Europäisches Patentamt
European Patent Office
Office européen des brevets

Landscape study on patent filing

Quantum metrology and sensing

Abstract

This study conducted by the European Patent Office shows that the number of patent filings for second-generation quantum metrology and sensing devices is still small but has recently started to grow. It also reveals that a large proportion of the patent filings in this field come from academia, suggesting that researchers still account for most knowledge and exploitation of quantum physics.

Quantum technologies

Quantum technologies (QT) have the potential to disrupt classical know-how. As technologies that explore the laws of quantum physics, they are capable of addressing some of the biggest challenges facing today's digital era, such as secure communications, computing power and sensor accuracy. In the last 20 years, research in QT has made remarkable progress, enabling its implementation in cross-disciplinary fields of applied research, and consequently its industrialisation. It is predicted that QT will enter major industries in three to ten years, depending on their type.[1,2,3]

QT can be divided into four different domains: quantum communication, quantum simulation, quantum computing and quantum metrology and sensing. Quantum communication uses single entangled photons to transmit data securely. Quantum simulation uses controlled quantum systems to replicate and test models of less-accessible quantum systems. Quantum computing exploits quantum effects in order to increase computational power. Quantum metrology and sensing use the properties of coherent quantum systems and their interactions with the environment.[4]

The four domains are set to disrupt industry with higher-volume and more secure data transfer, increased computational power, greater energy efficiency and improved sensor accuracy. Most importantly, QT will address the limitations of existing, classical approaches. QT will not replace current, viable technology but instead address challenges which classical approaches cannot.[1,5]

European institutions and national governments have begun strategically investing in the four domains. Recently, various authorities have announced large research incentives in the QT field that highlight the importance of collaboration between universities and businesses. This vast strategic investment is to enable major scientific breakthroughs and to facilitate the arrival on the market of the second generation of quantum applications.[3,6]

This study analyses the current landscape in patent applications related to second-generation (2G) quantum metrology and sensing. All references to quantum technology or QT mean the second generation, unless otherwise stated.

1 https://qt.eu/app/uploads/2018/04/93056_Quantum-Manifesto_WEB.pdf.

2 http://publications.jrc.ec.europa.eu/repository/bitstream/JRC101632/lbna28103enn.pdf.

3 Jonathan P. Dowling and Gerald J. Milburn, Quantum technology: the second quantum revolution. The Royal Society, 2003 https://royalsocietypublishing.org/doi/pdf/10.1098/rsta.2003.1227?origin=publication_detail.

4 https://iopscience.iop.org/article/10.1088/1367-2630/aad1ea.

5 https://www.gov.uk/government/publications/quantum-technologies-maximising-the-benefits-for-the-uk.

6 http://ec.europa.eu/transparency/regexpert/index.cfm?do=groupDetail.groupDetailDoc&id=34809&no=1.

Quantum metrology and sensing

The domain of quantum metrology and sensing aims to increase precision, efficiency and accuracy. Industry has identified the opportunity that this presents and is now pursuing the commercial development of corresponding technologies. First-generation quantum metrology devices, which exploit coherent quantum systems, are already on the market or expected to arrive soon (high technology-readiness level, or TRL). Second-generation quantum devices exploit phenomena such as quantum entanglement and superposition and are expected to enter the market later (low TRL).

Quantum-enhanced metrology and sensing devices will impact existing and new application areas, such as navigation, time, network synchronisation, civil engineering, materials and medical diagnosis. All quantum-enhanced technologies in sensing and metrology have potentially important applications where improvements of classical sensors have been well exploited.

In order to facilitate the investigation of the quantum metrology and sensing domain in more detail, we analyse five application sub-fields: gravitation, rotation and acceleration; time; magnetic fields; chemical detection; and imaging. The full commercial potential of QT in the field of metrology and sensing is not yet known because commercialisation is still at an early stage. However, specialists have indicated that they have the potential to infiltrate numerous industries with various applications and benefits. For instance, optical atomic clocks can improve time (frequency) standards, which can be used in navigation systems (GPS), telecommunications (synchronisation) and the financial sector (time-stamping).[7]

Overall, second-generation quantum devices are expected to enter the market in the next two to ten years.

