time periods, 1978-2010 and 2011-2016. While about 60.1% of 4IR inventions are assigned to just one sector in the period 1978-2010, the percentage drops to 50.8% in the period 2011-2016. This is mainly due to the large drop in the share of patent applications assigned to application domains only from 42.8% to 32.5%. At the same time, the share of patent applications in enabling technologies dropped from 4.8% to 3.1%, while the share of patent applications in core technologies increased slightly from 12.5% to 15.2%. However, the main observation is that more inventions are being assigned to more than one of the three 4IR sectors. Indeed, the number of inventions in the intersection of the main technology building blocks rose from 39.9% to 49.2%. Except for the share of inventions on the intersection of application domains and enabling technologies, which remains relatively stable at 6.6%, the relative importance of patent applications combining technical features of two or all three 4IR sectors has increased.

Figure 4.1

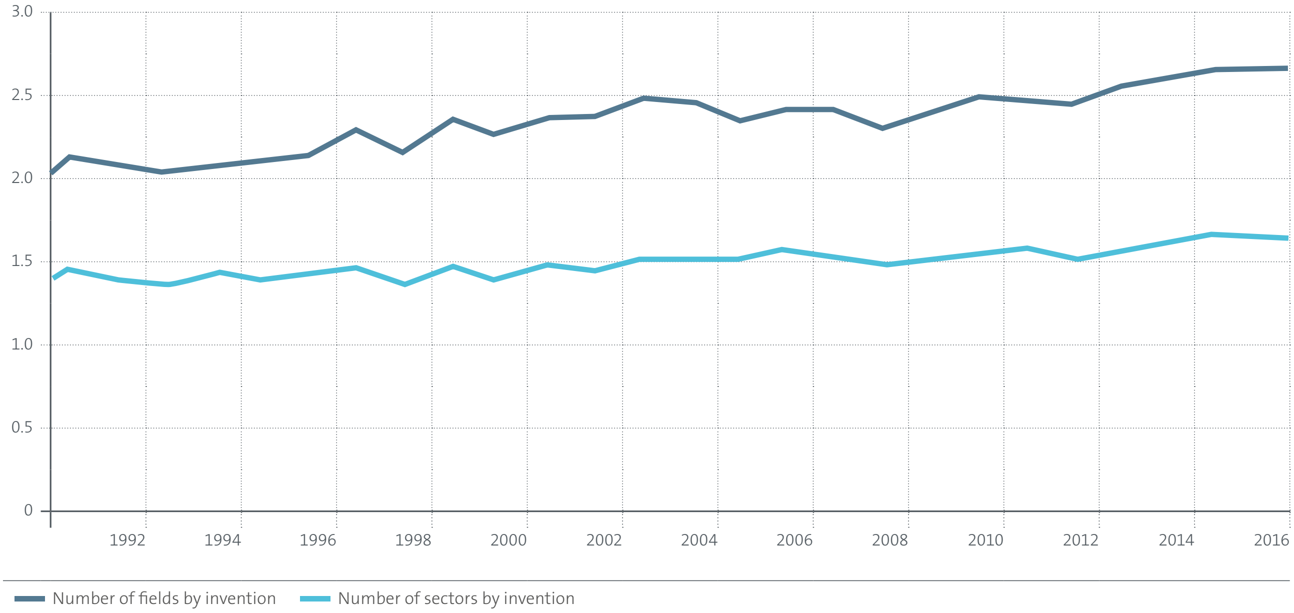
Distribution of 4IR inventions by cartography sector



Source: European Patent Office

Figure 4.2

Number of fields and sectors by inventions and year 1990-2016



Source: European Patent Office

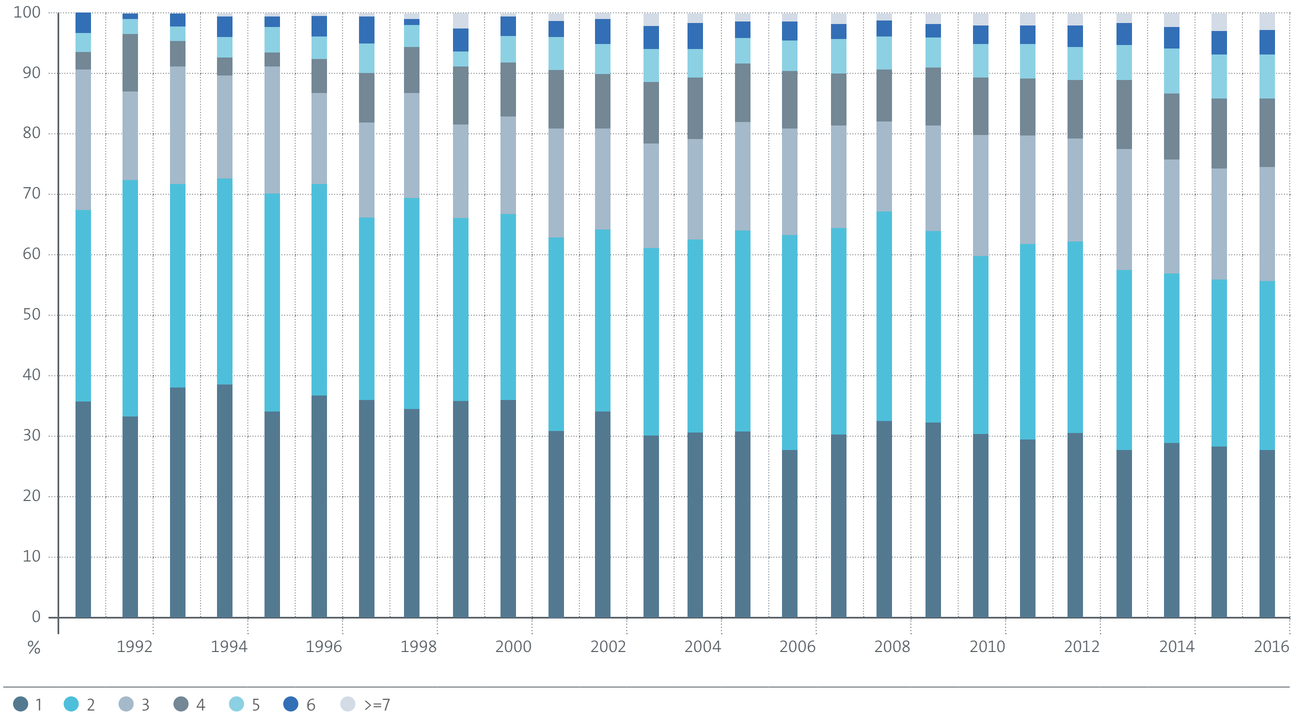
This pattern is confirmed in Figure 4.2, which shows the average number of sectors and fields per invention identified as relevant to the Fourth Industrial Revolution. It reveals a clear trend towards a growing integration of technologies from different fields and sectors.[4] The number of relevant sectors per invention rose from 1.3 in 1990 to 1.7 in 2016, and the average number of fields by patent application increased from 1.9 in 1990 to 2.6 in 2016.

Convergence at field level, which reflects both inter- and intra-sectoral integration of 4IR technologies, is further illustrated in Figure 4.3. It shows the distribution of the average number of fields assigned to each invention for the years 1990 to 2016. The percentage of patent applications specific to one or two technology fields only has fallen steadily from 80% in 1990 to 56% in 2016. This is essentially due to the proliferation of inventions assigned to more than two fields, such as *Security, Analytics* and *3D systems*, or *Hardware, Software, Personal* and other application domains. In 2016, 1 481 inventions, representing a 25% share of all 4IR inventions, were assigned to four or more fields. These dynamics reveal an increasing cross-fertilisation between fields: more and more patent applications combine technical features from core technologies, enabling technologies and application domains.

4 An OLS regression with a linear deterministic trend model is highly significant, confirming that the number of fields increases linearly with time.

Figure 4.3

Distribution of inventions by number of fields



Source: European Patent Office

4.2 Technology convergence in application domains

Available 4IR technologies are ultimately used to develop and implement practical applications for various economic sectors. The integration of core and enabling technologies into the six application domain fields of the cartography will drive the economic impact of the 4th Industrial Revolution.

4.2.1 Convergence with core technologies

The pattern of integration between core technologies and application domains is set out in Figure 4.4. Figure 4.4.a shows the relative importance of the three core technology fields for the application domains sector as a whole. In the period 2011-2016, 25% of inventions in application domains were also related to *Connectivity*. A slightly lower share of these inventions overlapped with *Hardware* (22%) and *Software* (17%). Compared with the period 1978-2010, the degree of overlap has increased for all fields, especially *Hardware*. This is largely driven by the increased integration of sensors into 4IR applications. Accelerated integration of basic *Software* inventions into 4IR applications is expected to be the next step in the development.

Figure 4.4.b in turn indicates how frequently inventions in core technologies overlap with each of the six application domain fields. *Personal* and *Enterprise* applications are the most integrated with core technologies, with overlapping shares of 32% and 27% respectively. Interestingly, these application domain fields are also the most mature ones, as reflected in the highest number of patent applications (see Figure 3.6). The comparison between patent applications filed before and after 2011 reveals a growing integration between core technologies and application domains, but not in all fields. The overlap with *Manufacture* and *Infrastructure* has increased, reflecting the need to find technical solutions for the biggest problem in the adoption of these technologies, which is the interoperability of devices. *Home* and *Vehicles* remain at a medium-low level of integration with core technologies needed to develop and connect devices.

Figure 4.4

Convergence between core technologies and application domains

Figure 4.4.a
Inventions on the intersection of application domains and core technologies as a share of all application domain fields

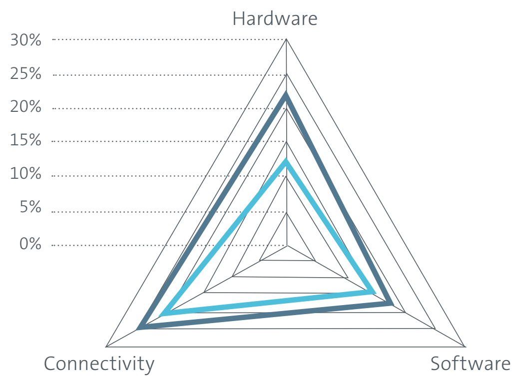
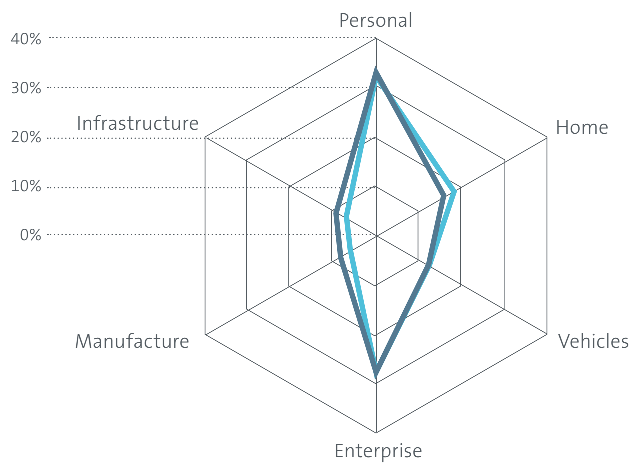


Figure 4.4.b
Inventions on the intersection of application domains and core technologies as a share of each application domain field



2011 - 2016 1978 - 2010

Source: European Patent Office

4.2.2 Convergence with enabling technologies

While the pattern of convergence between core technologies and the different application domain fields is relatively homogenous, there are significant variations in the way in which each application domain field draws on enabling technologies. This will therefore be discussed separately for each application domain field in the following paragraphs.

Figure 4.5.a indicates the share of inventions in *Personal* applications that integrate features from each of the seven enabling technology fields. *Position determination* is the most important enabling technology for this application domain. It is needed to track devices and provide localised services, and is present in about 15% of inventions in *Personal applications* (Figure 4.5.). These inventions also increasingly integrate *Analytics* and *User interfaces* technology.

Figure 4.5.b shows in turn how frequently *Personal* applications appear in inventions assigned to the seven fields of enabling technologies. *Personal* is a very important application field for all enabling technologies. About 30% of *Analytics*, 40% of *Position determination* and 50% of *User interfaces* inventions were related to *Personal* applications in the period 2011-2016. This mirrors the trend to integrate virtual and augmented reality technologies into *Personal* applications. Although only a small fraction of inventions in *Personal* are related to *3D systems*, *Power supply* and *Artificial intelligence* (Figure 4.5.a), they account for a significant share of innovation in these enabling technologies (Figure 4.5.b).

Personal

Figure 4.5

Personal applications and enabling technologies

Figure 4.5.a
Enabling technologies in *Personal* inventions

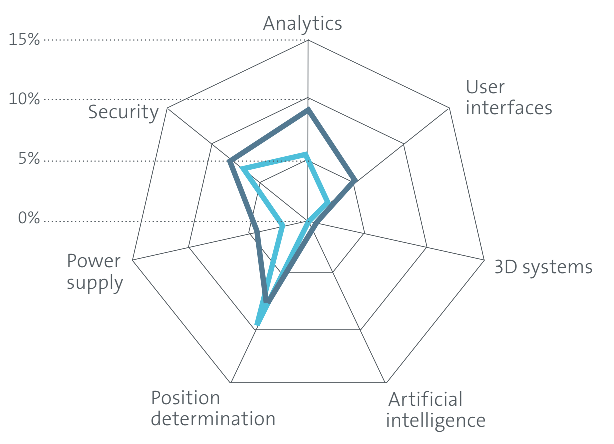
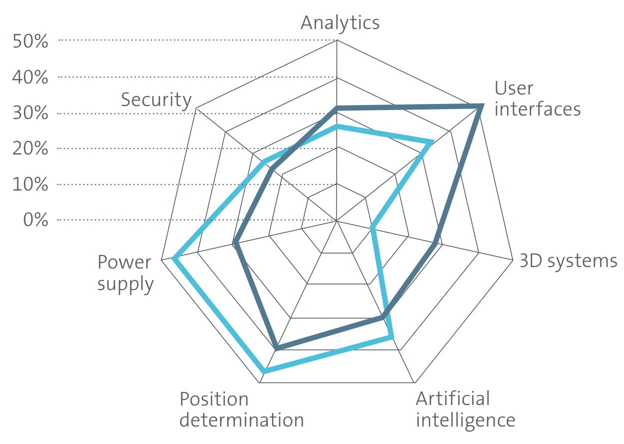


Figure 4.5.b
***Personal* applications in enabling inventions**



2011 - 2016 | 1978 - 2010

Source: European Patent Office

Home

Figure 4.6

Home applications and enabling technologies

Figure 4.6.a
Enabling technologies in *Home* inventions

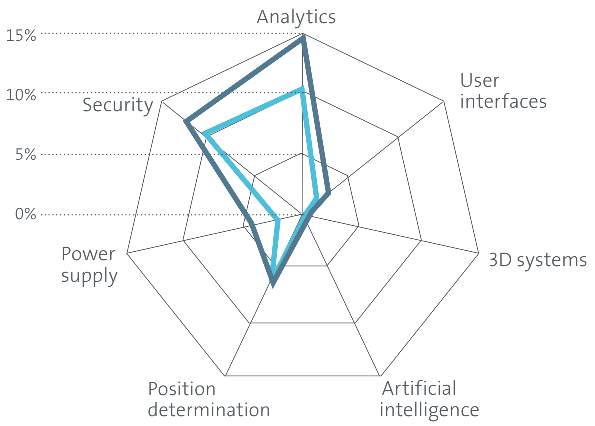
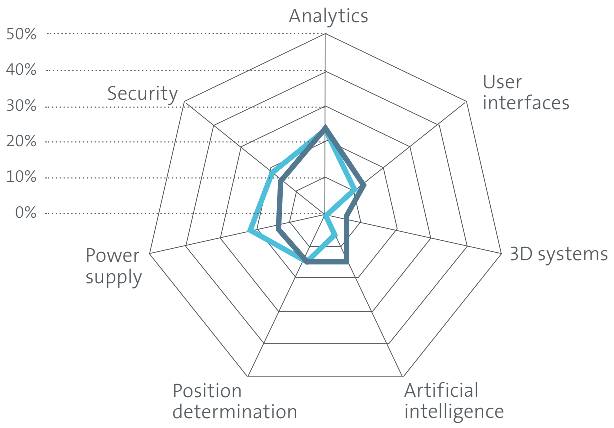


Figure 4.6.b
***Home* applications in enabling inventions**



2011 - 2016   1978 - 2010

Source: European Patent Office

Figure 4.6 similarly shows how frequently inventions in *Home* applications integrate features from the different enabling technology fields (4.6.a), and how frequently inventions in each of these enabling fields are related to *Home* applications (4.6.b). According to Figure 4.6.a, *Analytics* and *Security* of data and physical devices are the most frequently used enabling technologies in *Home* applications, where the overlap increased to 14% and 13% respectively in the period 2011-2016 (Figure 4.6.a). *Position determination* is also observed in about 7% of *Home* inventions. *Power supply* (4%) is present in even fewer inventions, but its importance is increasing strongly as is the case for all other application domain fields.

Figure 4.6.b shows that *Home* applications are represented in similar proportions among inventions assigned to each of the seven enabling technology fields. They account for a stable share of about 20% of inventions in *Analytics* and 15% in *Position determination*. More recently, they have gained in importance in *Artificial intelligence* and *3D systems*, while inventions in *Power supply* are targeted more towards applications in other technology fields.

