Intellectual Property Office

Eight Great Technologies

Robotics and Autonomous Systems

A patent overview

#8Great

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June 2014

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1 Introduction

The UK Government has identified ‘eight great technologies’ which will propel the UK to future growth. These are:

- the big data revolution and energy-efficient computing;
- satellites and commercial applications of space;
- robotics and autonomous systems;
- life sciences, genomics and synthetic biology;
- regenerative medicine;
- agri-science;
- advanced materials and nanotechnology;
- energy and its storage.

Patent data can give a valuable insight into innovative activity, to the extent that it has been codified in patent applications, and the IPO Informatics team is producing a series of patent landscape reports looking at each of these technology spaces and the current level of UK patenting on the world stage. As an aid to help people understand the eight great technologies and to consider the direction of future funding, the IPO is offering a comprehensive overview of what is already patented in the each of these technologies and in which direction the technology is developing.

This report analyses the worldwide patent landscape for robotics and autonomous systems. For robotics, the focus is on control technology and novel aspects of robotics, such as emotion simulation and home robots, rather than conventional robotic manipulators per se. Autonomous systems includes automated vehicles of all types (passenger vehicles, aircraft, drones, and submarines, for example), and includes various degrees of automation, from driver aids in human-controlled passenger cars to fully self-driving cars. The dataset used for analysis was extracted from worldwide patent databases following detailed discussion and consultation with patent examiners from the Intellectual Property Office who are experts in the field and who, on a day-to-day basis, search, examine and grant patent applications relating to robotics and autonomous systems.

This report is based on analysis of published patent application data and not granted patent data. Data for published patent applications gives more information about technological activity than the figures for granted patents because a number of factors determine whether an application ever proceeds to grant. These include the inherent lag in patent processing at national IP offices worldwide and the patenting strategies of applicants who may file more applications than they ever intend to pursue.

2 Worldwide patent analysis

2.1 Overview

Table 1 gives a summary of the extracted and cleaned dataset used for this analysis of robotics and autonomous systems. All of the analysis undertaken in this report was performed on this dataset or a subset of this dataset. The worldwide dataset for robotics and autonomous systems published between 2003 and 2013 contains almost 120,000 published patents equating to more than 35,000 patent families. Publications may be at the application or grant stage, so are not necessarily granted patents. A patent family is one or more published patents originating from a single original (priority) application. Analysis by patent family more accurately reflects the number of inventions present because generally there is one invention per patent family, whereas analysis by raw number of patent publications inevitably involves double counting because one patent family may contain dozens of patent publications if the applicant files for the same invention in more than one country. Hence analysis by patent family gives more accurate results regarding the level of inventive activity taking place.

Table 1: Summary of worldwide patent dataset for robotics and autonomous systems

Number of patent families	35,151		
Number of patent publications	119,644		
Publication year range	2004-2013		
Peak publication year	2013		
Top applicant	Toyota (Japan)		
Field choices	**Field name**	**Number of entries**	**Coverage**
People	Inventors	47,382	99%
Applicants	Patent assignees	16,425	100%
Countries	Priority countries	47	100%
Technology	IPC sub-group	10,199	99%

Figure 1 shows the total number of published patents by publication year (top) and the total number of patent families by priority year (bottom – considered to be the best indication of when the original invention took place). By both measures there has been growth over the last ten years, with numbers of publications and families having approximately tripled over the period. A flatter period up until 2009-2010 was followed by further strong growth towards the end of the period. The patent family chart in red does not show any patents filed after 2011 because a patent is normally published 18 months after the priority date or the filing (application) date, whichever is earlier. Hence, the 2012 and 2013 data is incomplete and has been ignored.