7 https://www.zeiss.com/content/dam/Corporate/innovation_and_technology/downloads/zeiss-symposium_whitepaper_qms_qei.pdf.

Aim of the study

QTs have been identified as future and emerging technologies which are expected to disrupt various industries. The economic gain from the adoption of QT in the mainstream is still to be estimated; however, they are certain to have a significant impact with society's increasing reliance on digital technologies and the importance of security and computing power.

The commercialisation of quantum metrology and sensing will depend on a successful transition from academic research to commercial applications. For this reason, governments and other authorities have recently announced strategic investments aimed at facilitating collaboration between research institutions and industry.

This study provides an up-to-date overview of the patent landscape in the domain of second-generation quantum metrology and sensing. It analysed EPO patent data with the support of patent data experts and EPO patent examiners. The search query for this study was tailored to retrieve only patent applications considered to relate to second-generation quantum technology.

Analysing patent data provides an indication of current technological trends and leading applicants, inventors and jurisdictions. This study therefore provides a unique insight into an emerging technology, enabling policymakers, industry and researchers to make informed, intelligence-based decisions.

Using patent information[8]

A patent grants its owner the exclusive rights to an invention. To be patentable, that invention must be technical, novel, inventive and capable of industrial applicability. Patents can be used to obtain investment. Patent applications are always published, making the technical details of the protected inventions available to the public.

In addition to granting high-quality patents, the EPO provides reliable, high-quality and up-to-date patent data in free-of-charge databases. For example, Espacenet – which is accessible at worldwide.espacenet.com – has more than 100 million documents from over 100 countries and offers machine translation in 32 languages.

This study provides a unique analysis combining the EPO's patent data with patent information and patent examiner expertise in quantum metrology and sensing. The search strategy was developed taking into account the latest developments in the field – including the evolution of terminology, and patent classification schemes.[9] Keywords, synonyms and semantics – as well as the relevant dates (priority filing and publication dates) and the key players (inventors and applicants) are also elements of the strategy.

For the purposes of this study, the domain of quantum metrology and sensing was divided into five sub-fields in order to run targeted searches in niche technology areas.

8 https://www.sciencedirect.com/science/article/pii/S017221901630103X.

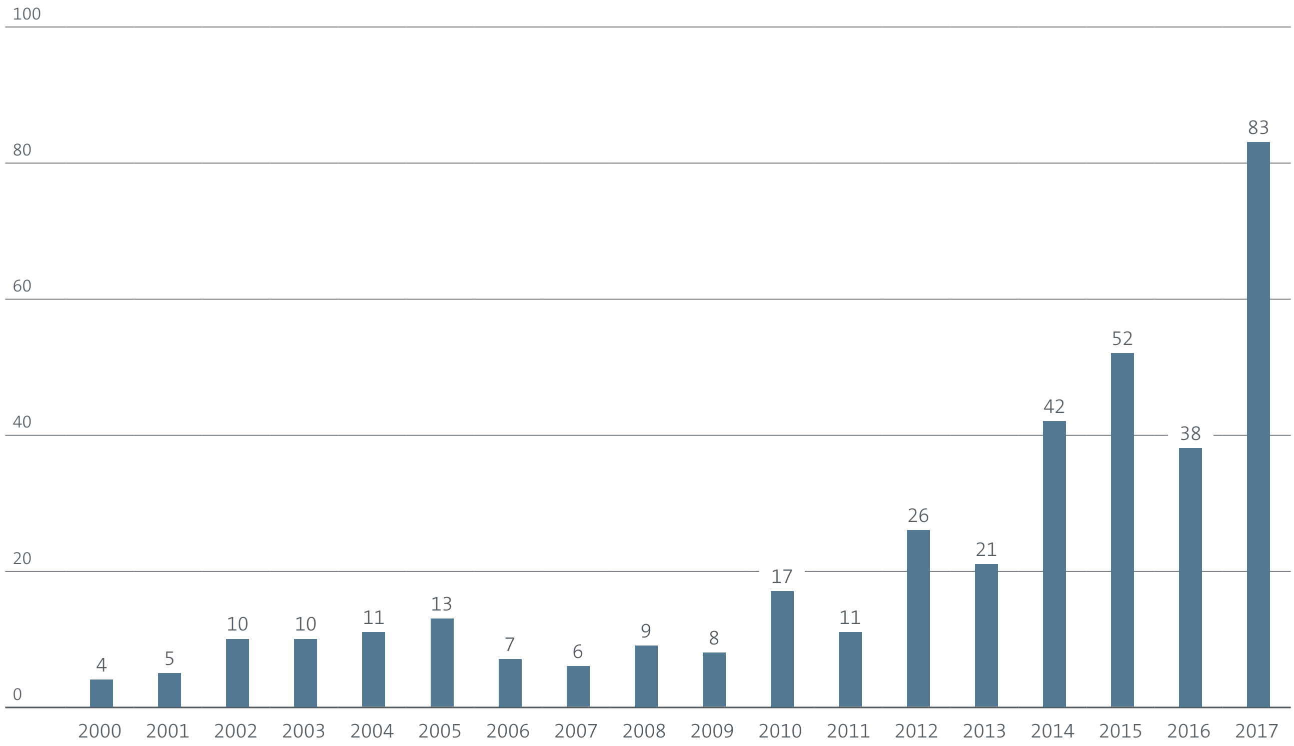
9 The International Patent Classification (IPC) and the Cooperative Patent Classification (CPC).