Vehicles

Figure 4.7

Vehicle applications and enabling technologies

Figure 4.7.a
Enabling technologies in *Vehicle* inventions

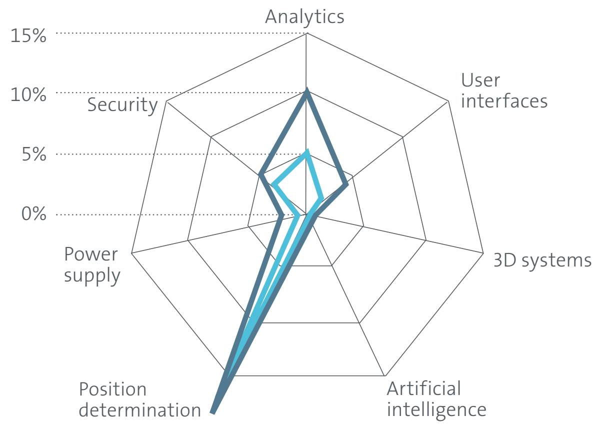
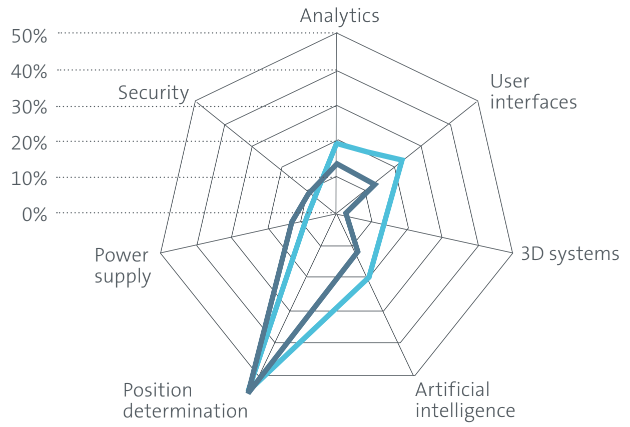


Figure 4.7.b
***Vehicle* applications in enabling inventions**



2011 - 2016 1978 - 2010

Source: European Patent Office

Position determination is by far the most important enabling technology in inventions related to *Vehicles*, with a stable presence in about 15% of all inventions in this field (Figure 4.7.a). Conversely, more than half of inventions in *Position determination* are actually related to *Vehicles*, which is therefore the main driver of innovation in this enabling field (Figure 4.7.b). *Analytics*, and to a lesser extent *Security* and *User interfaces*, are increasingly integrated in applications for *Vehicles*. Only a small fraction of inventions in *Vehicles* are related to *Artificial intelligence* or *3D systems* (Figure 4.7.a). However, they represent 20% and 13% respectively of inventions in *Artificial intelligence* and *3D systems*, and are therefore important drivers of innovation in these two enabling technologies.

Enterprise

Figure 4.8

Enterprise applications and enabling technologies

Figure 4.8.a
Enabling technologies in *Enterprise* inventions

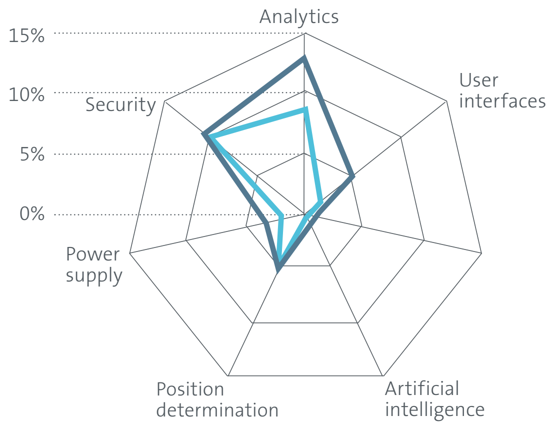
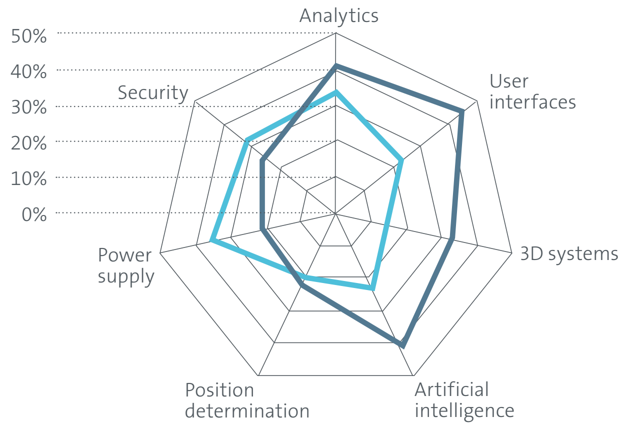


Figure 4.8.b
***Enterprise* applications in enabling inventions**



2011 - 2016   1978 - 2010

Source: European Patent Office

Enterprise applications (Figure 4.8) show a very similar pattern to *Home* applications. The most important enabling technologies for this field are *Analytics* (present in 13% of recent *Enterprise* inventions) and *Security* (11%), which are necessary to exploit the potential of business and customer information. *User interfaces* are present in 5% of *Enterprise* inventions. A similar proportion of these inventions is based in *Position determination*, which is particularly important for applications in agriculture and retail business.

Enterprise applications are an important driver of innovation in several enabling technologies (Figure 4.8.b). In the period 2011-2016, they accounted for more than 40% of inventions in *User interfaces*, *Analytics* and *Artificial intelligence*, and for about 35% of inventions in *3D systems*. These inventions typically enable better data visualisation and higher automation levels in intellectual tasks or customer services. *Enterprise* applications account for a relatively high but decreasing share of inventions in *Security* and *Power supply*.

Manufacture

Figure 4.9

Manufacture applications and enabling technologies

Figure 4.9.a
Enabling technologies in *Manufacture* inventions

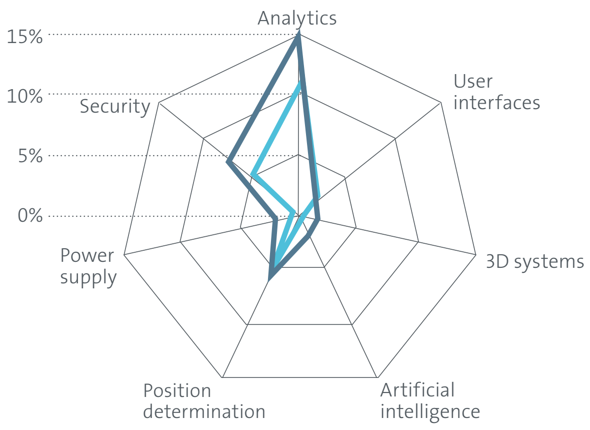
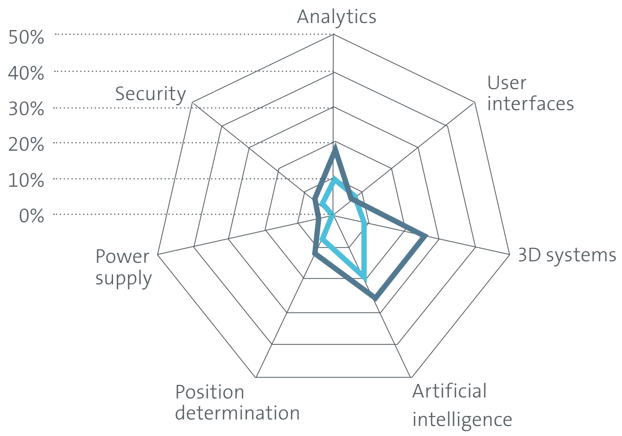


Figure 4.9.b
***Manufacture* applications in enabling inventions**



2011 - 2016   1978 - 2010

Source: European Patent Office

Analytics (15%) has been by far the most important enabling technology for inventions in *Manufacture* applications in recent years, followed by *Security* and *Position determination* with a share of 7% each (Figure 4.9.a). Figure 4.9.b) shows that a relatively large and increasing share of inventions in *3D systems* (27%), *Artificial intelligence* (27%) and *Analytics* (20%) are related to *Manufacture* applications. These enabling technology fields are important for recent developments in the direction of virtual factories and real-time decision-making by AI without human intervention (see the case study on smart manufacturing).

Infrastructure

Figure 4.10

Infrastructure applications and enabling technologies

Figure 4.10.a
Enabling technologies in *Infrastructure* inventions

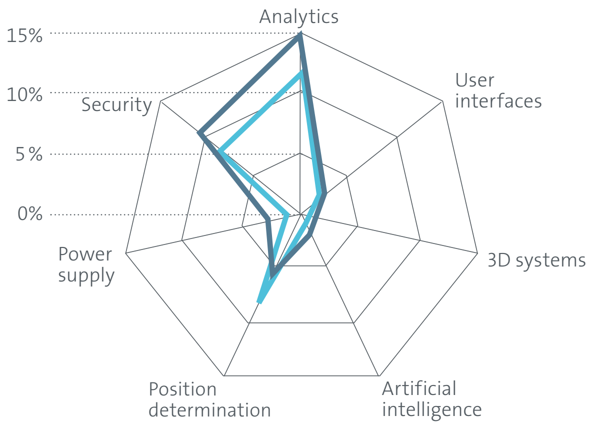
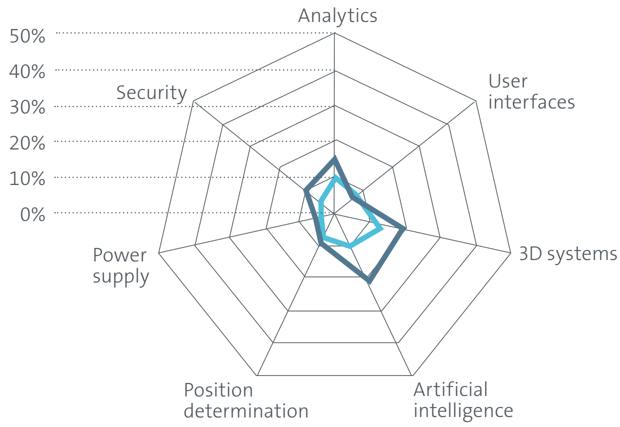


Figure 4.10.b
***Infrastructure* applications in enabling inventions**



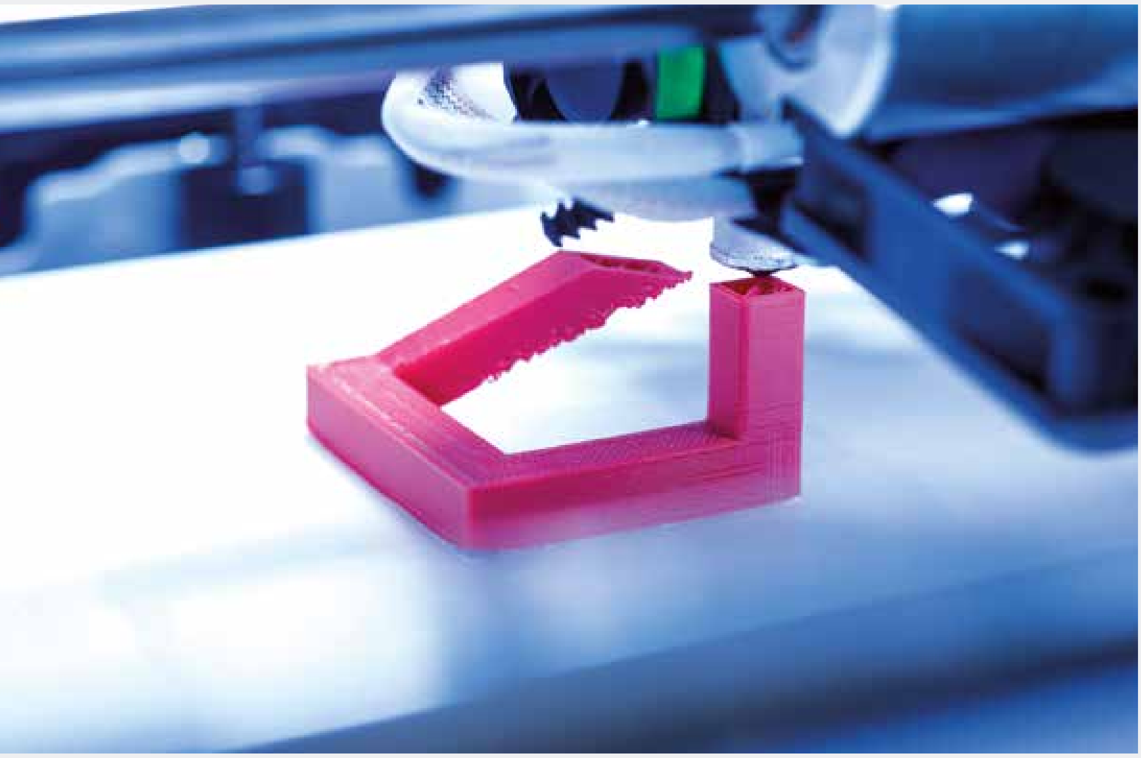
2011 - 2016 | 1978 - 2010

Source: European Patent Office

Inventions in *Infrastructure* increasingly overlap with *Analytics* (14%) and *Security* (12%), which is crucial in critical infrastructure such as utilities, communication and transportation networks (Figure 4.10.a). Although the number of patent applications in *Infrastructure* is the smallest of all the application domain fields, they now overlap with about 20% of all inventions in the two enabling fields of *3D systems* and *Artificial intelligence* (Figure 4.10.b). For example, in smart grid applications, inventions in the intersection of these technologies allow for fast and automated reactions to changing weather conditions or changing levels in energy utilisation.

Case study: Additive manufacturing

3D virtual design and 3D scanners are important examples of technologies related to *3D systems*. They support the on-going development of additive manufacturing in a wide range of domains, from metallurgy to bioprinting.



What do dental prostheses have in common with repair parts for the International Space Station? Additive manufacturing, also referred to as 3D printing, is a manufacturing method in which material is added layer-by-layer to create products. Material is only used where it is needed to define the product, in other words, a near-net shape is obtained. This is in contrast to traditional subtractive manufacturing, by which the product is obtained by taking away material locally from a larger block. Formless raw materials are applied in layers and hardened by light, most commonly a laser. That way any object, whatever its form, can be “printed”. Complex moulds or tools are no longer required – only the digital data set.

Technological perspective

Additive manufacturing brings together different technologies, some of which have existed since the 1950s: CAD (computer-aided design)/CAM (computer-aided manufacturing), laser and electron energy beam technology, CNC (computer numerical control) machining and laser scanning. Applying these technologies to a variety of materials, either in liquid, powder, wire or thin sheet form, led to the start of a whole new industry at the end of the 1980s, generating a growing number of patent applications. In the early 2000s, new entrants and applications accelerated this development. The process of additive manufacturing runs in three stages: data preparation, layered construction of the object, and post-processing. If a completely new product is being made, a 3D virtual design of it must first be crafted in a CAD file. Alternatively, a digital copy of an existing object can be created with the help of a 3D scanner. In the next step, 3D software slices the model into hundreds or thousands of horizontal layers. Based on the digital model it is possible to customise, redesign, produce or repair any physical part. Transferred to an additive manufacturing apparatus, the physical object is created by joining successive layers of material. Post-processing refers to activities such as the removal of loose or adhered material or the heat treatment of metals.

1. Systems
Concerning the "printing" process, many different techniques are available. Depending on whether the material is immediately fixated or not, there are two types of process: one-step and two-step. In the one-step process, the material is directly consolidated by curing, sintering or melting. In the two-step process, it is first bonded temporarily, with a binder or "glue", and then, in a separate step, heated to its final consolidation.

Overview of the major printing systems

Fused deposition modeling	Fused deposition modeling (FDM) has become one of the most adopted additive manufacturing technologies for plastics. Small thermoplastic filaments are extruded and harden to form layers. It is commonly used for modeling, prototyping and production applications.
Selective laser sintering or melting	Selective laser sintering (SLS) is another technology that is widely used commercially. Small particles of plastic, metal, ceramic or glass powders are fused by a laser into a mass and joined into the desired shape. Selective laser melting (SLM) is used for fusing metal powder. About 50 alloys, such as steel, aluminium or titanium, can be processed.
Stereo-lithography	Stereolithography (SLA) is the oldest technology. It was applied for the first time in 1984. A liquid photopolymer resin is cured in layers under UV light. This method is applied for filigree parts with a high precision and surface quality. It is still used in industry, mainly for rapid prototyping purposes.
Direct metal laser deposition	Direct metal laser deposition (DMLD): For this method, a laser is used to melt metal powders. Unlike most other techniques, this procedure is not based on a powder bed, but a delivery nozzle is used to move the laser powder into the laser beam.
Selective binding/ binder jetting	Selective binding/binder jetting: When binder jetting methods – a binder is printed onto a powder bed to form cross sections – were developed in the early 1990s they were called 3D printing (3DP), a name which was later adopted to describe diverse additive manufacturing processes.

2. Materials
Over the years, additive manufacturing has been applied to all sorts of materials, starting with polymers and followed by metals, ceramics and, more recently, biomaterials (see below). Commercially available materials can be broadly divided into four groups: metals, polymers, ceramics and biomaterials. In addition, mixtures of different materials and hybrid materials are applied to form alloys or composites. With combinations of materials, functionally graded products can be designed to have locally optimised mechanical, chemical and/or physical properties. The array of materials that can be printed is growing. For example, plastics, polymers, metals, resins, rubbers, ceramics, glass, sand, concretes, food, live cells, biomaterials and compound materials in various forms such as powder, paste, wire, liquidity or foil can be processed. There is increasing research into the development of new and unconventional materials, driven by applications with different quality requirements such as durability, reliability, weight, consistency, conductivity and cost. In addition, more eco-friendly materials are emerging. While some materials, such as the widely used ABS plastics, can emit harmful fumes when melted, researchers are investigating materials that are biodegradable or can be re-used as feedstock.

Materials used in additive manufacturing

Metals	Polymers
Stainless steel	Polyethylene (PE)
Titanium	Polypropylene (PP)
Aluminium	Polyetheretherkethone (PEEK)
Nickel	Polyetherkethonekethone (PEKK)
Co-Cr	Rubber
Cooper	Polyvinyl chloride (PVC)
Noble metals	Polyamides (e.g. nylon12)

Ceramics	Biomaterials
Alumina	Cell material
Silica	Hydroxyapatite
Stabilised Zirconia	Peptides
Silicon nitride	Proteines
Graphite	Polysaccharides
Fullerenes	poly lactic-*co*-glycolic acid (PLGA)

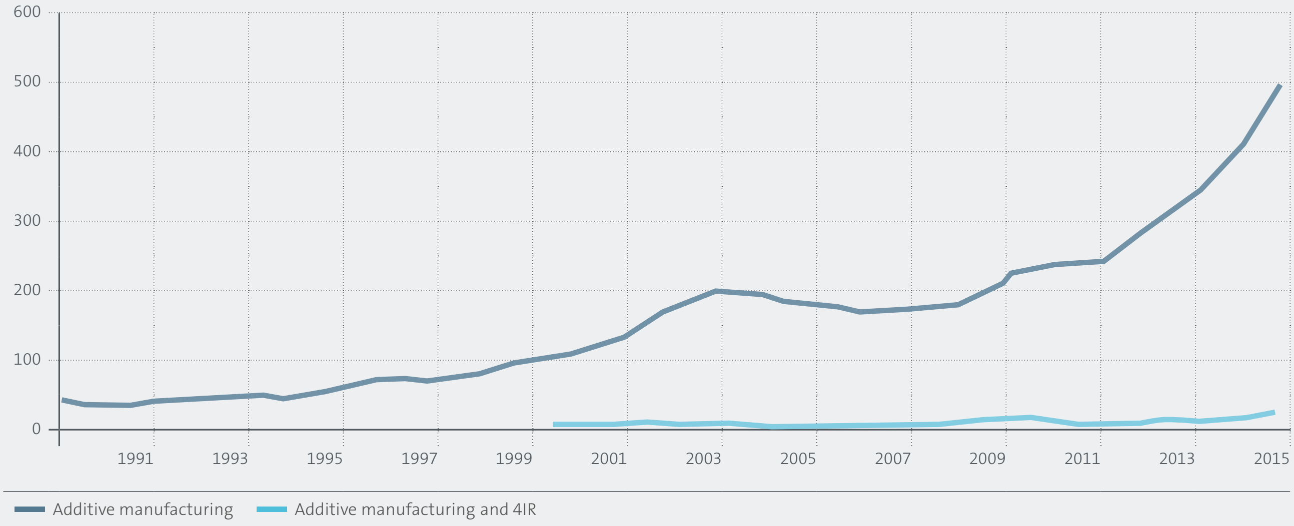
What patent data can tell us

Even though additive manufacturing was introduced as far back as the early 1980s, the current steady growth in patent applications only started in the early 2000s. Between 2011 and 2015, the number of applications filed per year at the EPO more than doubled (Figure 1), reaching 500 applications in 2015. Much of this increase was due to inventors from European countries (50.5% of patents filed at the EPO in 2011-2015) and the US (32.2%). However, the majority of additive manufacturing inventions do not correspond to the definition of technologies of the Fourth Industrial Revolution, namely digitisation and networking. In fact, up to 2009, only 2% of inventions in additive manufacturing incorporated those two features. However, between 2010 and 2015, this proportion rose to 3.5%, indicating that they are likely to become more important in the future.