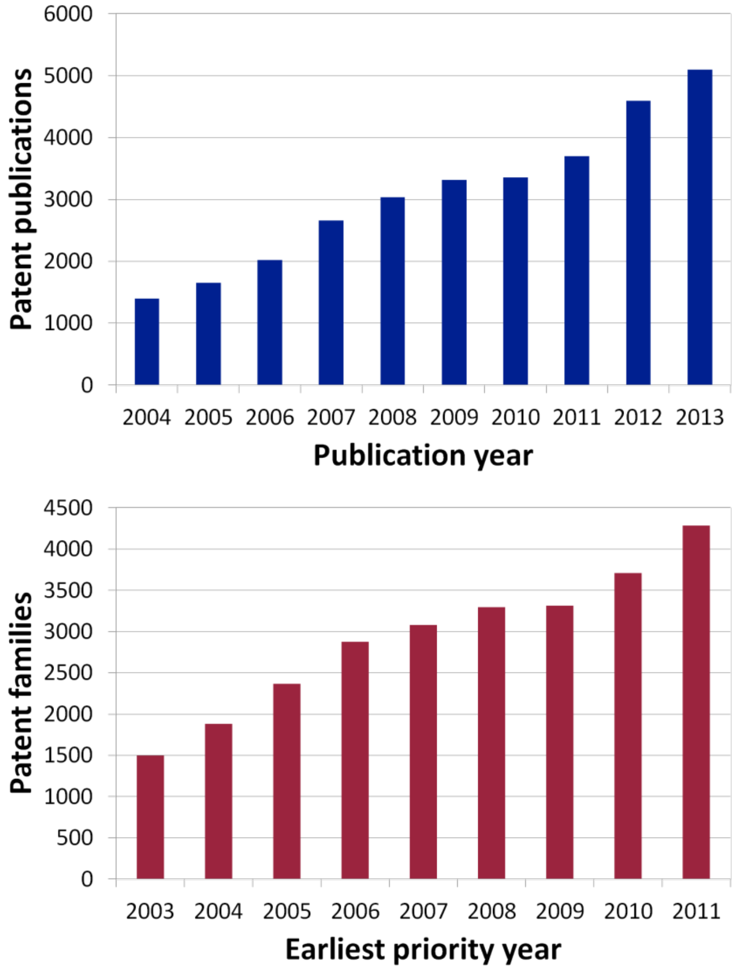

Figure 1: Patent publications by publication year (top) and patent families by priority year (bottom)

General patenting levels globally have continued to grow at an ever-increasing rate. Figure 2 shows the annual increase in the size of the worldwide patent databases across all technologies against the year-on-year change in the size of the robotics and autonomous systems dataset. For example, from 2011-2012 there was a 24% increase in robotics and autonomous systems publications, and 13% increase in publications overall. The growth in robotics and autonomous systems publications is well in excess of the overall growth in each year except 2009-2010, and demonstrates this growth is significant.