Results

A total of 445 patent families [10] were retrieved, covering quantum metrology and sensing devices from the year 2000 onwards (year in which a patent for the invention was first applied for).

1. Increase in patent filing worldwide

Number of patent families by first publication year



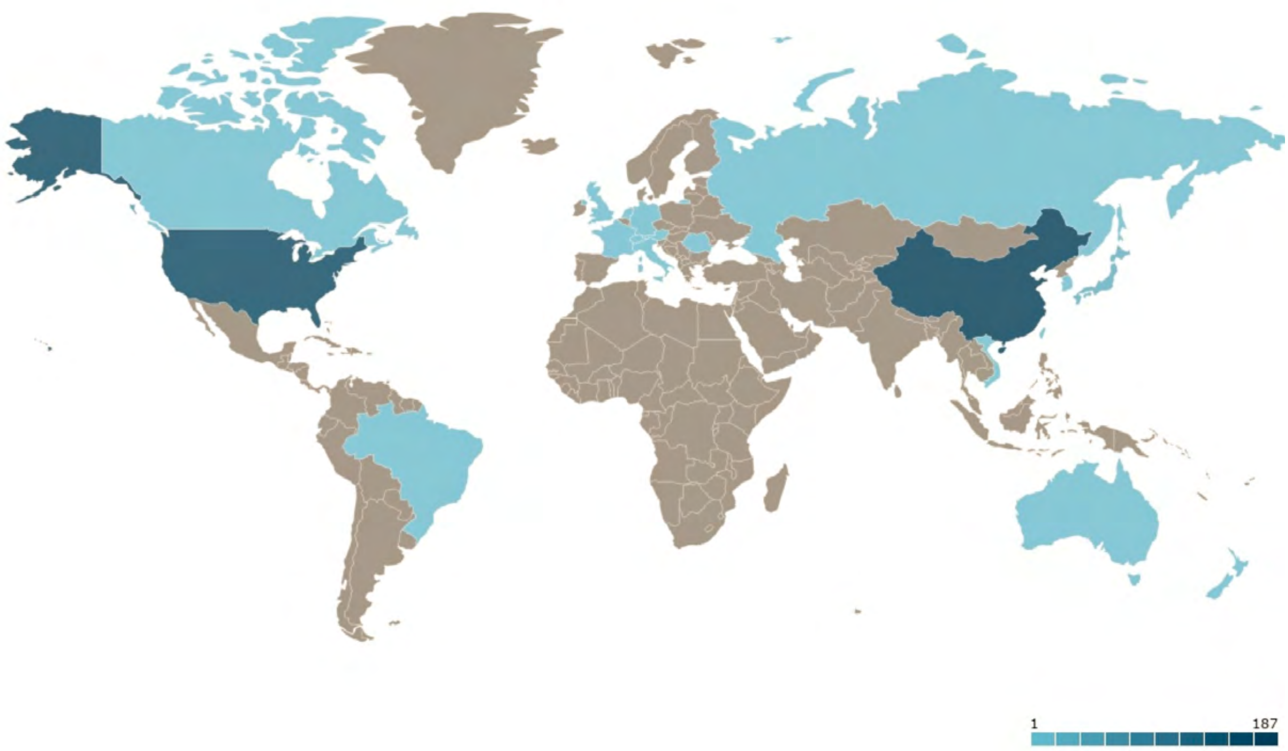
Comparing quantum metrology and sensing with other emerging technological fields, in the decade between 2000 and 2009 the number of patent applications was not very high, with an average of fewer than 10 applications per year. However, between 2010 and 2017 there was a noticeable increase in the number of patents applied for, with 290 applications filed worldwide in total.