3. Applications
Additive-manufactured products can be found in a wide range of sectors. Examples include consumer products such as home appliances, decoration and shoes, drones and turbine engine parts for the aerospace industry antennas and sensors, valves and drill bits for the oil and gas industry, toys and sports equipment, products for constructing houses and bridges, and medical prostheses and surgery guides. However, applications vary in their degree of technological maturity and market adoption. While prototyping in production has already achieved market maturity, 3D printed drugs, bio-printed organ transplants, 3D printing workflow software, 4D printing and 3D printed wearables are applications that are on the rise. They gather a lot of interest, but lack usable technology beyond a proof of concept or basic research. At the peak of expectations is currently additive manufacturing in surgical implants, a sector which have already had early success stories.

Figure 1

Patent applications for additive manufacturing at the EPO



Source: European Patent Office

Example: Bioprinting

It is clear that the more critical applications will take more time to develop before they are produced on an industrial scale. One promising group of applications concerns medical implants, in particular for soft tissue or organs. The bioprinting market is seen as having huge potential. In Europe alone, 59 000 people were waiting for a new organ at the end of 2015 (European Commission 2017).

Although the use of additive manufacturing in dental and bone prostheses, such as for hips, knees and spines, has become reality, the replacement of organs, arteries and skin is still in its infancy, and the required systems, materials, machines and products are currently at an early stage of development. Bioprinting requires specific conditions: human or mammalian cells must be processed at low temperatures and in most cases they need a support, either temporarily or permanently. The cells also have to be preserved until they are implanted. The development of supports, or "scaffolds", is the focus of the majority of the applications in the field. If no scaffolds are used, for example for skin tissue, cells need to be supported/kept in form by hydrogels. Various methods are being developed to apply the hydrogel to the cells without disturbing them.

The printing machines used for biomaterials such as human cells are similar to desktop printers (Figure 2), so inventions in this sphere typically refer to "bio-ink", "cartridges" and "printer heads".

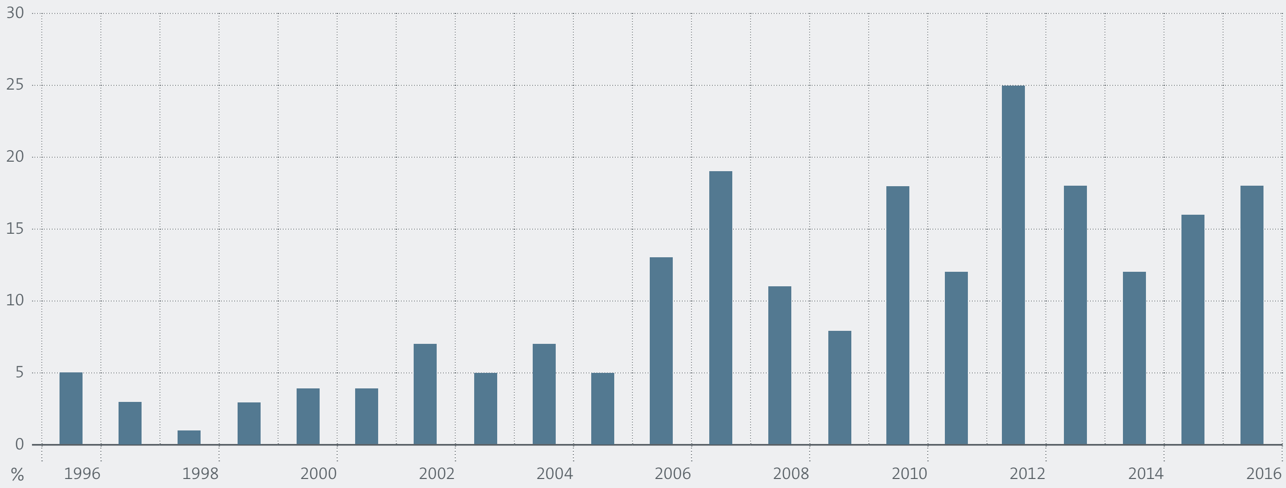
Figure 2

Bioprinter for human organs

Developments in bioprinting started in the 1990s, but patenting activity in the field has only really taken off in the last 10 years (Figure 3). As bioprinting technologies are still at an early stage of research and development (R&D), it is not surprising that universities and their spin-offs in the US and Europe, and in China too, dominate the list of applicants in that field. Companies represent less than 44% of applicants for European patents. Indeed, the list of applicants in bioprinting patenting shows that patenting activity is widely dispersed, without any clear domination by any entity.

Figure 3

Patent applications in bioprinting at the EPO



Source: European Patent Office

Business outlook

A global market volume of more than six billion US dollars in 2016 with double-digit growth rates shows the huge economic potential of additive manufacturing. While revenues increased by more than 17% in 2016 (Wohlers 2017), the sector is expected to keep growing fast, by a compound annual growth rate of 25.8%, to reach almost 33 billion US dollars by 2023 (MarketsandMarkets 2017). According to Wohlers (2017), there were 49 companies producing 3D systems in 2014, rising to 97 in 2016. Along the value chain, various sectors benefit from this growth in additive manufacturing, including producers of raw materials, manufacturers of 3D printer components and 3D printers, software developers, measurement technique providers and companies or households making use of these technologies.

Additive manufacturing has the potential to open up completely new business models. One of the main advantages is its suitability for producing complicated structures. It allows the copying of biological structures as well as designs that are not feasible using conventional methods, such as components with hollow structures or complex geometric structures (Schulz 2017). This enables the production of new products and designs and makes additive manufacturing a driver of product innovation.

The technology is also used to produce specialised products in low volumes at lower costs, due to reduced fixed costs compared with traditional manufacturing. Thus, complex niche products, previously assembled from numerous parts, can be printed efficiently. Sectors focused on complex low-volume production, such as components in aerospace or exotic cars, are increasingly using 3D printers.

Furthermore, additive manufacturing enables companies to address customer requirements more precisely without losing the cost advantages of mass production. Customers can personalise a mass product (mass customisation) or get directly involved in product development or enhancement (crowd-sourcing) with their own proposals and ideas. Individualisation also plays an important role in the medical sector, offering tailor-made products such as tooth inlays, artificial hip joints and glasses frames.

Additive manufacturing also leads to more efficiency in the production process along the supply chain. The lead time for the manufacturing of a product is reduced significantly as the number of steps in the production process is cut down. In addition, the input of materials is limited to what is really needed, implying less scrap and reduced warehouse storage costs. Long transportation routes can be avoided, as products can be produced directly where they are needed. Production becomes more flexible and can react much faster to market changes.

Conclusion

Initially, additive manufacturing was almost exclusively used for producing prototypes, and it soon became well established in that field. It has since reached the stage of being able to make final products, and this is where the sector reveals its strongest growth potential. Additive manufacturing can provide complex components and finished products that in the past could only be made by hand or by several work steps. As almost any geometric form can be produced by additive manufacturing, the technology is now predominantly used for small series of highly complex components. However, the shift from prototyping to end-product manufacturing requires further development to achieve higher sizes, as well as better quality control and reproducibility of the products. Furthermore, additive manufacturing still cannot ensure the quality needed for large-scale production. Therefore, technologies need to be developed further in the sectors of hardware, e.g. printers and printing methods, software to design and print as well as materials used in printing.

Nevertheless, new applications, an improving ease of use, the increasing availability of suitable materials and cost reduction will lead to a higher deployment of additive manufacturing in industry, healthcare and households. As a result, the sector's growth will accelerate. The development of 4D printing, which includes time as the fourth dimension, whereby materials transform through interaction with physical parameters from their surroundings (e.g. temperature, pressure, light, etc.), brings exciting new application possibilities. Products will be able to reshape or self-assemble over time. However, with the expansion into new fields of applications, new challenges around material processing will emerge. Bioprinting represents a particular area here, and current research is focusing on preserving and supporting biomaterials and on keeping them sterile.

5. Top EPO applicants in 4IR technologies

5. Top EPO applicants in 4IR technologies

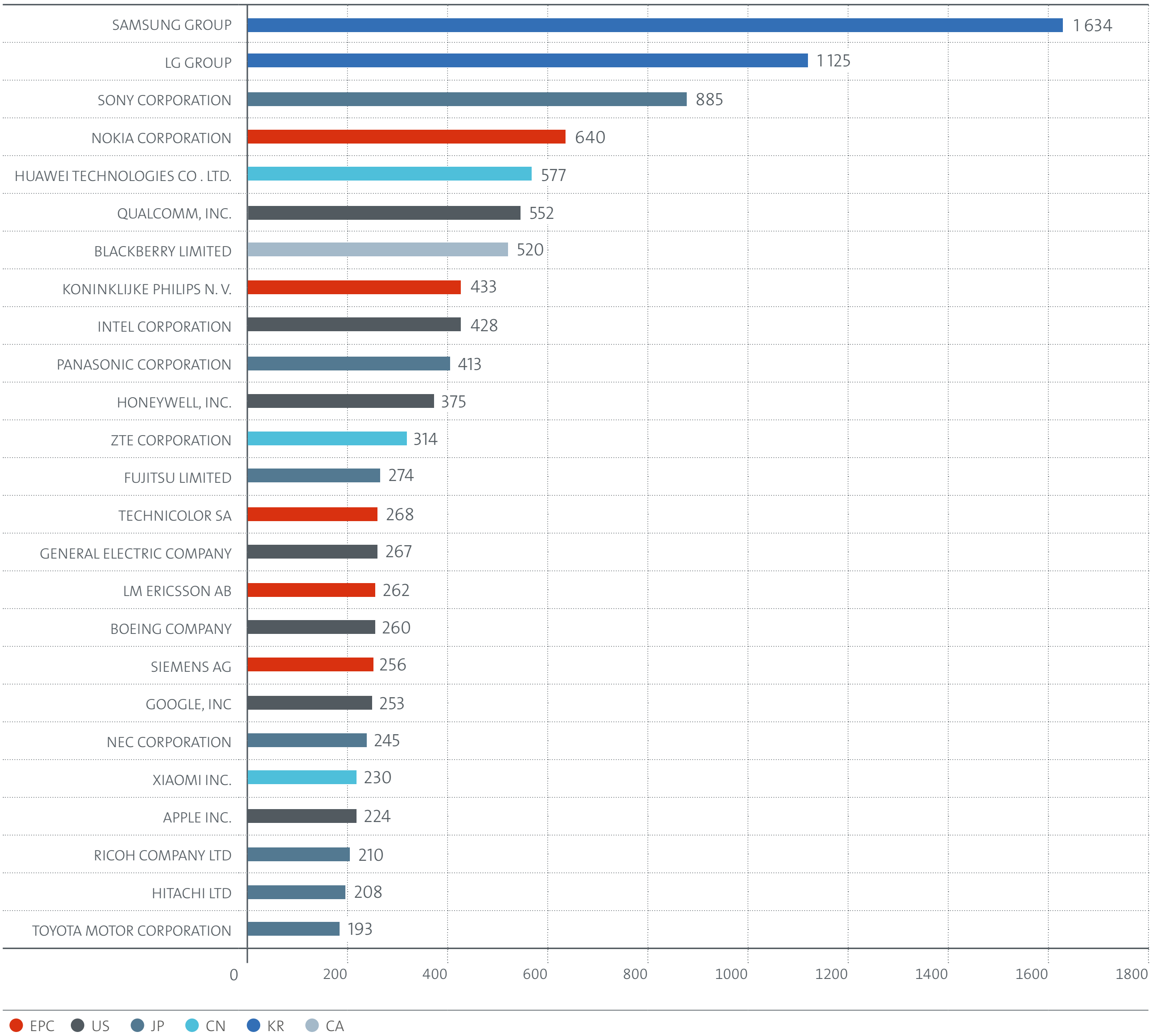
This chapter focuses on the main applicants in 4IR technologies at the EPO in the period 2011-2016. It reports on their locations and technology strengths, and the geographic distribution of their inventive activities.

5.1 Top applicants

The 25 biggest 4IR applicants at the EPO in the period 2011-2016 are shown in Figure 5.1. The two companies with the most 4IR patent applications are Samsung (1 634) and LG (1 125), both from the Republic of Korea (Korea). More generally, twelve of the top 25 4IR applicants at the EPO are Asian companies, of which seven are from Japan, three from the People's Republic of China (China) and two from Korea. This high proportion of Asian top applicants is not unique to 4IR. In a recent study, the JRC and OECD (Daiko et al, 2017) found that in the period 2012-2014, 30 of the 50 biggest patent applicants worldwide were Asia-based companies, 19 of them Japanese.

Figure 5.1

Top 25 4IR applicants at the EPO 2011-2016



Source: European Patent Office

Like Japan, the USA provide seven of the top 25 applicants. Another five of them originate in Europe. Blackberry, ranked 7th, is the only Canadian company on the list. While the number of large European enterprises in 4IR technologies is small, European applicants are better represented outside the top 25: an additional 51 companies in the list of top 150 applicants are located in Europe, compared with 31 US companies, 30 Japanese and only one additional company from Korea and China (Figure 5.2).

The list of top 25 applicants is dominated by large, traditionally ICT-focused companies. This is especially the case for Asian companies. Most of the Japanese top applicants (Sony, Panasonic, Fujitsu, NEC, Ricoh and Hitachi) are established conglomerates with long-established activities in computers, electronics and/or information technology services. Car manufacturer Toyota, ranked 25th, is the only exception. Chinese applicants are represented by telecom and electronics companies Huawei, ZTE and Xiaomi. Korean firms Samsung and LG are two other examples of conglomerates with traditionally strong global positions in electronics and communication technologies.

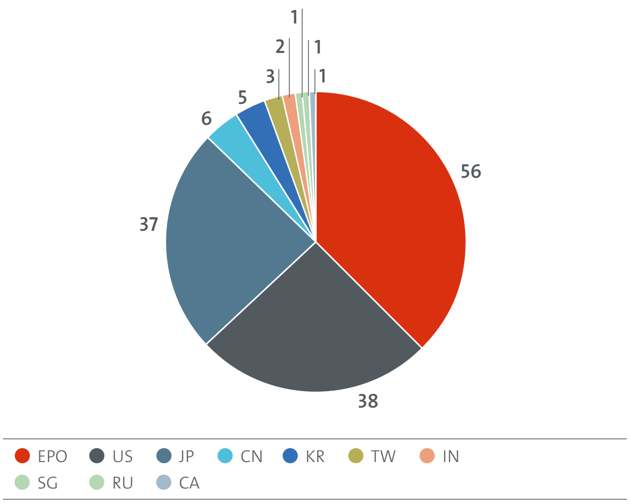
The list of top 4IR applicants from Europe and North America is less dominated by information and communication technology companies. It includes a number of ICT champions such as Qualcomm, Intel and Google in the USA, Nokia, Ericsson and Technicolor in Europe, and Blackberry in Canada. However, an equal proportion of the top US and European applicants are not traditionally ICT-focused companies. Among them are large conglomerates such as Philips, Siemens, General Electric and Honeywell, with main activities in medical technologies, machinery, consumer electronics, transportation equipment and energy, as well as Boeing, which is mostly active in the aerospace industry.

5.2 Patent positions of top applicants

In the period 2011-2016, 46% of all 4IR patent applications filed at the EPO originated from the top 25 applicants listed in Figure 5.1. The concentration is stronger in the case of core technologies (Figure 5.3), where 54% of the inventions originate from these 25 top applicants. This is in line with the prevalence of ICT champions on this list. The same 25 applicants generated 48% of inventions in enabling technologies and only 41% in application domains, which appears to be the least concentrated sector of the cartography.[5] The cumulative shares of the top5/top10 applicants in each sector confirms this pattern.

Figure 5.2

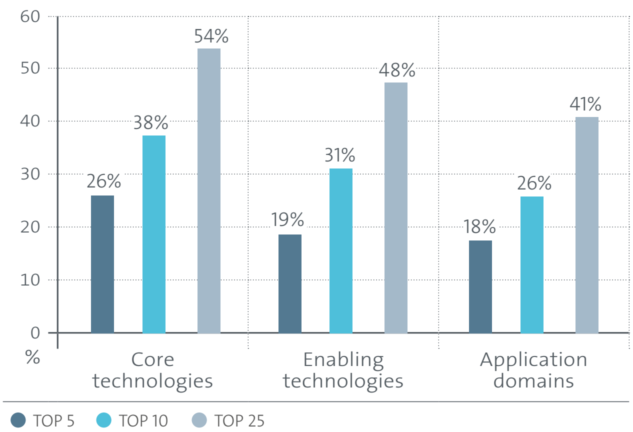
Top 150 4IR applicants by country of origin 2011-2016



Source: European Patent Office

Figure 5.3

Share of top applicants in 4IR patent applications at the EPO 2011-2016



Source: European Patent Office

5 These results do not significantly change when the top 25 or 150 applicants are identified at sector level. The top 25 applicants by sector generated 56% of inventions in core technologies, 49% in enabling technologies, and 42% in application domains.

The individual 4IR patent portfolios of the top 25 applicants at the EPO are further analysed in Figure 5.4. Shares of inventions in each field of the cartography are calculated for each company as a measure of the technological strengths. This reveals a further concentration of innovation within the group of top 25 applicants and shows different specialisation profiles amongst the companies.