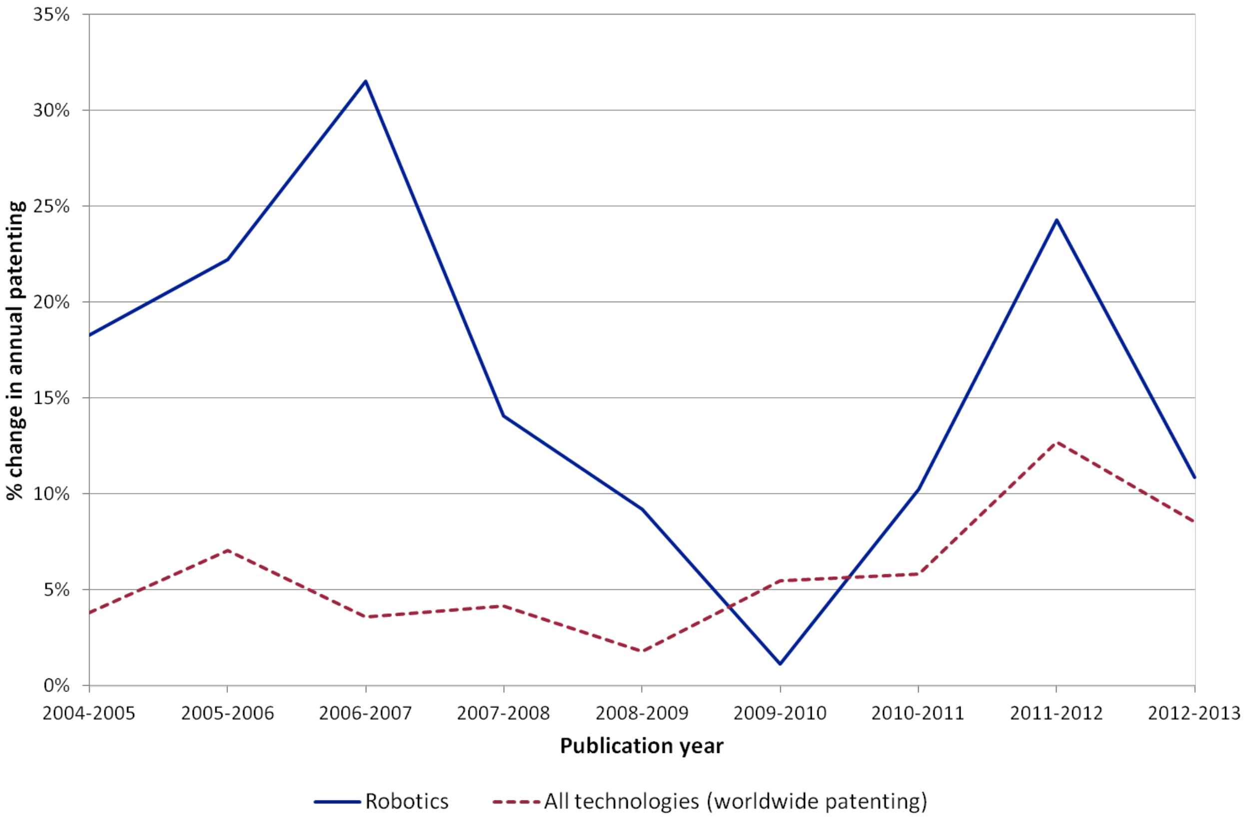

Figure 2: Year-on-year change in robotics and autonomous systems patenting compared to worldwide patenting across all technologies

Figure 3 shows the priority country distribution across the dataset. Japan leads with almost one third of robotics and autonomous systems patents first filed in Japan. 2% of robotics and autonomous systems patents are first filed in the UK. Traditionally priority country analysis has been a good indicator of where the invention is actually taking place because many applicants will file patent applications first in the country in which they reside[1], but in recent years drawing firm conclusions from this data is harder because there may be other strategic reasons for an applicant choosing the country of first filing (*e.g*. tax treatment).