The low patent filing figures overall may be a consequence of the strong links between applications of quantum metrology and sensing and basic research and the fact that the technology is still at an early stage of development.

10 A patent family is a set of interrelated patent applications filed in one or more countries and intended to protect the same or a similar invention by a common inventor. Each family is linked by a common priority or priorities.

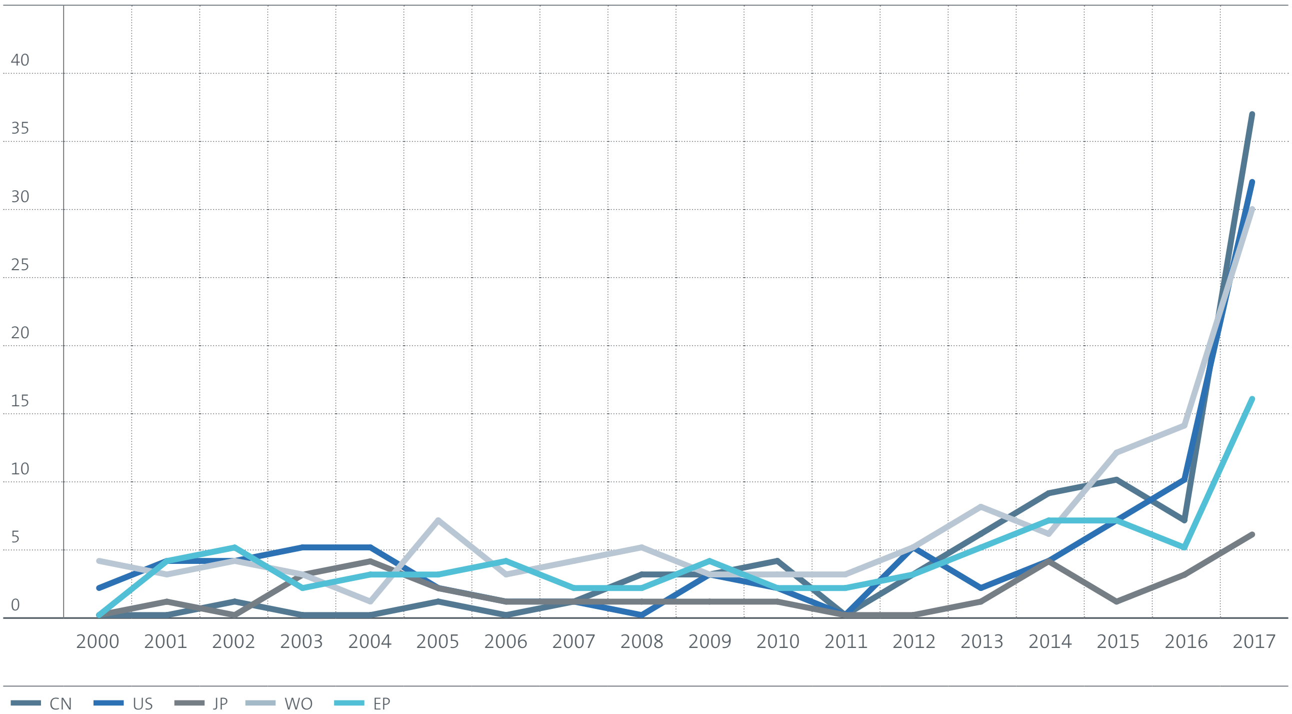
2. Most patent filings originate in China and the US

Number of priority filings per jurisdiction cumulative to 2017 (excluding European patent and PCT applications)



The country where the first patent application for an invention is filed (known as the “priority filing”) is frequently the country of origin of the invention. Thus, data on priority filings provides us with information on inventions’ geographical origins. In the field of quantum metrology and sensing, we observe that China and the US lead in terms of the number of priority filings.