The most extreme concentration can be observed in *Power supply*, where Intel Corporation alone contributes 17%, and more than 40% together with the shares of three other companies (Samsung, LG, Qualcomm). A high level of concentration is also observed in *Hardware*, where the top four applicants (Samsung, LG Group, Sony and Nokia) account for 30% of all inventions. Inventions in other fields such as *Software*, *Analytics* or *Personal* and *Enterprise* are concentrated on a small group of top applicants. Since all these fields are characterised by a relatively large number of patent applications (see chapter 3), it is not surprising that leading innovators in these fields rank high in the list of top 4IR applicants.

The top four companies - Samsung, LG Group, Sony and Nokia - have comparable patent portfolios, with leading positions in all core technology fields, and strong positions in several enabling technologies and application domains. Other companies show less diverse technology profiles. However, a certain difference between ICT-focused and non-ICT-focused companies is visible.

Figure 5.4

4IR technology profiles of top 25 applicants 2011-2016 (in %)

SAMSUNG GROUP	10,7	7.8	2.4	8.5	3.6	2.0	7.5	7.1	0.5	6.4	4.5	11.9	6.9	13.6	7.7	6.3
LG GROUP	6.0	6.7	2.9	5.3	4.2	3.3	4.8	5.9		1.3	1.5	7.0	2.4	7.7	3.5	5.5
SONY CORPORATION	5.3	3.4	1.8	3.3	1.7	2.2	3.7	11.0	2.7	3.4	2.1	3.7	2.3	5.1	2.5	3.4
NOKIA CORPORATION	2.1	2.0	2.8	1.8	1.3	2.1	2.8	3.6	1.6	3.4	3.6	3.9	2.6	2.8	3.6	3.9
HUAWEI TECHNOLOGIES CO. LTD.	0.9	1.1	0.5	0.7	0.5	0.8	1.3	0.2	0.5	0.0	1.7	3.5	3.6	1.7	3.8	5.3
QUALCOMM, INC.	2.3	0.6	2.7	0.7	0.3	0.6	1.0	0.7		0.9	6.3	5.3	2.0	1.4	2.2	3.6
BLACKBERRY LIMITED	2.9	1.0	1.3	1.8	0.5	0.6	1.1	0.7		0.4	2.3	2.5	4.0	3.2	2.9	3.0
KONINKLIJKE PHILIPS N. V.	2.8	2.6	1.1	2.6	1.5	1.2	2.1	2.4	1.1	1.7	2.6	1.2	1.5	1.3	1.1	1.5
INTEL CORPORATION	1.1	1.1	0.4	0.4	0.2	0.2	1.6	0.1	3.2	0.9	1.0	16.8	2.9	1.5	2.0	3.7
PANASONIC CORPORATION	1.8	3.6	2.0	2.5	3.4	4.1	1.9	2.5		0.9	1.5	1.8	1.3	1.2	0.9	1.3
HONEYWELL, INC.	0.9	3.0	2.6	2.0	2.3	2.0	2.9	3.5	1.1	1.3	3.7	0.6	0.9	1.9	1.3	1.0
ZTE CORPORATION	0.6	1.0	0.5	0.5	0.5	0.7	0.9	0.1			1.0	1.5	1.8	0.8	2.5	3.0
FUJITSU LIMITED	0.6	0.5	0.6	0.8	0.8	0.9	2.1	0.3	1.6	1.3	0.4	1.6	0.6	1.3	1.7	1.3
TECHNICOLOR SA	1.5	1.6	0.4	1.2	0.4	0.8	1.7	2.8	1.1	1.0	0.8	0.4	1.4	1.1	1.1	0.9
GENERAL ELECTRIC COMPANY	0.2	0.7	0.9	0.8	4.3	5.6	0.5	0.1	1.1	0.9	0.5	0.2	0.6	0.4	0.6	0.5
LM ERICSSON AB	0.2	0.4	0.4	0.2	0.2	0.2	0.3	0.0		2.6	2.5	2.1	1.4	0.3	1.4	2.4
BOEING COMPANY	0.4	0.6	2.6	1.1	3.3	2.6	1.0	0.5	14.9	1.3	2.0	0.1	0.5	0.8	1.0	0.5
SIEMENS AG	0.3	1.0	1.7	0.9	2.8	2.3	0.7	0.1	4.3	2.1	0.4	0.2	1.3	0.4	1.0	0.9
GOOGLE, INC.	0.9	1.0	1.2	1.1	0.7	0.6	1.2	1.3		3.0	1.3	1.5	1.1	1.8	2.5	1.0
NEC CORPORATION	0.7	0.5	0.8	0.7	0.6	1.0	1.4	0.6	0.5	0.4	0.6	0.8	1.3	1.3	1.6	1.6
XIAOMI INC.	1.3	2.4	0.6	1.5	1.4	1.0	1.4	0.5		0.9	0.6	0.7	1.6	1.1	1.7	1.4
APPLE INC.	1.4	0.5	0.7	0.9	0.2	0.3	0.3				0.5	1.5	1.0	2.1	1.5	1.0
RICOH COMPANY LTD	0.7	1.8	0.4	1.7	0.4	0.4	1.5	3.0		0.4	0.7	0.8	0.8	0.9	0.9	0.6
HITACHI LTD	0.5	0.5	2.2	0.8	1.5	1.4	1.5	0.5	0.5	0.0	0.4	0.6	0.3	0.8	1.2	0.5
TOYOTA MOTOR CORPORATION	0.3	0.3	3.6	0.3	0.6	0.6	0.8	1.1	0.5	1.3	1.4	0.0	0.2	0.3	0.4	0.2

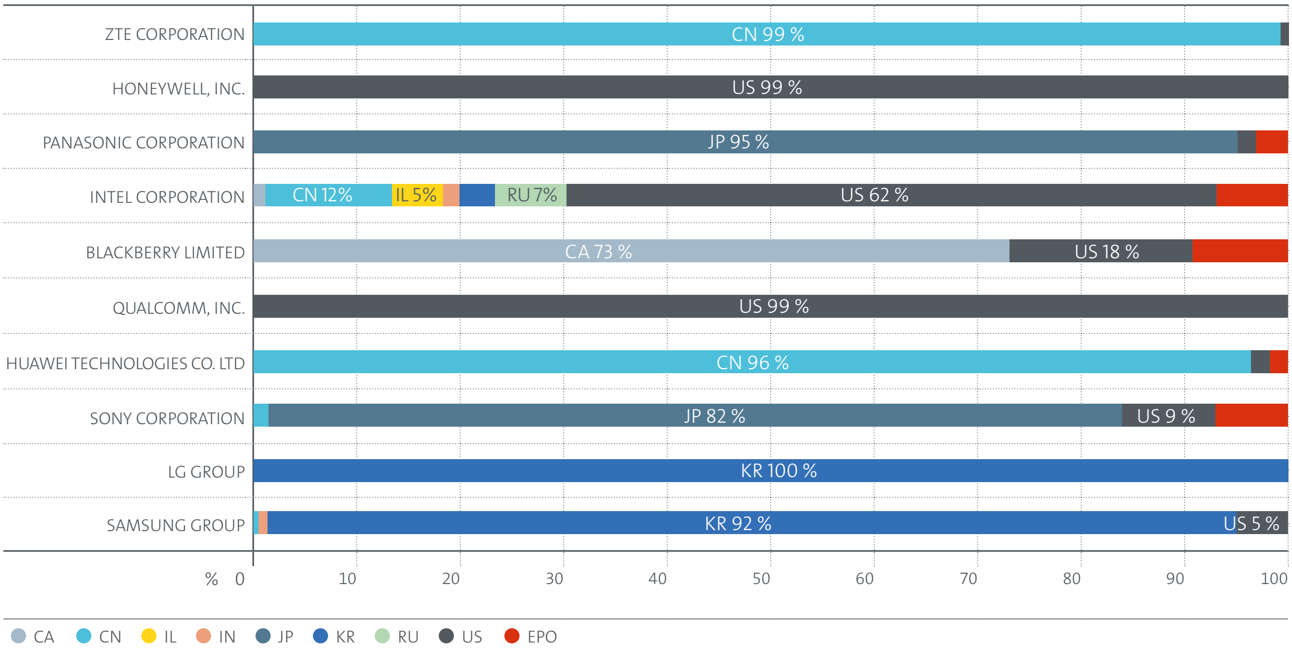
Source: European Patent Office

Generally speaking, ICT-focused applicants tend to be concentrated in core and/or enabling technologies. Chinese companies Huawei and ZTE have strong positions in *Software* and *Connectivity*, and in enabling technologies related to *Power supply*, *Security* and *Position determination*. Qualcomm and Blackberry have similar relative advantages to those of the two Chinese companies. They also have significant shares in certain application domains (Blackberry in *Personal* and Qualcomm in *Personal* and *Vehicles*). Other ICT-focused companies stand out in specific enabling technologies, for example Intel in *Power supply*, Google in *Artificial intelligence*, Gemalto in *Security*, Ricoh in *User interfaces* and Ericsson in *Artificial intelligence*, *Power supply* and *Security*.

In contrast, major applicants from non-ICT industries have stronger relative positions in 4IR application domains and enabling technologies. Philips, Panasonic and Honeywell have large proportions of inventions in most application domains, but also in *Analytics* and *User interfaces*. General Electric, Siemens and Boeing have strong positions in *Industry*, *Infrastructure* and *3D systems*. Toyota is the leader for inventions in *Vehicles*.

Figure 5.5

Origin of inventions of the top 10 non-European applicants at the EPO 2011-2016



Source: European Patent Office

5.3 Geographic origins of top applicants' inventions

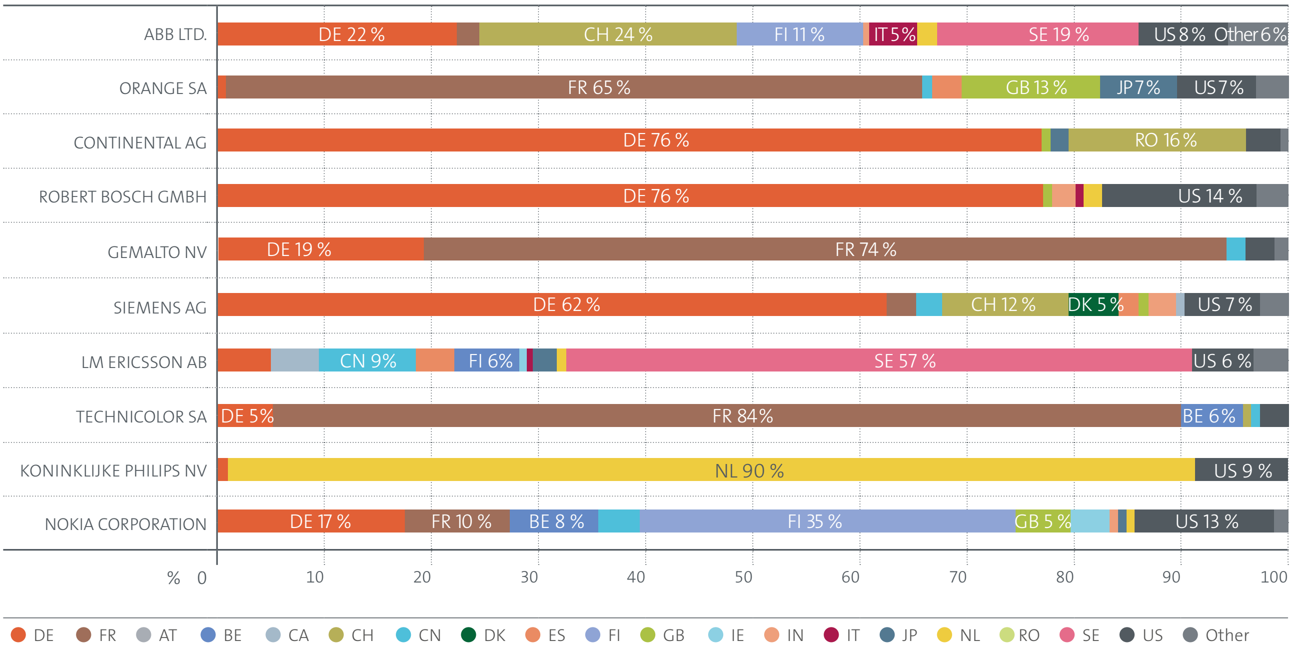
Although the R&D activities of international companies usually span various countries, the top 4IR applicants at the EPO have developed most of their 4IR inventions in their home country. This is especially the case for non-European companies (Figure 5.5). For seven of the top 10 non-European applicants, of which five are Asian and two US companies, 90% of 4IR inventions originate in the headquarters country. Intel is the single major exception, with only 62% of inventions coming from the USA, and the rest from ten other countries. The remaining two companies, Blackberry from Canada and Sony from Japan, have developed 73%/82% of their inventions in their home country, 18%/9% in the USA, and the remainder in a number of other countries.

Most of the 4IR inventions of the top European applicants were similarly invented in Europe. However, they usually originate from several European countries, regardless of the main location of the applicant (Figure 5.6). The most striking examples are Nokia (Finland), Ericsson (Sweden) and ABB (Switzerland).

The share of domestic inventions is 35% for Nokia, 24% for ABB and 57% for Ericsson. The other 4IR inventions of these three companies originate in about ten different countries in Europe and beyond. Applicants based in large European countries have the highest proportions of inventions originating in their main location. This is the case for Gemalto (74% of inventions from France) and Technicolor (84%). Continental, Bosch and Siemens developed 76%, 76% and 62% respectively of their inventions in Germany. Although it is located in a smaller country, 90% of Philips' 4IR inventions originate from the Netherlands.

Figure 5.6

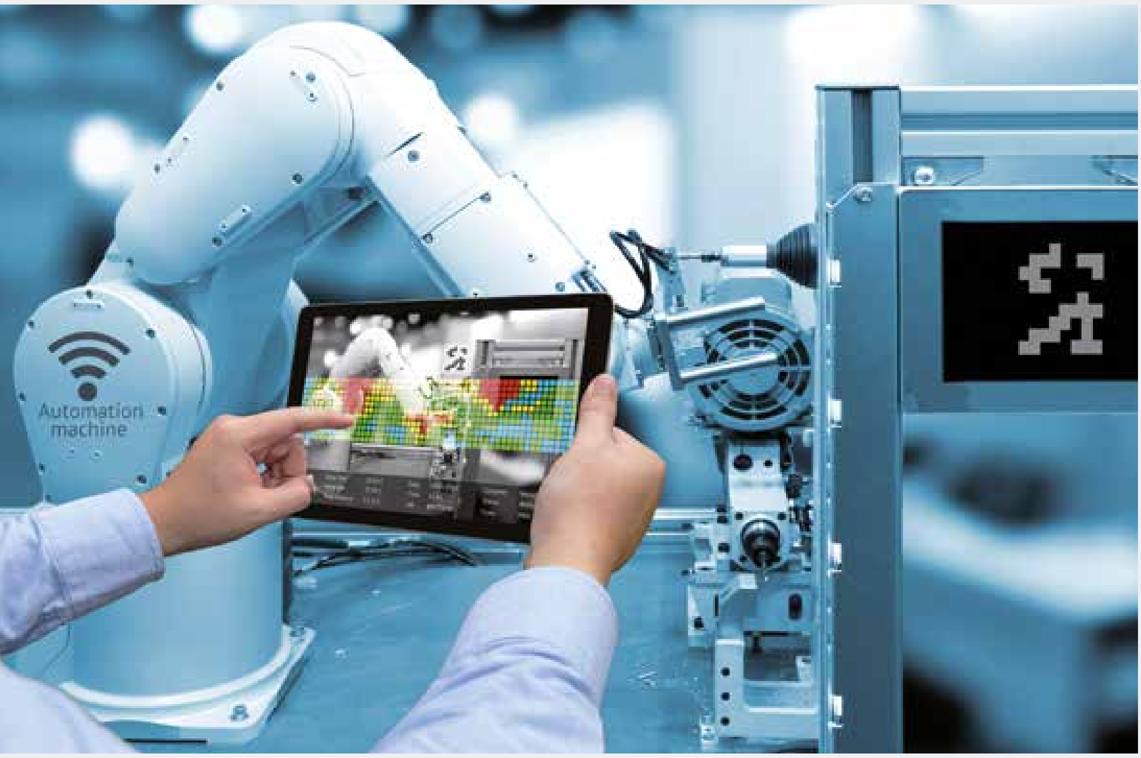
Origin of inventions of the top 10 European applicants at the EPO 2011-2016



Source: European Patent Office

Case study: Smart manufacturing

The application domain *Manufacturing* of the 4IR cartography refers to the new, intelligent and connected production systems which have been developed by integrating modern information and communication technologies into the manufacturing process. It leads to the automation of production processes on an unprecedented scale.



Smart factories consist of machinery and components communicating with each other, with minimal human control. For example, components give input to machines about the next production step and transmit data not only to each other, but also to customers and suppliers. As smart manufacturing is more flexible than conventional processes, it is possible to produce a small number of lots, down to a single customised lot, at a similar cost to that of mass production.

Smart manufacturing is likely to revolutionise manufacturing processes in the next few years. According to a recent report (MarketsandMarkets 2017), the smart manufacturing market is forecast to grow from 66.7 billion US dollars in 2016 to 152.3 billion US dollars in 2022, at a compound annual growth rate of 15.7% between 2017 and 2022. The robotics industry will account for a major share of this development, with an expected market volume of 81.5 billion US dollars by 2022. Companies surveyed in a poll conducted by PricewaterhouseCoopers in 2016 estimated that their average costs will decrease by 3.6% annually, and said that they expect an increased efficiency of 4.1% annually by 2020. This amounts to a total cost reduction of USD 421 billion between 2015 and 2020.

How it works

Cyber-physical systems (CPS) are one of the technical cornerstones of smart manufacturing. CPS can be described as physical and engineered systems whose operations are monitored, co-ordinated, controlled and integrated by a computing and communication core (Rajkumar et al. 2011). They comprise mechanical and electronic components such as production facilities, robots, field devices, sensors and actuators which are interconnected and able to exchange information within the network about production processes and the products themselves, as well as logistics chains. This large amount of information is collected, processed and analysed by software, meaning that all operations can be optimised and adapted to maximise productivity.

The entire production process from start to finish, including production, marketing and related services, is thus integrated and can even operate autonomously. Intelligent sensors record all data emerging from the production process and transmit this information to the corresponding actuators, which mechanically control production. These data are transmitted to cloud applications, allowing companies to exploit huge amounts of information in order to analyse the manufacturing process. Based on that information, the production process can be initiated, changed, stopped or corrected without human intervention, resulting in a "smart" factory that can organise and run itself. By means of cloud computing, services such as storage capacity and application software can be provided via the internet. Within this network, worldwide communication between software programs and mechanical and electronic parts is possible. This allows constant and real-time co-ordination and optimisation of the manufacturing process between different locations or even different companies throughout global value chains.