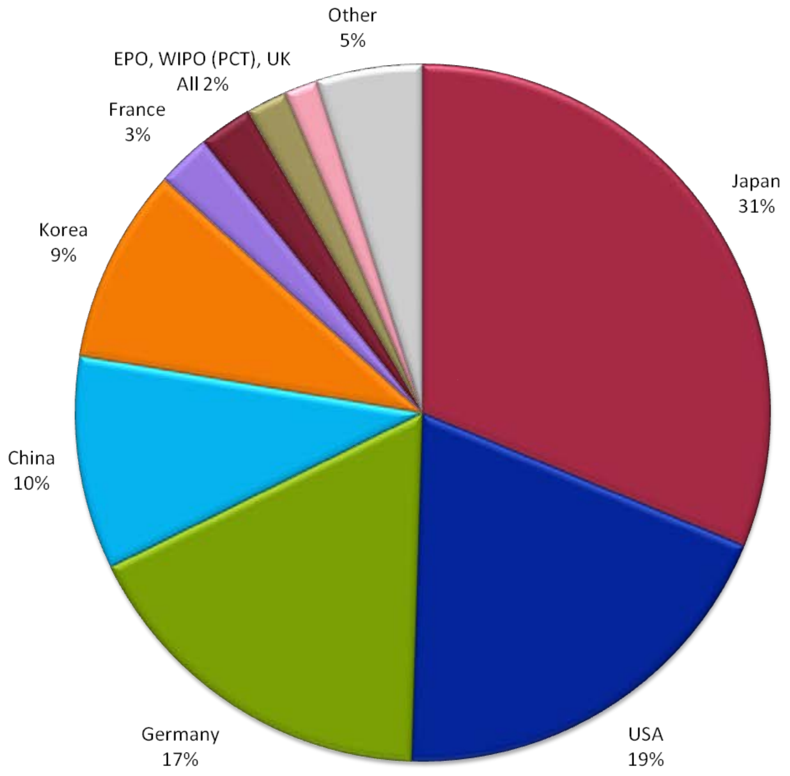

Figure 3: Priority country distribution

[1]In some countries this is/was a requirement (e.g. in the UK this was a requirement until 2005).

The applicant country distribution shown in Figure 4 approximately follows the priority country distribution shown in Figure 3, and so it appears that applicants generally do file first in the country where they reside in this case. Note that EPO and WIPO[2] may exist as priority countries but not as applicant countries.

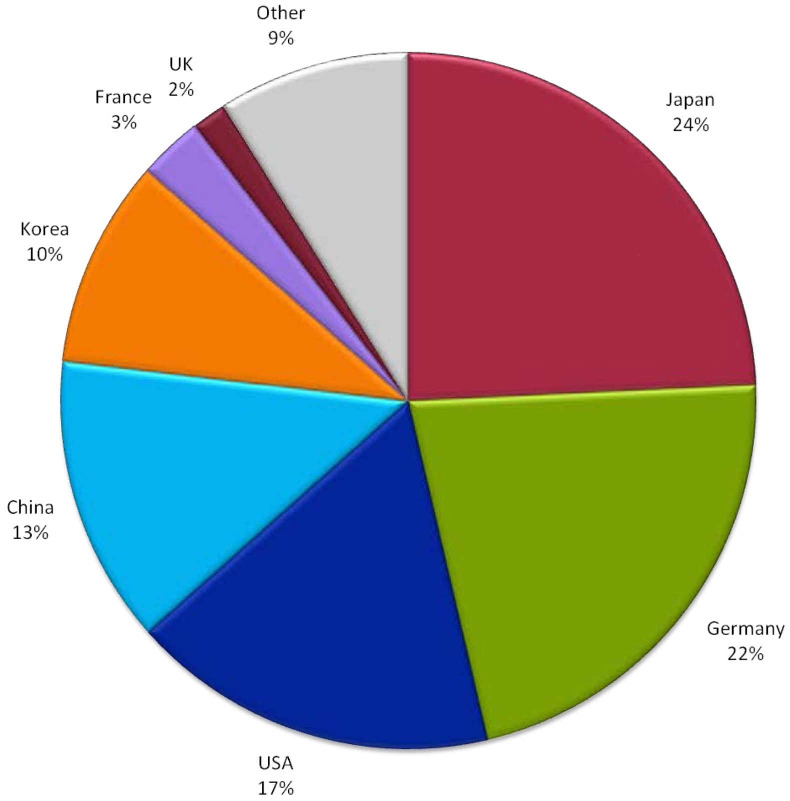

Figure 4: Applicant country distribution

[2] Alternative filing routes to single national patents, as outlined in Appendix A.3.

It is well known that there is a greater propensity to patent in certain countries than others, and the trends shown in Figure 4 may change if the figures are corrected for this difference in behaviour. A Relative Specialisation Index (RSI)[3] for each applicant country has been calculated to give an indication of the level of invention in robotics and autonomous systems for each country compared to the overall level of invention in that country, and is shown in Figure 5.

Figure 5 indicates that Japan, China, Germany, Sweden, and Korea all have a significant positive specialisation in robotics and autonomous systems, whilst Israel has a small but positive specialisation. The UK is amongst the remaining countries with a significant negative specialisation. This indicates that patent applicants based in the UK have a lower tendency to patent robotics and autonomous systems related inventions compared to other types of inventions in the UK.