Number of priority filings by jurisdiction and publication year (including European patent and PCT applications)

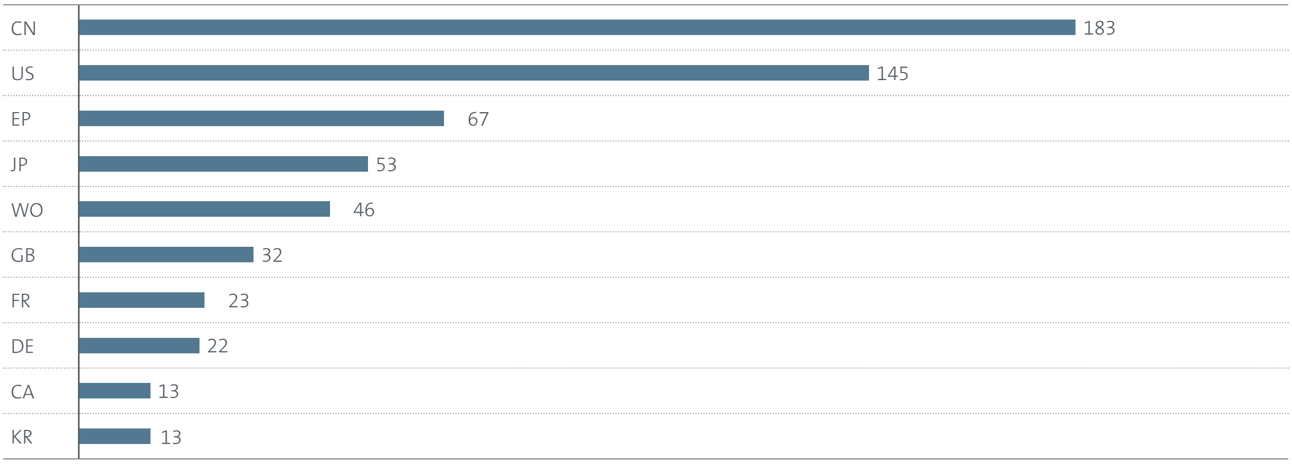


This breakdown of priority filings by jurisdiction and year shows too that, in quantum metrology and sensing, the overall number of patent families is small, yet it also shows that there has been a clear increase in patent filing in all jurisdictions.

Based on this chart – which includes European patent and PCT applications - a majority of applicants sought protection first in China (CN), followed by in the United States (US), via the PCT system (WO) and at the European Patent Office (EP).

3. China and the US are the most important markets

Number of patent filings per jurisdiction



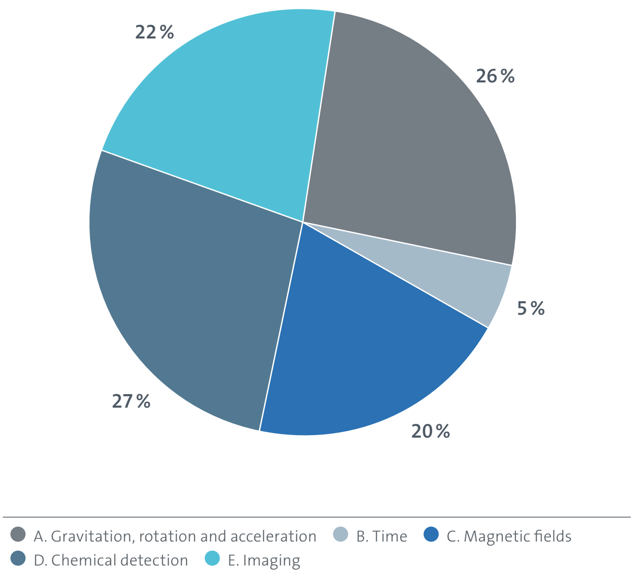
The chart above includes priority and subsequent patent filings for each jurisdiction. It thus provides an indication of the markets which applicants consider important.