Figure 1

A smart factory – connected shop floor

Source: Bosch

Example: Bosch's smart factory

Companies such as German multinational engineering and electronics group Bosch are taking advantage of the exciting new possibilities offered by smart manufacturing. Bosch first entered this area about 15 years ago. Since then, it has gradually integrated ever more "smart elements" into its manufacturing processes. In 2013 it revamped its plant in Blaichach, Germany, with the aim of interconnecting the entire production process. Bosch's pioneering project of smart manufacturing, with a connection grade of 99%, has created a new working world. In this intelligent factory, about 3 500 employees produce more than six million anti-lock braking systems (ABS) and electronic stability programmes (ESP) annually for the automotive industry. The following are three examples of smart manufacturing applications:

Bosch uses radio-frequency identification (RFID) technology to digitally map the internal product flows and create a virtual image of the real factory. RFID systems are the main means of identifying components, machines and transport equipment via a tag (attached to any component, be it a machine, a production facility or a manufacturing product) that transmits radio signals. At the start of the production process, all initial components are equipped with an RFID tag. A transport device brings the required components into the warehouse, where they are registered by an RFID access control system. By monitoring the inventory, material flow can be optimised and goods automatically re-ordered in real time. Next, the components enter the manufacturing process and undergo various production stages. The meta information describing the production steps to be carried out on each component are stored in the RFID code and transmitted to a central control system that enables the machines to carry out the steps autonomously. A transport device automatically brings the component to the next work step for further processing.

Bosch has also installed sensors in the assembly-line machines in order to collect and analyse data on the production process. The sensors record parameters relating to aspects such as cylinder movement, gripper cycle times, temperature and humidity, and provide information about the condition of the machines. All this information is presented in real time on a dashboard, and precise instructions for the elimination of errors or suggestions for improvement are given automatically. Throughout, employees can continuously monitor the condition of the machines by means of a performance app on their smartphones, and can receive instructions during troubleshooting, if required. This helps to avoid unscheduled interruptions and the resulting loss of production.

The Bosch plant in Blaichach is not the company's only application of smart manufacturing. In fact, it is the prototype for a global production network of eleven digitally connected production sites. The performance of all plants can be compared with one another by centrally accessing all their data. If a particular site records a higher productivity than the others, the cause is determined quickly and the successful production model is transferred to the other plants. This has led to a doubling of the number of brake control systems manufactured per hour in five years. Bosch uses the complete data-based information from its global production network to build up a knowledge database, which in turn can help all its locations to become more competitive.

Smart manufacturing opens up possibilities for higher productivity, flexibility and quality through the integration of information and communication technologies in manufacturing processes, and will spur further innovation. Vast amounts of data are collected from each step of the production cycle and every point of the supply chain. Intelligence derived by advanced analytical software can be used to create new and improved production processes. In addition, the combination of manufacturing knowledge with insight into customer preferences, which have been gathered and evaluated since the early days of e-commerce, will trigger further process and product innovations.

6. Global geography of 4IR inventions

6. Global geography of 4IR inventions

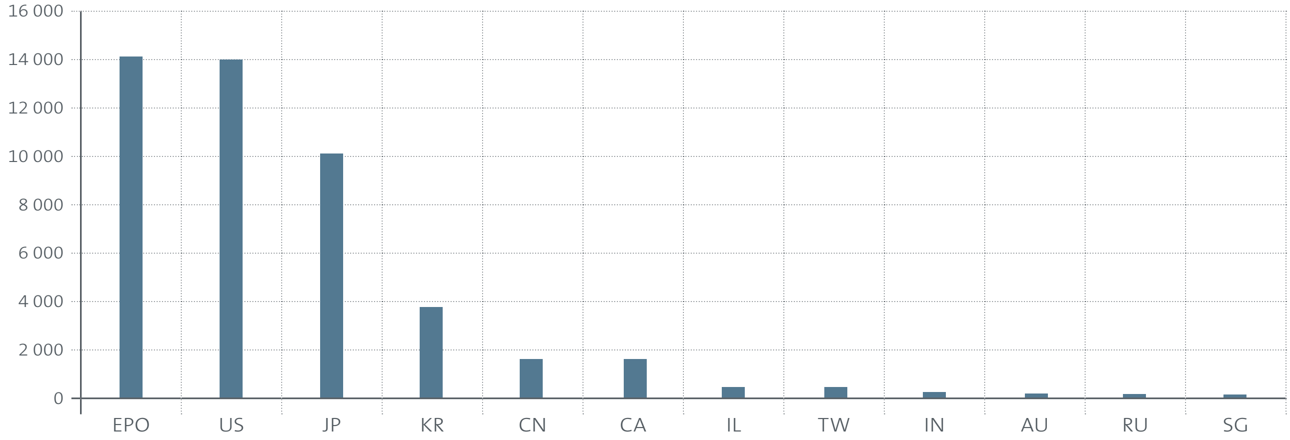
This chapter reports on the geographic origin of 4IR inventions. It focuses on the main 4IR innovation centres on a global scale. For the purposes of this chapter, Europe is treated as a single entity, including all EPO member states.[7]

6.1 Global innovation centres in 4IR technologies

Inventions in 4IR technologies at the EPO have been largely dominated by the USA, Europe and Japan, which together account for about 80% of all 4IR European patent applications since 1978 (Figure 6.1). The USA and Europe have both generated about 30% (14 000 patent applications each) of 4IR inventions in this period. Japan is the third biggest contributor, with 10 140 applications, or 21% of the total.

Figure 6.1

4IR patent applications at the EPO by major innovation centres 1978-2016



Source: European Patent Office

7 The performance of the EPO member states is analysed in more detail in chapter 7.

Innovation in 4IR technologies has grown in parallel in these three major innovation centres since the end of the 1990s. However, the trends have diverged over the last decade (Figure 6.2). The number of inventions increased more slowly in Japan in 2007 and in the USA after 2010, whereas the growth in European inventions accelerated after 2012. As a result, European countries have out-performed the USA and Japan for 4IR inventions in recent years.

Korea, China and Canada have also emerged as major innovation centres in 4IR technologies. In the years leading up to 2016, they rank as the fourth, fifth and sixth countries of origin of 4IR inventions respectively, with about 8%, 3.5% and 3.4% of all 4IR inventions (Figure 6.1).

Korea and Canada started innovating in 4IR technologies in around 2000, about five years after Japan, Europe and the USA. China took another five years to produce a significant number of inventions. Chinese and Korean patent applications at the EPO have risen markedly since then, especially since 2010 (Figure 6.2). Korea has already caught up with Japan and is likely to replace it soon as the third biggest innovation centre. Canada is nearly at the same level as China, with almost 1 700 inventions. However, its annual flow of 4IR inventions peaked in 2010, and it has been clearly outpaced by China since then.

Table 6.1 shows that the late but rapid growth of 4IR inventions in Korea and China has been largely driven by a few top national applicants. Samsung and LG together filed more than 90% of all patent applications originating in Korea. In China, Huawei and ZTE likewise account for more than two thirds of all domestic 4IR inventions. In contrast, the top 2 domestic applicants generated just 16.6% and 15.5% of home-grown 4IR inventions in the USA and Europe respectively. This confirms that European and US innovation in 4IR technologies is more evenly distributed between a larger group of applicants (see also Figure 5.2). With 30% of domestic inventions originating from Sony and Panasonic alone, Japan occupies an intermediate position in this respect.

Table 6.1

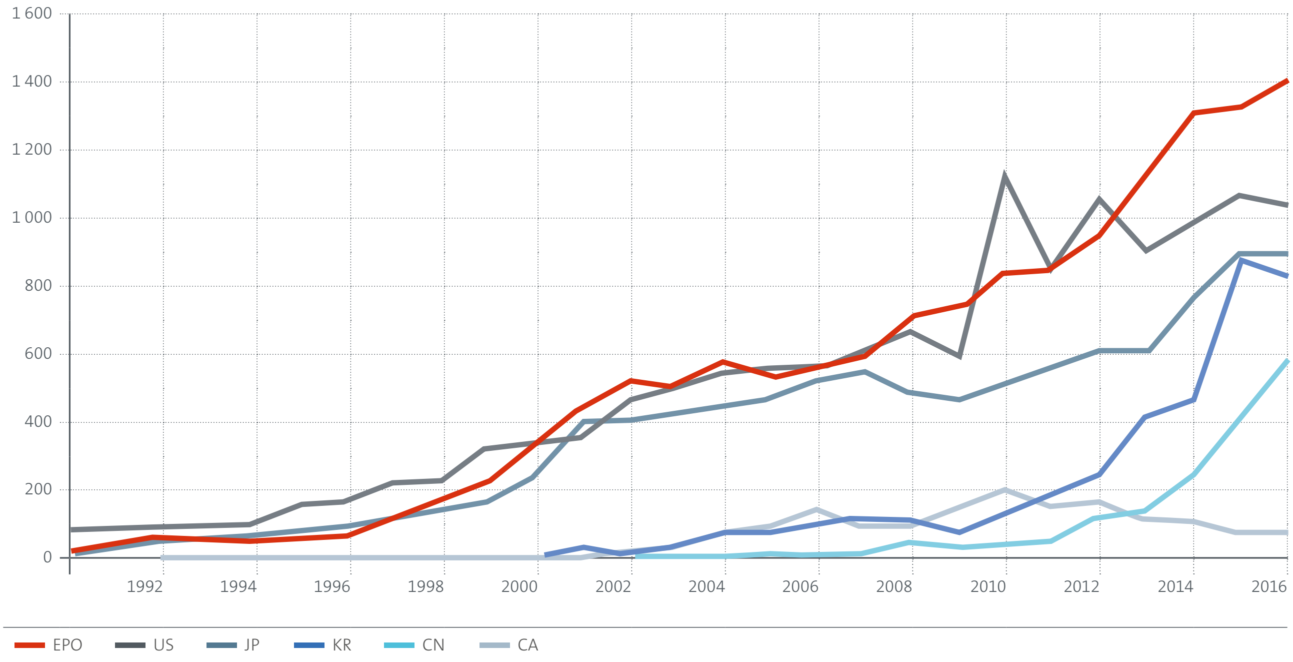
Share of domestic 4IR patent applications originating from the two largest national applicants 2011-2016

	Top 2 4IR applicants at EPO	Top 2 share of domestic 4IR inventions
EPC countries	Nokia, Philips	15.5%
USA	Qualcomm, Intel	16.6%
Japan	Sony, Panasonic	29.9%
Korea	Samsung, LG	91.3%
China	Huawei, ZTE	68.9%

Source: European Patent Office

Figure 6.2

Trends in 4IR inventions at the EPO by the top 6 innovation centres



Source: European Patent Office

6.2 Technology profiles of global innovation centres

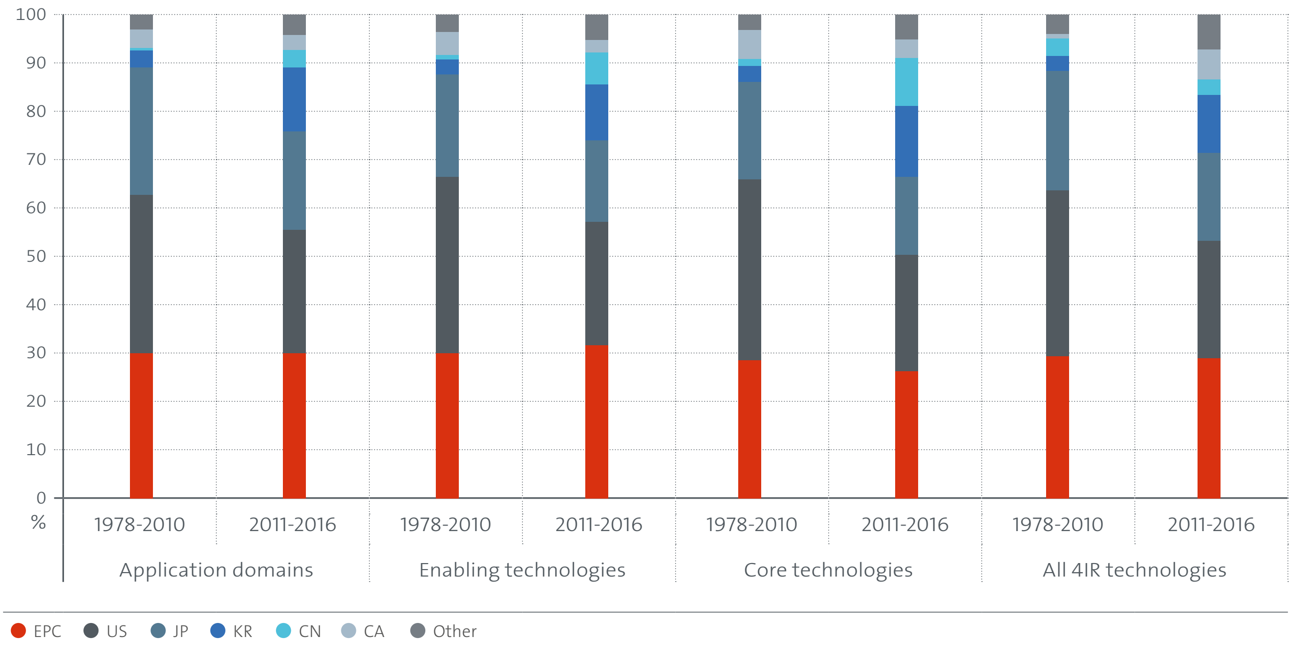
As a first step in the assessment of the technology profiles of leading innovation centres, their respective strengths can be measured by their share of inventions in the three main sectors of the 4IR cartography: application domains, enabling technologies and core technologies (Figure 6.3). These shares are given for two successive periods of time - 1978-2010 and 2011-2016 - each accounting for about half of the 4IR inventions identified in EPO patent applications.

Statistics by technology sector confirm the changing geographic distribution of 4IR inventions observed at the aggregate level. The USA headed each sector in the early years, but this position has been eroded in 2011-2016, especially in core technologies. European countries have maintained a stable share of about 30% of inventions in each sector. Taking the number of EPO patent applications as a measure, they now rank as the leading innovators in all sectors.

The decreasing proportion of 4IR inventions originating not only in the USA, but also in Japan and Canada, stems from the growing inventive activity of Korea and China in the period 2011-2016. As already indicated, this is mainly driven by a few large corporations in these two countries. Although it can be observed in every field, it is particularly marked in core technologies, where the combined share of Korea and China increased from 5% to 25%. Korea has already overtaken Japan in core technologies, with a share of 15.6% of inventions in this sector, and also has strong positions in application domains (13.2%) and enabling technologies (11.4%). Besides core technologies (9.4%), China has a significant position in enabling technologies (6.5%). In contrast, it still accounts for a relatively small portion (3.4%) of the largest 4IR sector at the EPO, which is application domains.

Figure 6.3

Evolution of 4IR patent applications by origin and sector



Source: European Patent Office

6.3 Technology profiles by 4IR field

Figures 6.4-6.6 present more details about the different 4IR fields pursued by the main innovation centres in recent years (2011-2016).

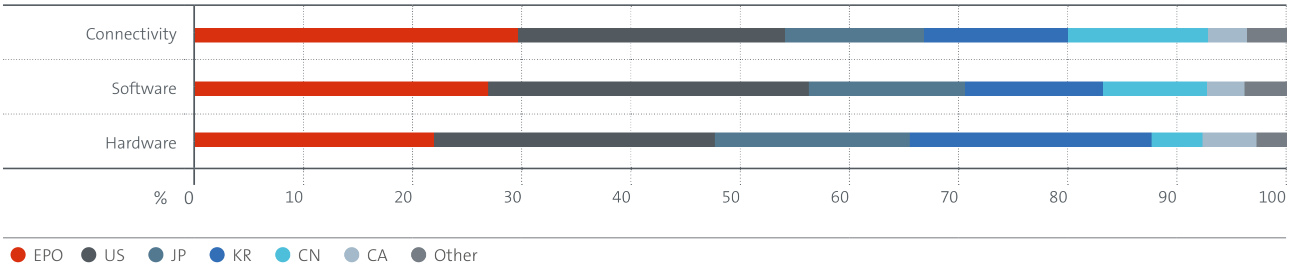
In core technologies, *Software* and *Connectivity* are dominated by US and European inventions, which together account for more than half of the total (Figure 6.4). European countries account for almost 30% of *Connectivity* inventions, followed by the USA (24%). The two areas contribute in roughly equal proportions to all *Software* inventions. Japan, Korea and China have comparable shares of 10% to 13% of all inventions in both fields.

The field of *Hardware* looks different, with a lower combined percentage - below 50% - of US and European inventions and a larger proportion of Korean and Japanese inventions. Thanks to the strong contributions of Samsung and LG in this field, Korea stands out, with about the same share of inventions as Europe. In contrast, the contribution of Chinese inventions is marginal.

The geographical distribution of inventions in enabling technology fields reveals clearer specialisation patterns (Figure 6.5). The fields of *Position determination, 3D systems, Artificial intelligence* and *Security* are largely led by Europe and the USA, which jointly account for more than 60% of all inventions in each case. This predominance is equally visible in *Position determination* and *Artificial intelligence*. However, the USA has the vanguard position in *3D systems*, whereas European countries are ahead in Security.