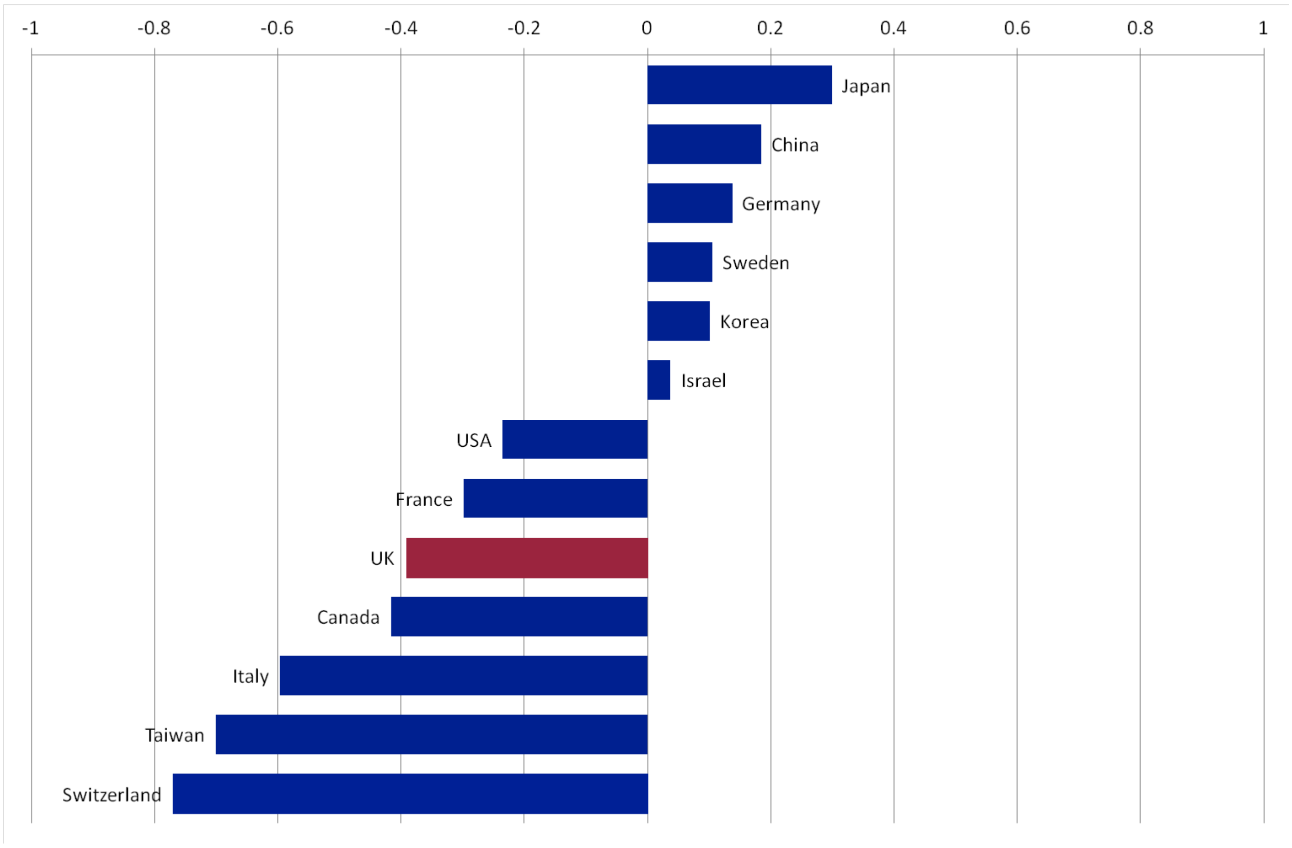

Figure 5: Relative Specialisation Index (RSI) by applicant country

[3] See Appendix B for full details of how the Relative Specialisation Index is calculated.

Figure 6 shows the countries in which applicants in the field of robotics and autonomous systems are interested in seeking patent protection, with the strength of colour reflecting the quantity of published patents in each jurisdiction. Patents filed via the EPO [] and WIPO (PCT) [WIPO] routes are also shown. Strong coverage is found in the USA. Even though Japan is the source of much innovation in robotics and autonomous systems, coverage of the USA is important for applicants wherever they are based because of the importance of the USA as a market. Coverage in China, Japan, Germany, and through the EPO and WIPO, are the next most significant. Direct coverage of the UK is lower but is only a partial picture because the majority of patents obtained via the EPO will cover the UK.