The data shows that, in quantum metrology and sensing, the leading patent authorities are China (CN), the United States (US) and the European Patent Office (EP).[11]

4. Mostly equal distribution of patent families across the five sub-fields

The distribution of patent families over the five sub-fields analysed shows that each has a similar share of families with one exception: time. Patent family numbers are similar in gravitation, rotation and acceleration; magnetic fields; chemical detection; and imaging. Chemical detection has 121 patent families, followed by gravitation, rotation and acceleration with 116, then imaging with 97, magnetic fields with 90 and finally time measurement with 21.

Percentage of patent families per quantum metrology and sensing sub-field



11 At the European Patent Office, applicants can apply for a patent in several European jurisdictions in a single application. European patents have to be validated in each of those jurisdictions after grant.

5. Majority of applications are from research institutions

Top applicants from the top regions

Region	Applicant	Sector	Patent families
Asia	WUHAN INSTITUTE OF PHYSICS & MATHEMATICS, CHINESE ACADEMY OF SCIENCES	Research – government	14
Asia	HUAZHONG UNIVERSITY OF SCIENCE & TECHNOLOGY	University	8
Asia	SEIKO EPSON	Company – electronics	8
Asia	SHAOGUAN UNIVERSITY	University	7
Asia	UNIVERSITY OF SCIENCE & TECHNOLOGY OF CHINA	University	7
Europe	CARL ZEISS	Company – optics	8
Europe	OBSERVATOIRE DE PARIS	Research – government	6
Europe	CNRS - CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE	Research – government	6
Europe	ELEMENT SIX	Private company – optics	5
Europe	ONERA - OFFICE NATIONAL D'ETUDES & DE RECHERCHES AEROSPATIALES	Research – government	4
America	LOCKHEED MARTIN	Company – defence	55
America	HARVARD	University	11
America	CHARLES STARK DRAPER LABORATORY	Research – private	5
America	HONEYWELL INTERNATIONAL	Company – electronics	4
America	NATIONAL TECHNOLOGY & ENGINEERING SOLUTIONS OF SANDIA	Research – government	4

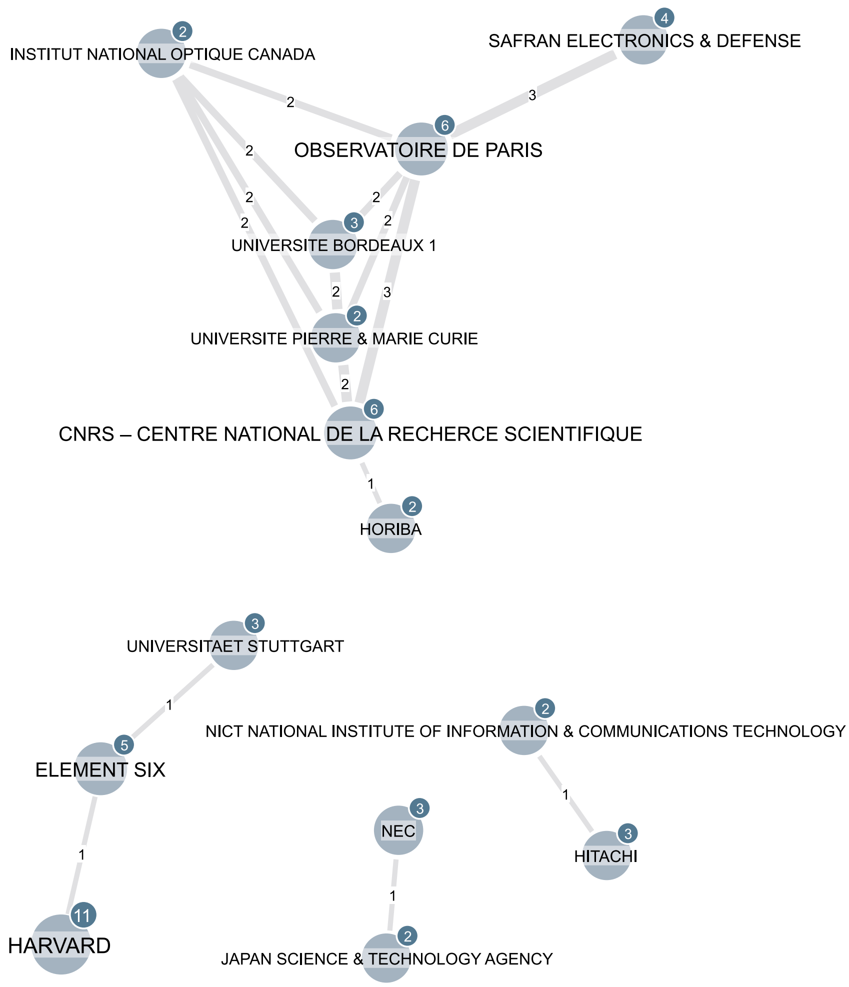
The analysis of the data by geographical region shows that the majority of patent applications related to quantum metrology and sensing are filed by applicants from Asia (majority from China), Europe (majority from France) and America. It is important to note the strong presence of research institutes in each of the geographical regions, which indicates that, for the majority of technical fields, there is no established industry leader.