Figure 6.4

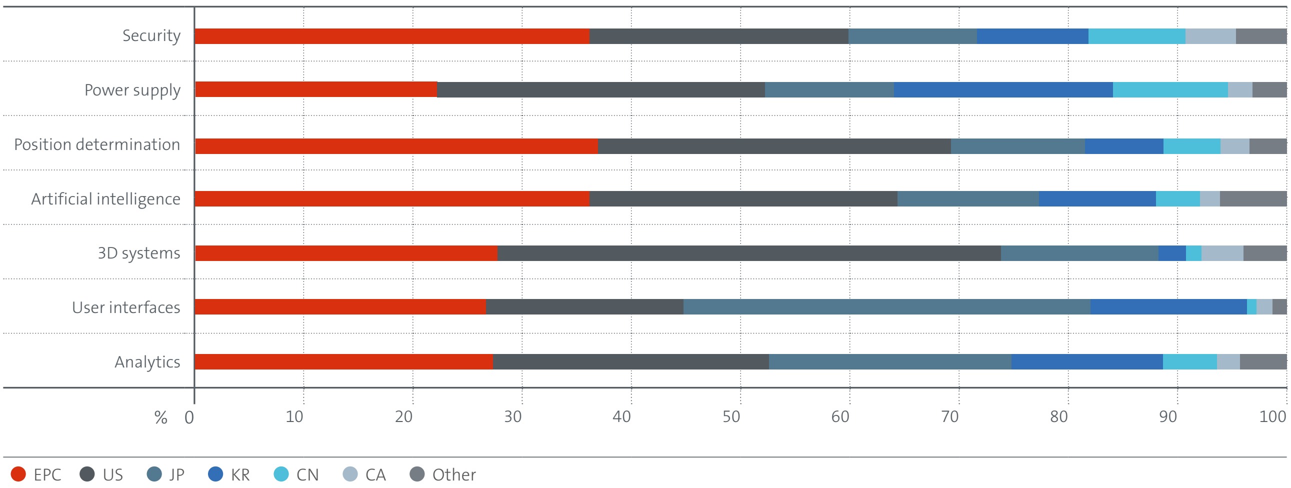
Origin of patent applications in core technology fields 2011-2016



Source: European Patent Office

Figure 6.5

Origin of patent applications in enabling technology fields 2011-2016



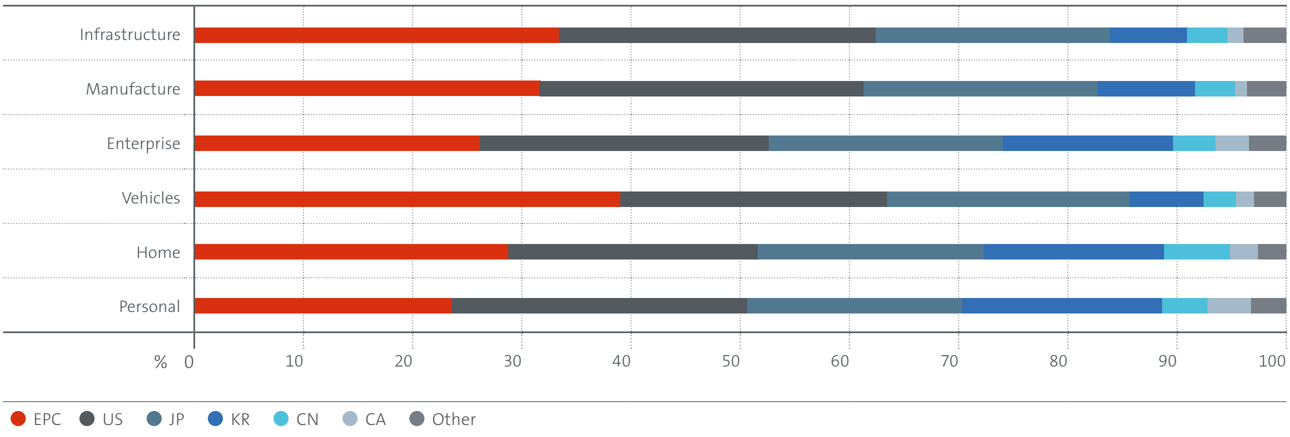
Source: European Patent Office

Inventions related to *Analytics* are relatively evenly distributed between the USA, Japan, European countries and, to a lesser extent, Korea. In the field of *Power supply*, US inventions account for about 30% of inventions, but European countries and Korea also appear as important innovation centres, each with about 20% of inventions. *User interfaces* is clearly dominated by Japan, which owns about 35% of all inventions. While there is no enabling technology in which China plays a leading role, its strongest positions are in *Power supply* and *Security*.

The analysis of application domain fields (Figure 6.6) reveals a relatively uniform domination of Europe, the USA and Japan in all of them. Of these top 3, the USA and Europe are also strong in the fields of *Manufacture* and *Infrastructure*, with about 30% of all inventions each. Europe has a clear lead in *Vehicles*, with a share of 38% of all inventions, while the USA has a greater proportion of inventions in *Personal*. Japan has an evenly spread percentage of inventions (around 20%) in all application domain fields. Korea is a major player in the fields of *Personal, Enterprise* and *Home*, where Europe and the USA are less active.

Figure 6.6

Origin of patent applications in application domains 2011-2016



Source: European Patent Office

Case study: Smart health

A large number of inventions in the application domain *Personal* are related to healthcare and they drive of one of the fastest-growing sectors of 4IR.

The advent of digital technology is providing new opportunities to improve the quality of healthcare by transforming traditional into smart healthcare. Automated digital processes which enable data to be collected and shared between different health service providers will complement or even replace existing diagnostics, treatment and devices. Smart healthcare will help prevent diseases and provide much earlier diagnosis and better treatment in the future, enabling people to live longer, healthier and more active lives and to recover more quickly from illness.

The potential of the smart health market is enormous. It is expected to exceed 200 billion US dollars by 2020, with a predicted annual growth rate of more than 20% between 2015 and 2020 (Roland Berger 2016). The mobile health sector is set to increase by 41% annually, making it the fastest-growing sector for technologies that use mobile devices such as mobile phones, patient monitoring devices or personal digital assistants (PDAs) to record health-related data and recommend adjustments to treatment.

Technologies and applications

Smart health elements are used in various medical fields, where they improve existing processes and create new business possibilities.

Real-time monitoring uses sensors and mobile devices to track vital signs outside the clinical setting. Tracked data can be sent to healthcare providers, who are immediately alerted if there are warning signs. Real-time monitoring is particularly important for the care of elderly and chronically ill persons at home. For diagnosis, doctors can be increasingly supported by **artificial intelligence**. Algorithms can help to reduce errors in decision-making and, in standard cases, can analyse and interpret test results quickly and accurately, leaving the doctor more time for complicated cases.

Telemedicine is the name given to interactive remote communication between medical staff and patients using telecommunication technologies. Patients' vital data can be remotely monitored, and medical staff can communicate with patients direct and give them instructions. The term is also used to describe internet consultations with patients or the exchange of medical records between different doctors.

Information on patient medical and social data can be digitally stored in electronic health records (or health cards) and made available to healthcare providers. Data about medical history, diagnoses and treatment, socio-economic problems and risk profiles are collected and recorded at different medical sites. Big data allows this data to be analysed and evaluated and converted into decision-relevant information (PwC 2013). Patient behaviour and current state of health can be extracted from big data at any time. The bundling of this data into an electronic health record means that doctors and insurance companies have immediate access to a patient's entire medical history. This information can facilitate a correct diagnosis and prevent dangerous drug interactions. The technical basis for an electronic health record can be a platform. Doctors who are connected via platforms can give a preliminary consultation and recommend a specialist. An anonymous comparison with persons who have similar symptoms in order to identify possible causes aids the detection of diseases.

The entire chain of medical care, from doctors to pharmacists and laboratory personnel, can be integrated into the portal. Moreover, experts from other areas, such as nutrition, can also be linked to the platform and can be consulted to give a comprehensive picture of the individual patient care

Smart health can also use **blockchain technology** (a distributed system which records and stores transaction records using cryptographic techniques) as a basis for a comprehensive electronic health record. Blockchain technology unites the different system languages of health records and decentralises their use. Important information is often scattered over several sites and sometimes not accessible when it is most needed. Unlike a health card, a blockchain can be viewed from anywhere, so that the potential for telemedicine is increased. A sick person can contact a doctor by smartphone. The doctor can then access the patient's medical data, which are recorded by the sensors of the smartphone or other wearable devices. He or she also has access to the patient's entire medical history, which is logged in the blockchain.

Personalised medicine takes into account individual differences in people's genes, environments and lifestyles, as shown in their medical data. By comparing combinations of drugs effective for specific genomic profiles, more accurate predictions can be made about the probability of a person developing a particular disease, the prognosis of the disease and the likely response to treatment.

Computer-aided surgery supports surgical interventions in a digital operation theatre. Image-guided surgery, surgical navigation and robot-based surgery are examples of processes that may be wholly or partly carried out using computer technology.

Smart health focuses not only on the treatment of diseases but also on their prevention. Tracking a person's health data in everyday life, combined with expert analysis of that data, could help to promote a healthy lifestyle through better nutrition and fitness. This is giving rise to new consulting services for data collected with **smart wearables** such as fitness bracelets, or health applications for smartphones. Companies can use this data to advise users on how to improve their fitness, thus assuming the function of a virtual fitness or nutrition consultant. Based on the data, it may even be possible to recognise an emerging disease, which can then be treated earlier, and consequently with a greater chance of a cure. Routine examinations may no longer be necessary if medical data are constantly monitored. If the data shows a pattern that might indicate a certain disease, the person is informed.

Micrel Medical Devices – a smart health company

Micrel Medical Devices, a family-owned Greek company that develops, manufactures and markets a full range of ambulatory infusion pumps, administration sets and patient infusion control and monitoring systems, was a pioneer in smart health technology. Its first product, an ambulatory syringe pump, allowed patients suffering from thalassaemia, a rare blood disease that is prevalent among people of Mediterranean descent, to be treated at home instead of in hospital.[6]

Following that success, Micrel specialised in the design, manufacture and marketing of "smart" drug delivery systems for hospital and home care applications. It developed a new rhythmic web-programmable ambulatory pump for clinical research. These innovative and user-friendly infusion pump systems are tailor-made for delivering specific therapies, including pain control, parenteral and intravenous nutrition, and the treatment of Parkinson's disease and cancer. The products are small in size, have a low power consumption, which makes them particularly user-friendly, and use the "Rythmic connect" technology.

6 See www.org/sme for a full case study about Micrel Medical Devices.

Figure 1

Rythmic™: Remote control for home infusion therapies

Source: Micrel Medical Devices

Rythmic connect is a real-time wireless technology which uses a GPRS device ("IP Connect") to enable an ambulatory pump to communicate with a web server and provide its infusion status online through the MicrelCare system. MicrelCare is a web-based service that enables, for example, doctors, nurses and homecare service providers involved in infusion care to report and monitor clinical and technical information relating to the infusion therapy and to adjust the infusion protocol remotely. The system also provides instant feedback on therapy results and side-effects. This feedback can be obtained by inserting an implantable catheter tip into the bloodstream to measure parameters such as temperature, blood pressure, glucose, oxygen and certain ions via sensors embedded in the catheter or by the pump asking the patient about conditions such as diarrhoea, vomiting, nausea or pain. These "smart" systems also alert service providers to the need for preventive maintenance. Thus, the various people involved in the infusion therapy can act to prevent technical failures that might have serious consequences.

The current medication practice is still to infuse drugs to unattended patients, based on preliminary tests resulting in a provisional treatment schedule. In many cases, the patient has to stay in hospital until the doctor finds a working prescription protocol. Using Micrel's solutions, doctors can send the patient home and refine the treatment over the internet. Patients can easily inform healthcare staff about their state of health and can live a normal life while their therapy parameters are being monitored. Healthcare service providers can access the status of their patients' infusion and therapy outcome online from anywhere, and receive text messages with selected notifications about the status of the infusion and therapy, enabling them to anticipate potential problems.

Conclusion

Healthcare systems around the world are faced with the challenges of an aging society, financial constraints and a trend towards personalised medicine, under which medication and treatment schedules are tailored towards the individual patient. The Fourth Industrial Revolution provides the technology to meet these challenges. Greater convergence of the health and technology sectors will transform the healthcare system while at the same time reducing costs, increasing efficiency and improving and saving lives.

7. Focus on Europe

7. Focus on Europe

This chapter analyses the geographic origin of European inventions in order to assess the performance of the EPO member states in 4IR innovation.

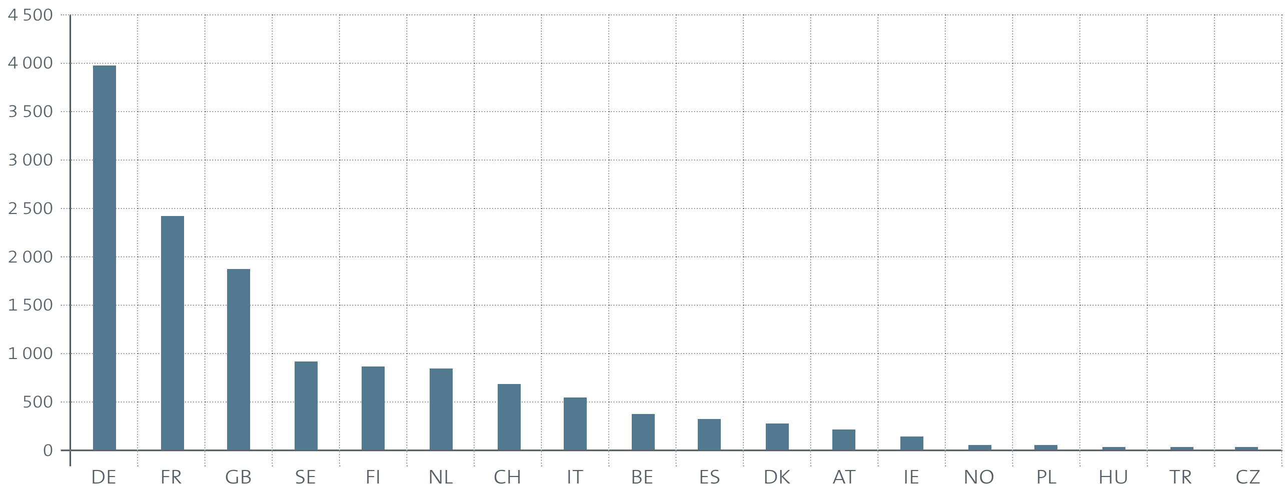
7.1 European inventions in 4IR technologies

European inventors were responsible for more than 14 000, or almost 30%, of all 4IR patent applications at the EPO up to 2016. Germany's share of approximately 4 000 inventions was the largest in Europe, followed by the other two big European countries, France and the United Kingdom, with more than 2 400 and 2 000 patent applications respectively (Figure 7.1).

Behind the top 3 appears a group of other countries showing significant innovative activities in 4IR technologies: the two Scandinavian countries, Sweden and Finland, and the Netherlands, with approximately 900 patent applications each. Switzerland is not far behind. Italy and Spain, two other big European countries, are 8th and 10th respectively.

Figure 7.1

4IR patent applications at the EPO by member state 1978-2016



Source: European Patent Office

Figure 7.2 shows the trends in 4IR patent applications for the six most innovative European countries. Until 1999, at a very early stage, the United Kingdom was the leading country in 4IR, with more than 50 patent applications per year. After that, Germany became the most innovative country, increasing its annual number of patent applications to more than 400 in 2016. For most of that period the annual patent application levels of French and United Kingdom inventors were roughly the same. However, the last five years have seen France more than double its innovative output, to almost 300 patent applications in 2016. In contrast, the United Kingdom remained on the same trajectory as Sweden and Finland, coming close behind with approximately 100 patent applications each in 2016.

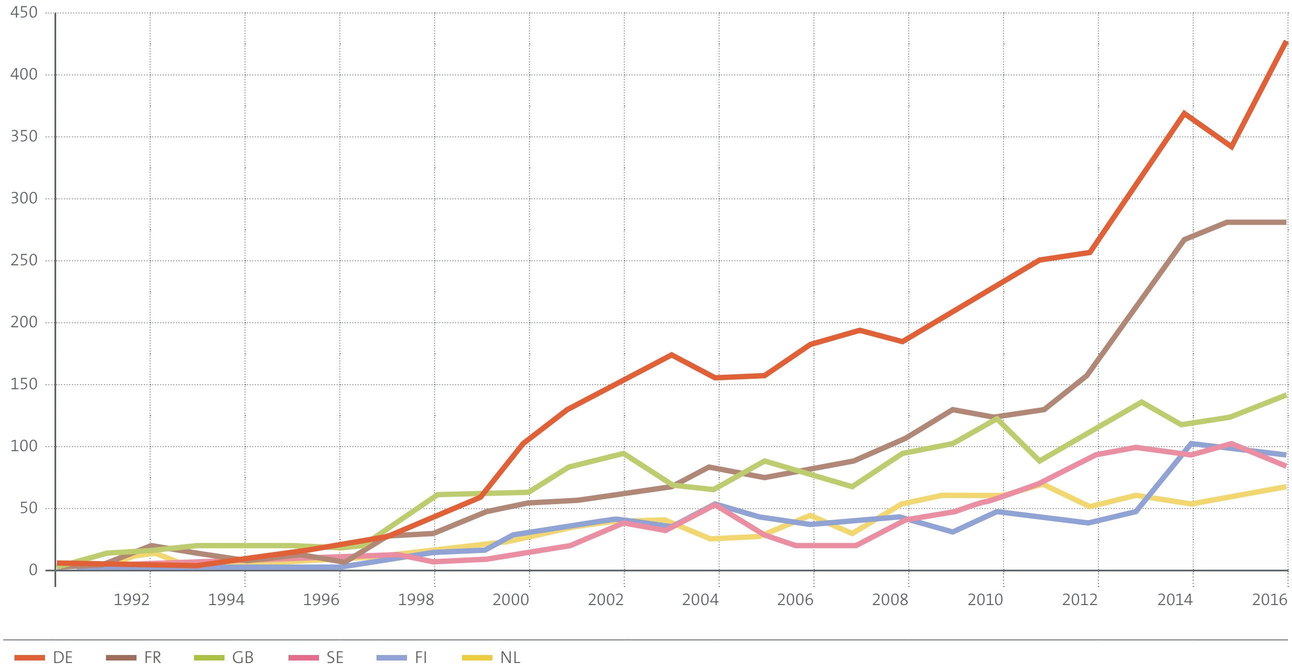
7.2 Technology profile of European countries

This section assesses the strengths of leading European innovation countries in different 4IR technology sectors and their fields. The columns in Figure 7.3 show the contributions of individual EPO member states to the European share in application domains and enabling and core technologies in 1978-2010 and 2011-2016.

Considering Europe as a whole, the three sectors evolved differently in the period 2011-2016. While European countries have maintained an aggregate share of about 30% of all inventions in 4IR application domains, their relative contribution to innovation has increased over time in enabling technologies, while diminishing in core technologies.