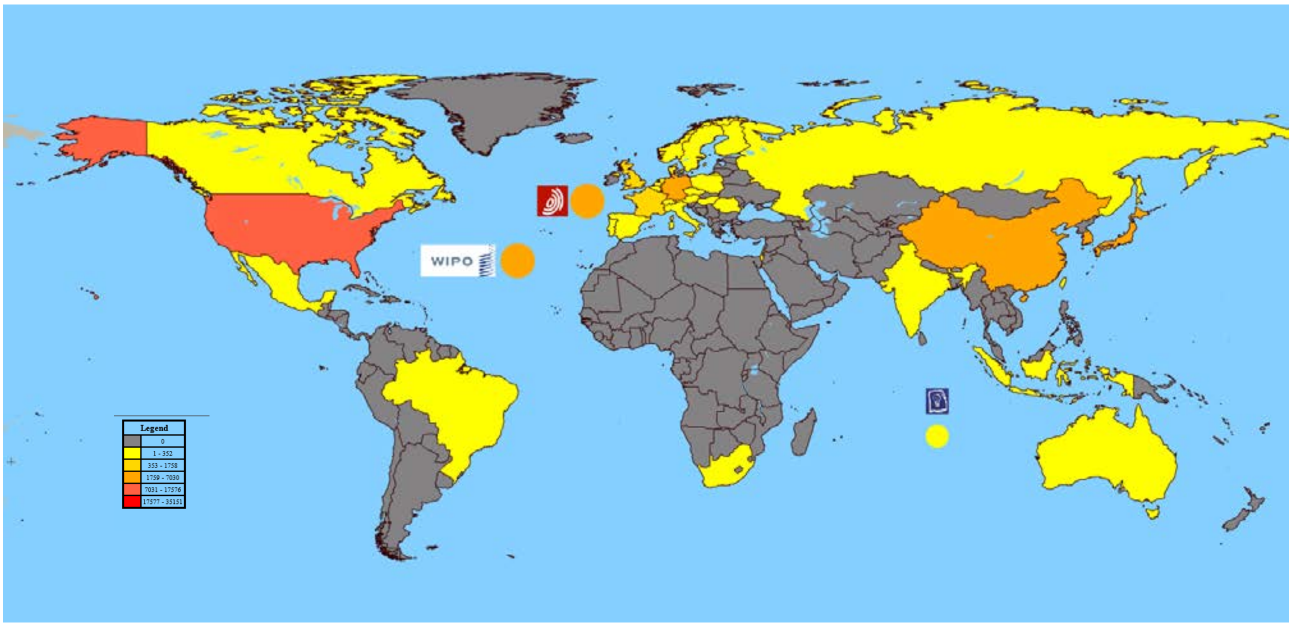

Figure 6: Patent coverage (publication country coverage)

2.2 Top applicants

Patent applicant names within the dataset were cleaned to remove duplicate entries arising from spelling errors, initialisation, international variation and equivalence[4]. Figure 7 shows the top 20 applicants in the robotics and autonomous systems dataset and selected other applicants.

Many of the leading applicants are automotive manufacturers, and are consequently large and well-established organisations. Japan and Germany are well represented in this list. Toyota leads by a large margin with 2346 patent families, Robert Bosch follows with 1326, and Nissan is third with 1190. Overall, around a third of the patent families have an automotive manufacturer named as an applicant. Manufacturers of other types of vehicles, such as trucks, buses, agricultural machinery, aircraft, and aerospace/defence, are also represented, albeit in smaller numbers. A selection of these is given in Figure 7, indicated in red.