In the research sector, applicants from China lead, accounting for around 50% of all patent families from research institutions across the three top regions (Asia, Europe and America). However, US applicants lead in terms of the total number of patent families; Lockheed Martin has a particularly high number. As for the top European applicants, the number of applications is evenly distributed between industry and public research institutes from Germany, France and the United Kingdom.

6. There is collaboration and influence between research and industry

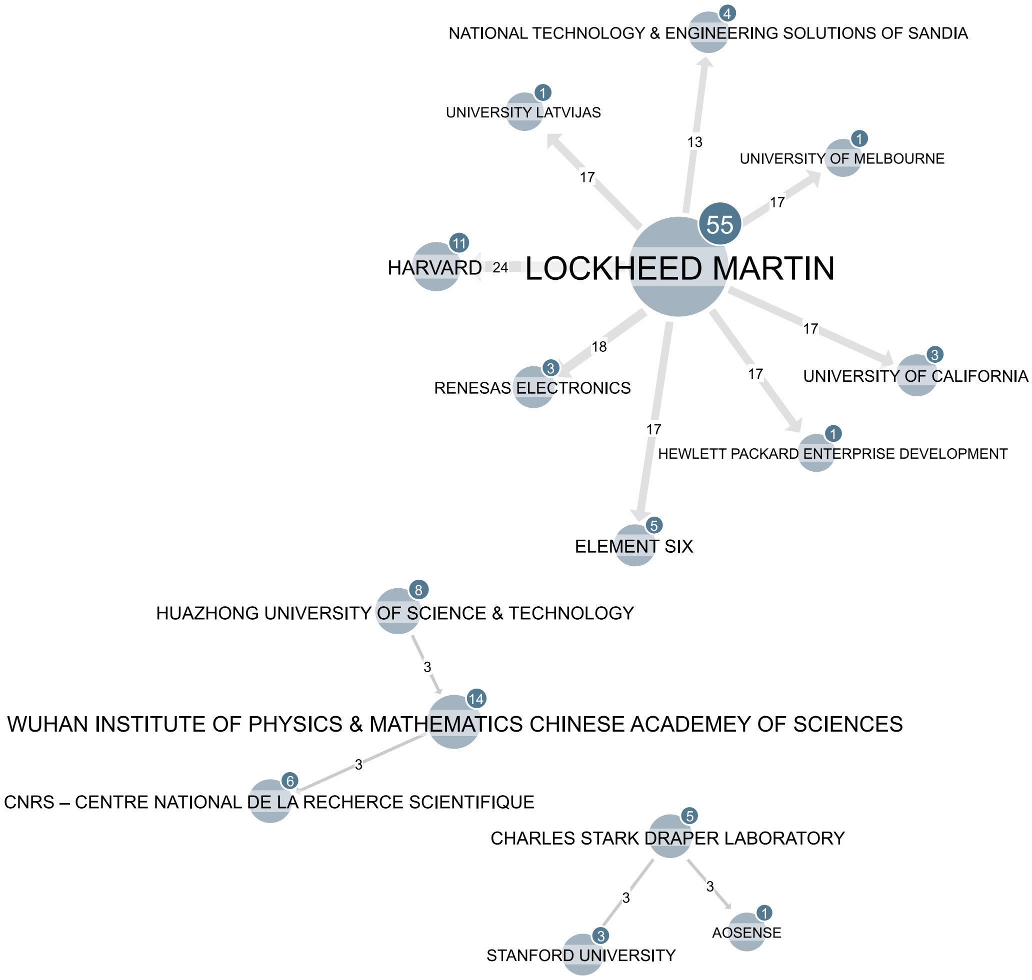
Network node maps that visualise the co-ownership of patents provide us with information on collaborations between companies and/or research centres. Some examples are given below.