Figure 7.2

4IR inventions at the EPO from the top 6 European countries over time

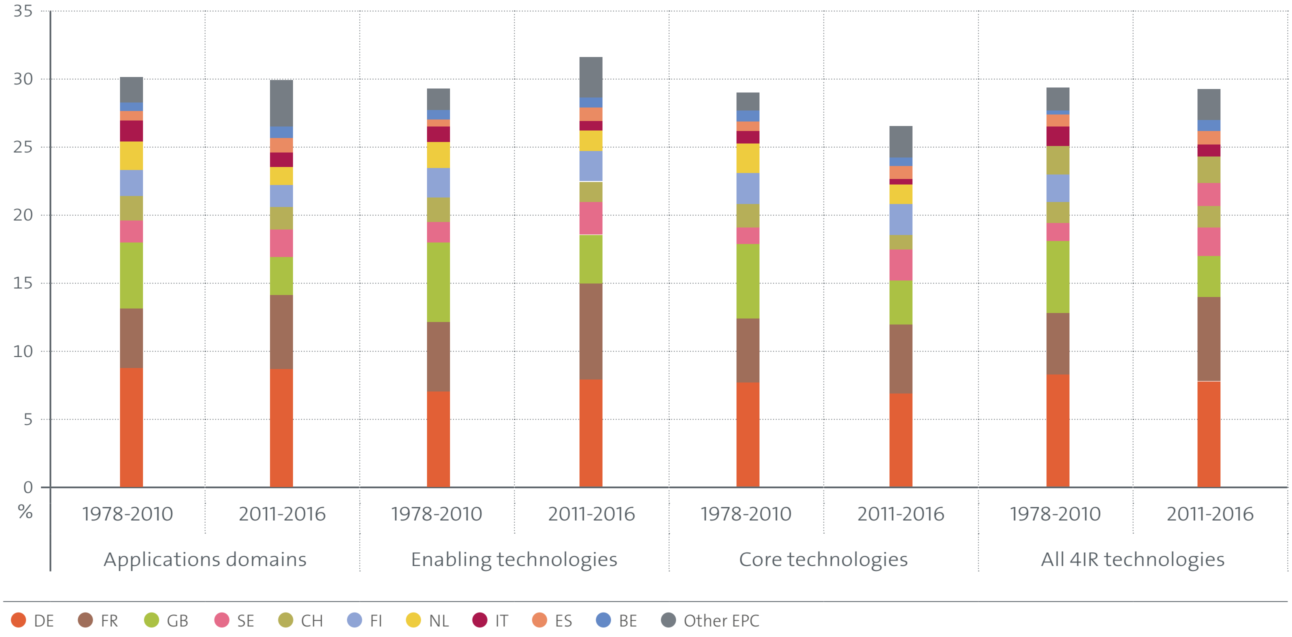


Source: European Patent Office

With a combined share of approximately 60% of all European inventions, Germany, France and the United Kingdom were the three biggest inventor countries in all three 4IR sectors in both time periods. However, while the United Kingdom's shares eroded, France's shares grew significantly in all sectors. Germany's shares remained unchanged in application domains, increased in enabling technologies, and decreased in core technologies. Sweden is another country showing a positive development. It expanded its share in application domains and enabling technologies and more than doubled it in core technologies. Inventive activity in 4IR technologies also increased outside the major European innovation centres: the share of countries outside the top 10 (other EPO member states) has grown significantly in all three sectors in the more recent period.

Figure 7.3

Evolution of patent applications by origin and sector – EPO member states



Source: European Patent Office

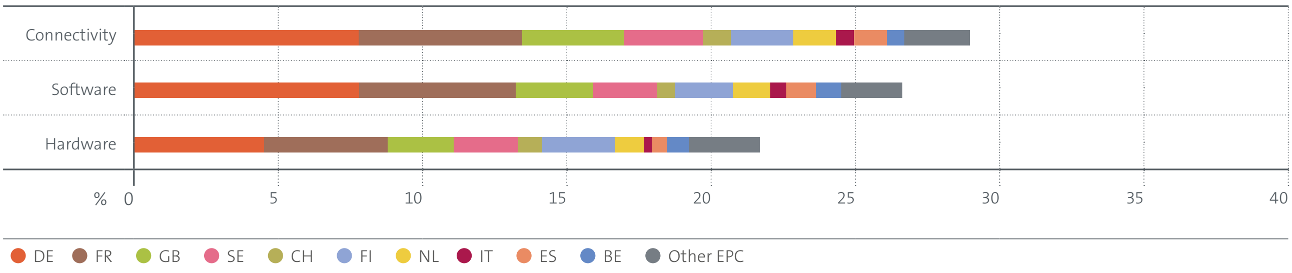
7.3 Technology profiles by 4IR field

A closer look at the individual fields of the main technology sectors reveals further specialisation patterns. In core technologies (Figure 7.4), European countries are strongest in *Connectivity* and weakest in *Hardware*. The relative positions of European countries are very similar in all three core technology fields. Germany and France together account for 40-45% of all European inventions originating from European countries, with a marked lead for Germany in *Software* and *Connectivity*. The United Kingdom, Sweden and Finland are responsible for a further 30% of Europe's share in each field.

In enabling technologies (Figure 7.5), Europe as a whole is particularly active in *Position determination, Artificial intelligence* and *Security*. In contrast, it has a markedly low share of inventions in *Energy supply*. The performance of the respective European countries is not evenly distributed across enabling technology fields. France is clearly dominant in *Artificial intelligence, User interfaces* and, to a lesser degree, *3D systems* and *Security*. Together with Germany, it accounts for more than half of all European inventions in these four fields. The European shares in *Analytics, Position determination* and *Power supply*, where Germany has a leading position, are more equally distributed among several countries.

Figure 7.4

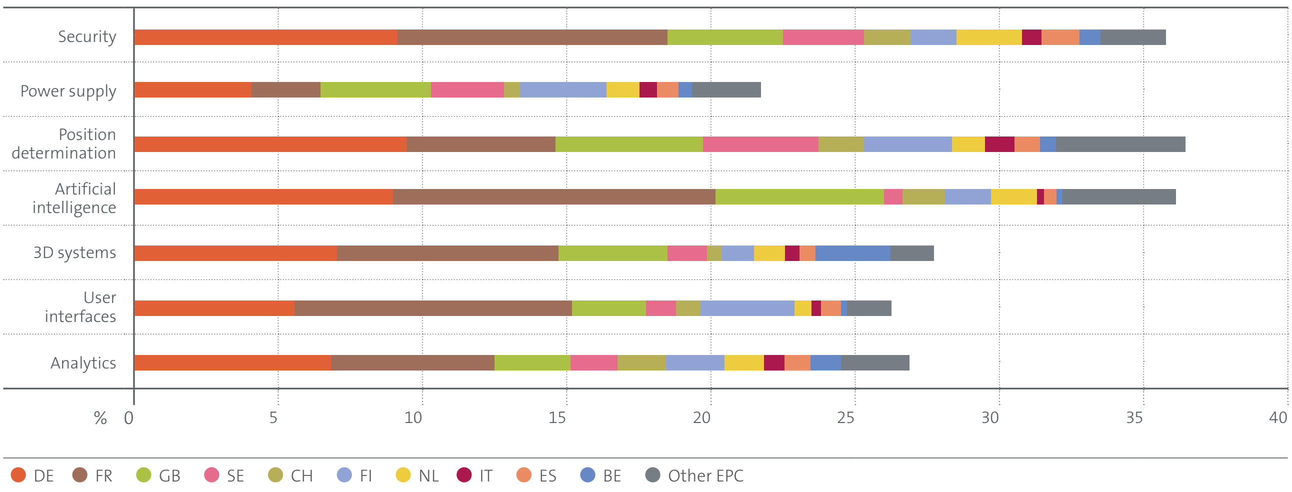
Origin of patent applications in core technology fields – EPO member states



Source: European Patent Office

Figure 7.5

Origin of patent applications in enabling technology fields – EPO member states



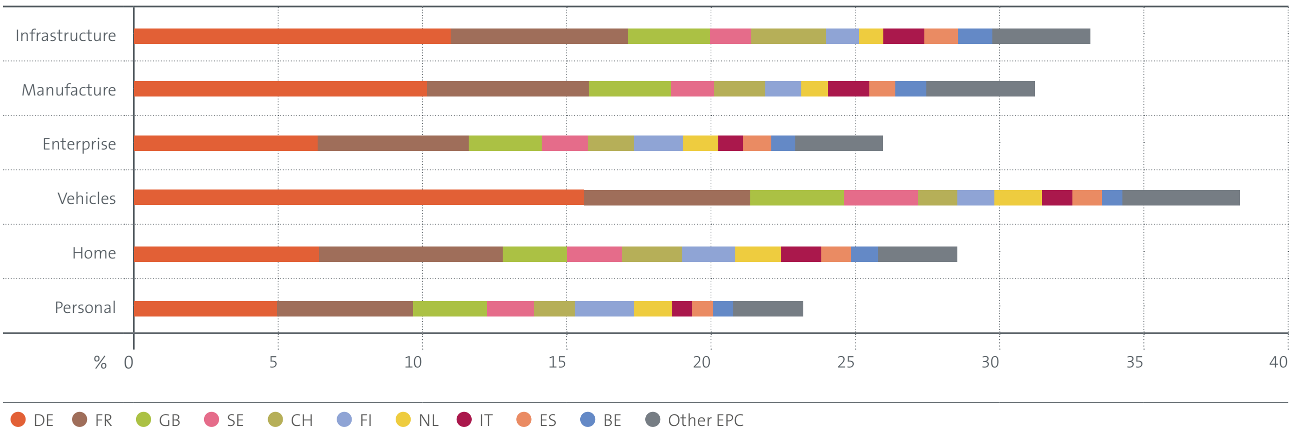
Source: European Patent Office

Other European countries reveal more specialisation. For example, the United Kingdom is relatively strong in *Power supply, Position determination* and *Artificial intelligence*. Sweden performs well not only in *Position determination* and *Power supply*, but also *Security*, while Finland is active in *Position determination*, but even more so in *Power supply* and *User interfaces*. Belgium has a relatively high share in *3D systems* and the Netherlands in *Security*.

Regarding 4IR application domains (Figure 7.6), European countries rank highly for inventions in *Vehicles* and *Infrastructures*, thanks to the leading position of Germany in these areas. With an absolute share of 10%, Germany is also largely responsible for Europe's strong position in *Manufacture*, reflecting the country's efforts to increase the application of digital technologies to industrial production (INDUSTRY 4.0 initiative). France is performing equally well in all seven application domain fields of the cartography. In *Enterprise, Home* and *Personal*, its share equals or surpasses Germany's. However, several more European countries, including the United Kingdom, Sweden, Switzerland, Finland, the Netherlands, Italy, Spain and Belgium, also contribute to each of the seven application domain fields without specialising in any of them.

Figure 7.6

Origin of patent applications in application domains – EPO member states



Source: European Patent Office

7.4 4IR inventions in European regions

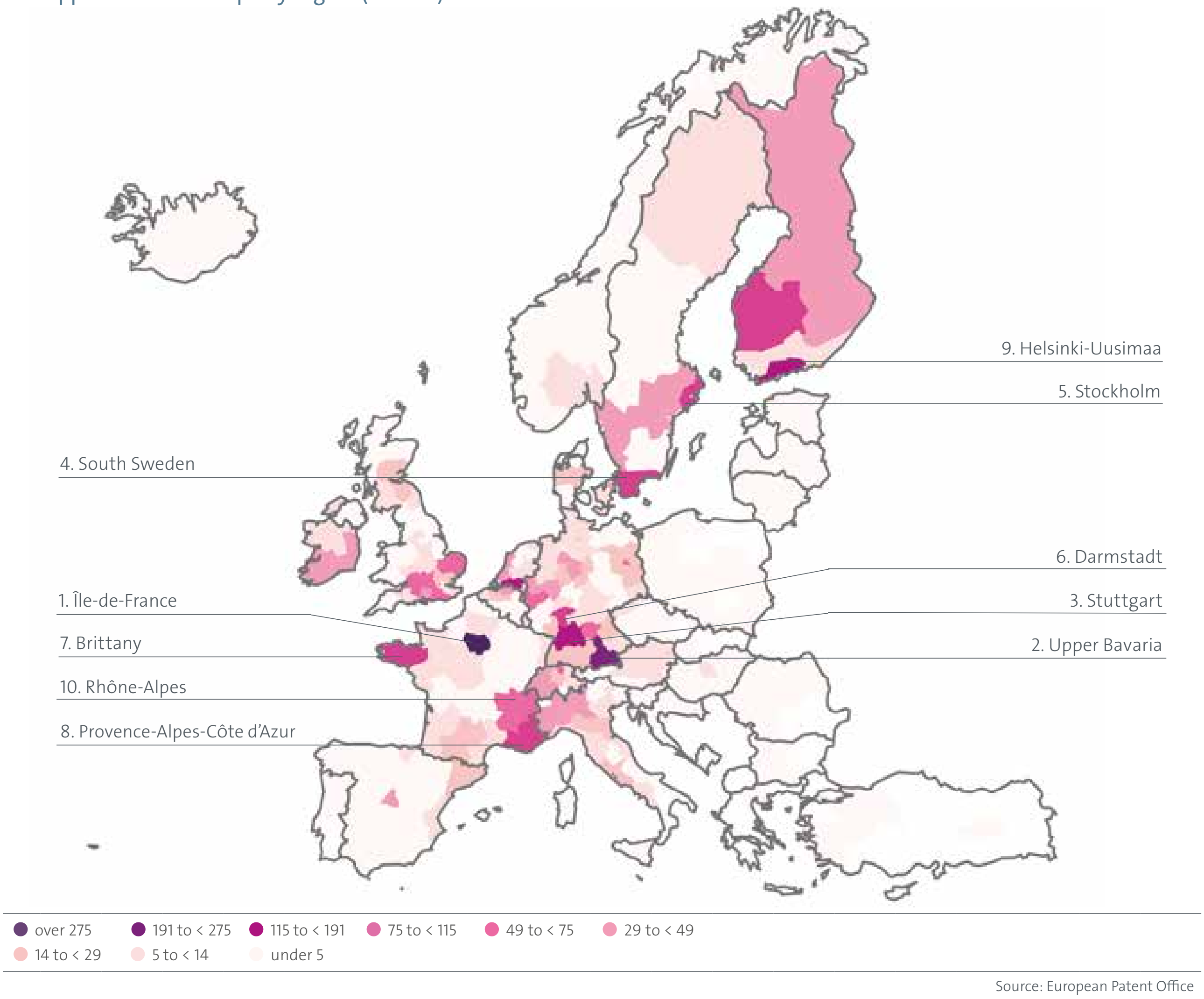
This section compares 4IR innovations in Europe's different regions[8] in 2011-2016. As can be seen in Figure 7.7, there is a very marked regional concentration of 4IR inventive activity.

The two leading European regions are Île-de-France in France and Upper Bavaria in southern Germany. Other major French and German innovation centres with a high number of 4IR inventions include Brittany, Provence-Alpes-Côte d'Azur and Rhône-Alpes in France and the area around Stuttgart and Darmstadt in Germany. In addition, important 4IR clusters can be found in other European countries, such as Stockholm and South Sweden in Sweden, and Helsinki-Uusimaa in Finland, or North Brabant in the Netherlands.

Most of the leading European regions are associated with top 4IR EPO applicants. Île de France and Provence-Alpes-Côte d'Azur host major innovative companies, including Technicolor and Gemalto. Siemens, BMW and many high-tech SMEs are located in Upper Bavaria, while Opel's International Technical Development Centre is based in Darmstadt. Likewise, the big applicants Philips, Ericsson and Nokia are reflected in the strong positions of North Brabant, Stockholm and South Sweden, and Helsinki-Uusimaa, respectively, in 4IR technologies.

Figure 7.7

4IR applications in Europe by region (NUTS 2) 2011-2016



Source: European Patent Office

8 The regions are defined according to the NUTS 2 classification (Nomenclature of territorial units for statistics).

An analysis of the regions' shares by 4IR fields (Figure 7.8) reveals that Île-de- France is the leading European region in ten of the sixteen 4IR fields. However, it is especially dominant in enabling technologies such as *Artificial intelligence* (3.2%), *3D systems* (2.7%) or *Security* (2%). Upper Bavaria has a different profile. It particularly stands out for its contribution to *Vehicles* (2.5%), but is also well represented in a number of other core technologies (*Software, Connectivity*), enabling technologies (*Security, Position determination*) and application domain fields (*Manufacture, Infrastructure*).

Innovative activities in other French and German regions reinforce the comparative advantages of their respective countries. Besides Île-de-France, the regions of Brittany, Provence-Alpes-Côte d'Azur and Rhône-Alpes produce a significant proportion of the patent applications for *Security, Artificial intelligence* or *User interfaces*. In Germany, the regions of Stuttgart and Darmstadt have leading positions in *Vehicles* and, in the case of Darmstadt, *Artificial intelligence* and *3D systems*.

Among the other leading regions in 4IR innovation, the regions of South Sweden and Stockholm stand out in core fields of *Hardware, Software* and Connectivity, and in enabling technologies related to *Power supply* and *Position determination*. In Finland, the region of Helsinki-Uusimaa stands out in the field of *Power Supply*.

Figure 7.8

4IR technology profiles of top 10 European regions 2011-2016 (in %)

Île-de-France	FR10	0.8	1.2	1.8	1.1	1.8	1.7	0.9	1.1	2.7	3.2	0.7	0.8	2.0	0.9	1.3	1.3
Upper Bavaria	DE21	0.7	0.6	2.5	0.6	1.0	1.2	0.7	0.9	0.4	0.2	1.2	0.4	1.6	0.4	0.8	1.0
Stuttgart	DE11	0.1	0.3	1.3	0.3	0.6	0.7	0.5	0.1	0.0		0.6	0.2	0.3	0.2	0.6	0.6
South Sweden	SE22	0.5	0.6	0.2	0.5	0.4	0.3	0.5	0.5	0.5		0.5	1.2	0.8	1.1	1.0	0.8
Stockholm	SE11	0.2	0.3	0.3	0.3	0.1	0.2	0.3	0.2		0.6	1.3	0.9	0.9	0.5	0.4	0.9
Darmstadt	DE71	0.3	0.3	1.2	0.3	0.3	0.4	0.7	0.2	1.1	1.9	0.7	0.3	0.5	0.2	0.6	0.6
Brittany	FR52	0.6	0,6	0.2	0.5	0.2	0.4	0.7	1.2	0.9	0.6	0.2	0.4	0.6	0.5	0.7	0.6
Provence-Alpes-Côte d'Azur	FR82	0.2	0.3	0.3	0.3	0.4	0.5	0.6	0.0		0.9	0.2	0.2	2.3	0.1	0.8	1.0
Helsinki-Uusimaa	FI1B	0.4	0.3	0.2	0.4	0.4	0.4	0.6	0.1		0.4	0.5	1.3	0.6	0.6	0.5	0.7
Rhône-Alpes	FR71	0.2	0.6	0.3	0.3	0.8	0.8	0.3	1.1		1.1	0.4	0.4	0.3	0.3	0.2	0.3

Source: European Patent Office

Conclusion

The statistical analyses presented in this study highlight the rapid rise in the number of patent applications in 4IR technologies in recent years. In 2016, more than 3% of all applications filed at the EPO combined the features of computing, connectivity, smart objects and data exchange that define 4IR inventions. They are a clear sign of the considerable potential of connected objects operating autonomously.