Patent co-applications: who collaborates with whom?



The map at the top illustrates collaboration between several French research institutions, universities and a defence company (Safran) – including with the Quebec-based Canadian National Optics Institute.

The other three networks, although smaller, are nevertheless good examples of research-industry collaboration in patenting. The collaboration depicted in one of the smaller networks – between Harvard University (US), the UK company Element Six and the University of Stuttgart (DE) – is noteworthy because of its international dimension.



Similar to references in scientific publications, patent citations – by which in this study we mean only citations in patent examiners' search reports – typically refer to other, previously published patents. These cited patents can reveal which earlier publications have influenced the claimed invention. We have not taken into account any non-patent literature citations in this study.

Our analysis of patent citations illustrates the strong collaboration between research institutes and industry (nationally and internationally). For example, of Lockheed Martin's 55 patents, 17 cite patents from the University of Melbourne.

Conclusions

This study shows that, while patent filing numbers in quantum metrology and sensing are still low, the effect of public administrations' increasing interest in investing in and supporting the commercialisation of QT is a notable increase in patent applications in recent years. Increased investment suggests that this trend will continue.[1,2]

The fact that research institutes are the top patent applicants suggests that academia is currently the main driver of developments in quantum metrology and sensing. However, increased industry involvement can be expected in the near future.

This initial analysis of one domain of QT confirms too the need to create and facilitate synergies between research and industry.

Note on the limits of the study

This study makes best use of the EPO's publicly available data, search and analysis tools, as well as of other publicly available visualisation resources.

Like many patent analyses, it is based on a search query. That query is designed to optimise recall (i.e. to retrieve as many relevant documents as possible) and to optimise precision (i.e. to exclude as many non-relevant documents as possible). In reality, for a large dataset it is impossible to obtain 100% recall and 100% precision simultaneously. This affects which documents we found, as did the need to use a number of disparate classification codes in the search.

We set an arbitrary, but reasoned cut-off date for our analysis (Dowling and Milburn, 2003).[3] We considered that, before 2003, only first-generation QT patents were published, and after it both first- and second-generation ones were. Thus, the search query was tailored to exclude first-generation quantum metrology and sensing patents, and to include the second generation.

As experts are divided over some definitions of second-generation QT, we took a broad one.

As a result of the above parameters, "noise" in the dataset is inevitable and some relevant documents may have been missed. Nevertheless, we are confident in our methodology and assumptions.

Annex: The five sub-fields of quantum metrology and sensing

A. Gravitation, rotation and acceleration

Cold atom interferometry techniques are used, which allow atoms to interact with matter for a relatively long time. This enhances the sensitivity and accuracy of measurements, resulting in high-precision, drift-free gravitometry, gyrometry and accelerometry. Devices using such techniques can be used in civil engineering and inertial navigation systems and for natural-resource prospecting and exploration.

B. Time

This is one of the most developed sub-fields of QT; atomic clocks already use caesium fountain microwave standards. However, as precision requirements increase, new technologies are required. Currently being investigated are optical atomic clocks, which use light in the visible spectrum and provide superior time precision. They can be useful in the telecommunications and energy sectors for optimal network synchronisation.

C. Magnetic fields

Magnetometers which exploit nitrogen-vacancy (NV) centres in diamond are capable of measuring very small magnetic fields. Although superconducting quantum interference devices (SQUIDs) can obtain similar measurement accuracy, they require cryogenic cooling; NV centre magnetometers, by contrast, work at room temperature. They can be used to detect human brain activity.

D. Chemical detection

Techniques which exploit quantum effects in nanoscale semiconductor structures, such as quantum dots, are used. Devices making use of such techniques are potentially useful instruments for law enforcement – for example to detect illegal substances. Detectors for specific chemical entities are expected.

E. Imaging

Quantum-enhanced imaging techniques include ghost imaging, quantum multiphoton microscopy, quantum interferometry, quantum coherence tomography and NV microscopy. Devices exploiting such techniques can greatly increase imaging performance; harnessing two-photon entanglement can improve image resolution, for example.

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