Although such patent applications have been filed since the mid-1990s, the real growth started just over ten years ago, and has been accelerating ever since. Seen in all 4IR technology fields, this growth is expected to continue in the coming years. It is characterised by the increasing integration of different core and enabling technologies into application domains.

Application domains and core technology fields have attracted the most patent applications so far. The most active application domains have been *Personal* and *Enterprise*, followed by *Vehicles* and *Home*. Among core fields, the largest number of patent applications is related to *Connectivity*. By contrast, there are lower numbers of patent applications in the enabling technology fields. However, some of them, such as *3D systems*, *Artificial intelligence* and *User interfaces*, have experienced a very fast growth in recent years.

The increase in patent applications is largely driven by a limited number of applicants. In the most recent period (2011-2016), a group of 25 applicants accounted for 48% of all 4IR applications filed at the EPO. This top 25 is dominated by companies specialising in information and communication technologies (ICT), the majority of them located in Asia. Core technologies exhibit the highest level of concentration, with 54% of patent applications filed by the top 25 4IR applicants. This is also the sector where Asian ICT companies have the strongest positions. The "enabling technologies" and " application domains" sectors are less concentrated, with 48% of enabling technology inventions and 41% of application domain inventions originating from the top 25 applicants. Furthermore, the top applicants in these two sectors operate in a larger variety of industries.

Europe, the USA and Japan have been the main innovation centres for 4IR technologies since the mid-1990s. The top European, US and Japanese applicants include large companies from different industry sectors (ICT, car industry, aeronautics, medical technologies and machinery) with strong patenting positions in application domains and enabling technology fields. By contrast, 4IR innovation did not start until after 2000 in Korea, and even later in China. However, it has been increasing at a very fast rate since then. 4IR innovation in these two countries is highly concentrated on a few ICT companies. In Korea, more than 90% of 4IR applications come from Samsung and LG, both of which have developed strong patent positions in many different technology fields. Nearly 70% of Chinese patent applications originate from two companies, Huawei and ZTE, whose main patenting activity is in core technologies of 4IR.

Germany and France are the most important European innovation centres for 4IR technologies. Germany has been in the lead since the late 1990s. It is particularly strong in the application domains of *Vehicles*, *Infrastructure* and *Manufacture*, whereas France's technology specialisation profile is focused more on enabling technologies such as *Artificial intelligence*, *Security*, *User interfaces* and *3D systems*. Other European countries, such as the Benelux countries, the Nordic countries and the Netherlands, also show activity in these fields.

The distribution of 4IR innovative activities in Europe is subject to a marked regional concentration. Of the top 10 EU regions for 4IR innovations, three are in Germany and four in France, including the first (greater Paris area) and second (greater Munich area) most innovative regions. Other regions stand out due to the local presence of national industry champions (Nokia in Finland, Philips in the Netherlands, Ericsson in Sweden and ABB in Switzerland, for example), which explains the good performance of these countries in 4IR innovation.

These results show that new applications of the IoT are about to penetrate a large number of sectors in the European economy, thereby accelerating the Fourth Industrial Revolution in Europe. These technologies open up new ways of creating economic value through data and software. Interconnected objects will autonomously process increasingly complex information, making it possible to automate entire business operations. Computer-implemented inventions are becoming the main driver of 4IR innovation in this context.

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Annex

Annex

Figure 1

Concordance table between CPC field ranges and 4IR technology fields

Sector	CPC Codes
Personal	A61H31/005
	D06M7/00-D06M23/18
	D06N7/00-D06N7/0097
	D06P7/00-D06P7/005
	D06Q1/00-D06Q1/14
	G09B1/00-G09B29/14
	G10H1/00-G10H3/26
	H04M1/00-H04M1/82
Personal, Home	F16M11/18
Personal, Home, Hardware	H04N21/40 -H04N21/4888
Personal, Vehicles, Position determination	G01S19/00-G01S19/55
Personal, Enterprise	G06F19/10-G06F19/26
	G06F19/28
	G06F19/30-G06F19/366
	G06F19/70-G06F19/708
	G06F19/709
	G07F17/00-G07F17/38
	H04N5/76-H04N5/956
Personal, Enterprise, Manufacture, Analytics, User interfaces, 3D systems, Position determination, Hardware, Software, Connectivity	A61B34/32-A61B34/37
Personal, Enterprise, Analytics	H04N17/00-H04N17/06
Personal, Enterprise, Analytics, Artificial intelligence, Hardware	A61B5/7264-A61B5/7267
Personal, Enterprise, Analytics, Connectivity	B01L2300/023
	B01L3/502715
Personal, Enterprise, Hardware	G06F3/14-G06F3/153
	G09G1/00-G09G2380/16
Personal, Enterprise, Connectivity	A61B5/7465-A61B5/747
Personal, Analytics	A63B71/06-A63B71/0697
Personal, Analytics, User interfaces, Software	A63B24/00-A63B2024/0096
Personal, Analytics, Power supply, Connectivity	A61B8/4472
	A61B8/56-A61B8/565
	A61N2005/1041-A61N2005/1074
	A61N5/103-A61N5/1038
Personal, Analytics, Connectivity	A61B8/582
Personal, User interfaces	A61B34/25-A61B2034/258
Personal, User interfaces, 3D systems	A61B2090/364-A61B2090/368
Personal, User interfaces, Hardware, Software, Connectivity	A63F13/00-A63F13/98
Personal, User interfaces, Connectivity	A61M2205/35-A61M2205/3592
	A61M2205/50-A61M2205/52
	A61M2209/01
Personal, 3D systems	A61C13/0004
	A61C7/002
	A61F2002/30943-A61F2002/30963
	A61B34/10-A61B2034/108

Personal, Position determination	A61B34/00
	A61B34/20-A61B2034/2074
	A61H3/00-A61H3/061
Personal, Hardware	A61M2016/0015-A61M2016/0042
	A61B5/0002-A61B5/0031
	A61B5/14532
	A61B5/68-A61B5/6802
	A61B5/6887-A61B5/6898
	A63B2230/00-A63B2230/755
	G04G21/00-G04G21/08
	G10H2220/321- G10H2220/336
Personal, Hardware, Connectivity	A61N1/37211-A61N1/37288
Personal, Software	H04N19/00-H04N19/99
Personal, Software, Connectivity	A63C2203/22-A63C2203/24
Personal, Connectivity	A61B2017/00221
	A61B90/90-A61B90/98
	A61F5/0036-A61F5/0046
	A61F5/005-A61F5/0059
	A61H2201/501-A61H2201/5012
	A61H2201/5097
	A63B2225/20
	A63B2225/305
	A63B2225/50-A63B2225/54
	A63F2009/2411-A63F2009/2429
	A63F2250/64-A63F2250/645
	A63F2300/00-A63F2300/1093
	G10H2240/171-G10H2240/175
	G10H2240/305
Home	A01K15/02-A01K15/023
	A47L11/4011
	D06F33/02
	D06F39/006
Home, Vehicles	E05C17/58
Home, Vehicles, Enterprise, Security	E05B47/00-E05B2047/0013
Home, Vehicles, Manufacture, Hardware	B05B12/00-B05B12/149
Home, Vehicles, Connectivity	E05F15/77
Home, Enterprise	A47K5/1217
	E05B65/108
	G08B1/00-G08B31/00
Home, Enterprise, Manufacture	F24D19/10-F24D19/1096
	F25B49/00-F25B49/046
	F25D21/006
Home, Enterprise, Manufacture, Infrastructure, Analytics, Hardware	F22B35/00-F22B35/16
	F22B35/18
	F28F27/00-F28F27/02
Home, Enterprise, Manufacture, Infrastructure, Security	H04N7/18-H04N7/188
Home, Enterprise, Manufacture, Analytics, Artificial intelligence, Hardware	F23N5/00-F23N5/265
Home, Enterprise, Manufacture, Analytics, Hardware	F22D5/26-F22D5/36
Home, Enterprise, Manufacture, Analytics, Connectivity	F24F11/00-F24F11/085

Home, Enterprise, Manufacture, Security	F25D29/00-F25D29/008
Home, Enterprise, Security	E05B2035/009
	E05B2047/0089
	E05B49/00-E05B49/008
Home, Enterprise, Security, Connectivity	E05B2047/0071
	E05B2047/0095
Home, Enterprise, Hardware	G03G15/00-G03G15/5095
	G08B13/19656
	A47K2010/3226
Home, Analytics	D06F93/00-D06F93/005
Home, Security	A47G29/141-A47G2029/149
Home, Hardware	D06F39/005
Home, Connectivity	G07C9/00103-G07C9/00103
	G07C9/00166
	G07C9/00571
	H04L12/2803-H04L2012/285
Vehicles	B60D1/01-B60D1/075
	B60D1/24-B60D1/465
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	B60N2/0244-B60N2/0276
	B60N2/28-B60N2002/2896
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	B60Q2300/00-B60Q2300/47
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	B60S1/56-B60S1/606
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	B60S5/02
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	B60T13/66-B60T13/748
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	B60W50/00-B60W50/16
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	B60K37/06
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Vehicles, Position determination	F16H2059/666
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	G01S17/87-G01S17/875
	G01S17/93-G01S17/936
	G01S2013/936
	G01S7/003-G01S7/006
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Vehicles, Power supply	B60L11/1824-B60L11/185
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	B60T17/18-B60T17/228
	E05B77/00-E05B77/54
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	A01G7/045
	A01J5/007-A01J5/0075
	A01J5/017-A01J5/0175
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	C12N5/0062
	E04H6/422-E04H6/424
	G06Q10/06-G06Q10/067
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	G06Q20/00-G06Q20/425
	G06Q30/0207-G06Q30/0239
	G06Q50/02
	G06Q50/22
Enterprise, Manufacture, Infrastructure,	G06Q10/00-G06Q10/067
Enterprise, Analytics, Connectivity	A61B6/581
Enterprise, Power supply	A61B1/00029
Enterprise, Power supply, Connectivity	A61B6/56-A61B6/566
Enterprise, Hardware	A01J5/01
Enterprise, Connectivity	A61B1/00016
	A61B2560/0271
Enterprise	G06Q30/00-G06Q30/08
	G06Q40/00-G06Q40/128
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	E21B44/00-E21B44/10
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	G01S15/89-G01S15/8997
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	G05B23/02-G05B23/0297

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Manufacture, Analytics, Artificial intelligence, Hardware	F05D2270/00-F05D2270/71
Manufacture, Analytics, Security	F01D21/003
Manufacture, Analytics, Hardware	B05C11/10-B05C11/105
	F01B25/00-F01B25/26
	F01C20/00-F01C20/28
	F01N11/00-F01N11/007
	F02D1/00-F02D41/408
	F02K9/00-F02K9/978
	F02N11/08-F02N2011/0896
	F02N2200/00-F02N2200/14
	F02P5/00-F02P5/1558
	F03B15/00-F03B15/22
	F03D17/00
	F03D7/042-F03D7/048
	F04B49/06-F04B49/065
	F04B51/00
	F04C14/00-F04C14/28
	F04C28/00-F04C28/28
	F04D27/00-F04D27/0292
	F16N2230/00-F16N2230/22
	F24J2/40-F24J2/407
	F25J1/0244-F25J1/0256
Manufacture, Connectivity	B65D2203/10
Manufacture, Hardware	E21B47/12-E21B47/187
Infrastructure	B64F1/366-B64F1/368
	G06Q10/08-G06Q10/0875
	G06Q50/06
	G06Q50/30
Infrastructure, Analytics	F01K13/02-F01K13/025
	F02C9/00-F02C9/58
Infrastructure, Analytics, Hardware	F01D17/00-F01D21/20
Infrastructure, Hardware	H03K19/18
	H03K21/00-H03K21/10
Infrastructure, Connectivity	H02J13/0006 -H02J13/0089
	Y02B70/30-Y02B70/346
	Y02B90/20-Y02B90/2692
	Y02E40/70-Y02E40/76
	Y04S10/00-Y04S50/14
Analytics	G06K1/00-G06K2215/111
Analytics, Hardware	G05D23/19-G05D23/32
	G06F11/30-G06F 11/3495
	G06F9/46-G06F 9/548
User interfaces	G02B27/01-G02B2027/0198
3D systems	G06F17/50-G06F 17/5095
Artificial intelligence	G06N3/00-G06N99/007
Position determination	G01S11/00-G01S17/95
	G01S3/00-G01S5/30
	G01S5/02-G01S5/145

Position determination, Hardware	G01S1/00-G01S1/82
Power supply, Hardware	G06F1/32-G06F1/3296
	H03K19/0008-H03K19/0016
Power supply, Connectivity	H04W52/02-H04W52/0296
Security, Connectivity	G06F21/00-G06F21/88
	H04L63/00-H04L63/308
	H04L9/00-H04L9/38
	H04W12/00-H04W12/12
Hardware	B82Y10/00
	F16K99/0001-F16K99/003
	G06F1/20-G06F1/206
	G06F11/08-G06F 11/1096
	G06F12/00-G06F12/1491
	G06F17/40-G06F 17/40
	G06F3/00-G06F 3/05
	G06F3/0626
	G10L15/00-G10L15/34
	H03K19/003-H03K19/00338
	H03K19/177-H03K19/17796
	H04R1/00-H04R31/006
	H04S1/00-H04S7/40
Hardware, Software	G06F11/14-G06F 11/2097
	G06F9/00-G06F 2009/45595
Software	G06F17/30-G06F 17/30997
	G06F3/067-G06F 3/067
	G06F8/00-G06F 8/78
	G06F9/46-G06F9/548
Software, Connectivity	H04L67/00-H04L67/42
Connectivity	H04B7/26-H04B7/2696
	H04L61/00-H04L61/6095
	H04L69/00-H04L69/40
	H04M11/00 -H04M13/00
	H04W4/005-H04W4/26
	H04W72/04-H04W72/10
	H04W84/00-H04W84/22

*Codes with a - in between indicate a range

Figure 2

Patent applications in 4IR technologies at the EPO by inventor country

		1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
AE	United Arab Emirates											
AR	Argentina								1			
AT	Austria							1		1	4	2
AU	Australia	2	1		1	2	2	1		4	3	7
AW	Aruba											
BB	AW											
BE	Belgium				1			1	5	3	3	5
BG	Bulgaria											
BH	Bahrain										1	
BR	Brazil			1							1	
BS	Bahamas											
BY	Belarus										1	
CA	Canada			1	3	1	2	6	4	4	10	9
CH	Switzerland			2	7	1	1	3	4	9	13	13
CL	Chile											
CN	China, People's Republic of								1			
CO	Colombia											
CR	Costa Rica											
CY	Cyprus											
CZ	Czech Republik											
DE	Germany	2	2		5	10	13	17	27	40	58	99
DK	Denmark							2	3	2	3	5
EE	Estonia											
EG	Egypt											
ES	Spain	1	1			1		1	1	1	3	2
ET	Ethiopia											
FI	Finland	1	2	1	1	2	1	4	7	9	13	27
FR	France	4	6	17	13	6	13	7	23	31	46	54
GB	United Kingdom	3	15	11	19	17	22	15	31	56	57	60
GI	Gibraltar											
GR	Greece			1								
HK	Hong Kong					1			1		1	
HR	Croatia											
HU	Hungary							1				
IE	Ireland			1	1			1			1	5
IL	Israel		1	4	1	1	2	2	3	4	10	15
IN	India											1
IR	Iran											
IS	Iceland											1
IT	Italy	3	3		2		6	7	2	4	3	13
JO	Jordan											
JP	Japan	28	36	48	53	60	76	88	109	140	169	236
KH	Cambodia											
KR	Republic of Korea				1	1	4	1	3	3	5	5
KY	Cayman Islands											
KZ	Kazakhstan											
LI	Liechtenstein											
LT	Lithuania											
LU	Luxembourg										1	
LV	Latvia											

2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	Grand Total
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					1				1							2
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																1
	2	1		1	1	1	3	2	3	1	4	1	3	4	2	29
							1									1
											1			1	1	4
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28	35	26	31	40	36	34	29	36	42	44	39	34	62	67	67	702
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		1									1					2
						1								1		2
		1								1		1	3		2	8
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131	150	171	153	159	180	192	185	205	227	249	254	315	370	339	417	3 970
10	9	5	10	7	8	10	27	13	11	17	29	20	35	42	31	297
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3	7	7	4	9	9	18	21	20	27	23	34	39	39	43	31	346
											1			1		2
35	41	34	54	41	35	38	42	30	45	45	38	49	98	94	95	883
57	59	66	80	76	80	86	104	130	122	126	164	216	265	281	282	2 414
83	91	69	65	89	81	68	95	102	121	88	109	133	118	121	136	1 875
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1				1		1										4
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401	405	419	441	464	523	546	489	470	518	568	608	601	776	891	892	10 055
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25	19	32	84	72	95	111	115	89	128	175	244	419	479	876	829	3 814
											1					1
											1					1
														1		1
													1	1	1	3
		2			1	1		1			2	3	3	4	4	22
												2				2

MC	Monaco											
MD	Moldova											
ML	Mali											1
MX	Mexico											
MY	Malaysia								1			
NL	Netherlands	2	4	11	1	6	1	5	10	14	16	28
NO	Norway									1	1	1
NZ	New Zealand									1	1	1
PA	Panama											
PE	Peru											
PH	Philippines											
PK	Pakistan											
PL	Poland											
PT	Portugal											
QA	Qatar											
RO	Romania											
RS	Serbia											
RU	Russian Federation									1	3	
SA	Saudia Arabia											
SE	Sweden			3	2	7	2	3	11	3	6	16
SG	Singapore					1	1			2	1	1
SI	Slovenia							1				
SK	Slovakia											
SU	Soviet Union				1							
TC	Turks and Caicos Islands											
TH	Thailand											
TR	Turkey											
TT	Trinidad and Tobago											
TW	Taiwan				1				1	1	1	4
UA	Ukraine											
US	United States of America	82	88	82	90	98	148	167	226	227	320	331
UY	Uruguay											
UZ	Uzbekistan											
VE	Venezuela, Bolivarian Republic of											
VN	Vietnam											
WS	Samoa											
YU	Yugoslavia/Serbia and Montenegro											
ZA	Zambia	1			2				1		1	

								1								1
						1										1
																1
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2	5			3	3	3	4	2	9	1		1		2		39

Published and edited by
European Patent Office
Munich
Germany

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4IR cartography
The cartography of the technologies of the Fourth Industrial Revolution was developed by Glenn Colvin, Norbert Wienold and Markus Arndt.

Case studies
Judy Ceulemans, Christoph Laub, Norbert Wienold (EPO)
Sven Jung, Cornelia Zoglauer (HRI)

Design and production
Graphic Design Munich (EPO)

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ISBN 978-3-89605-200-1