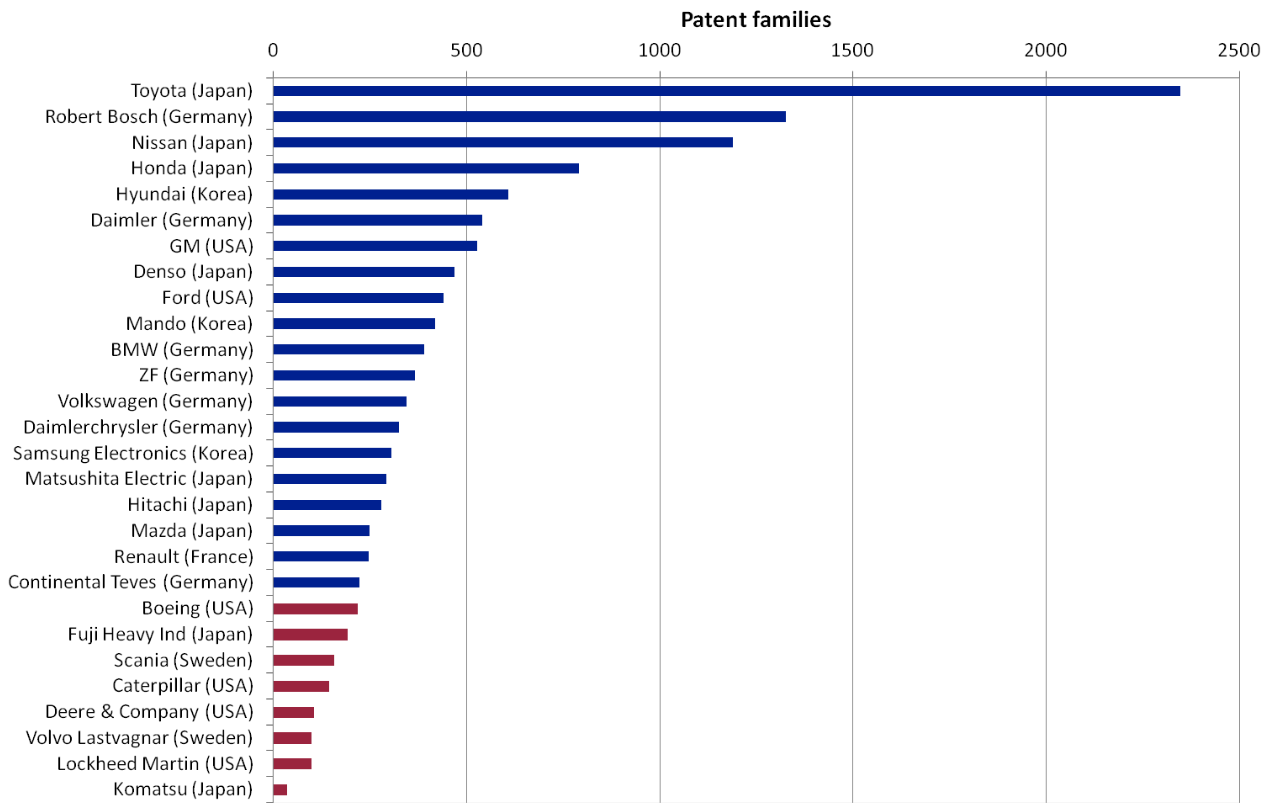

Figure 7: Top applicants (blue), and selected other applicants (red)

Google has attracted a lot of attention recently for its self-driving car but its patent portfolio is moderate, at 35 families. Most of its portfolio is very recent, with the majority of publications being in 2013, and with the earliest priorities being only in 2010. There is also clear and continuous growth in its portfolio over this short period and so further growth

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[4] See Appendix A.4 for further details

may be expected. Google has no collaborations with other organisations so its activity in autonomous vehicles appears to be entirely self-contained.

Figure 8 is a bubble map showing a timeline for the top 20 applicants and shows the filing activity of these applicants in the last 10 years. It shows that most of the top applicants have been involved in robotics and autonomous systems patenting throughout the period. Matsushita became inactive after 2007, and DaimlerChrysler appears to have transitioned into Daimler around 2006-2007. Hyundai had a spike of activity in 2010-2011, whereas Robert Bosch has grown steadily over the period. Toyota has been highly active throughout the entire period.

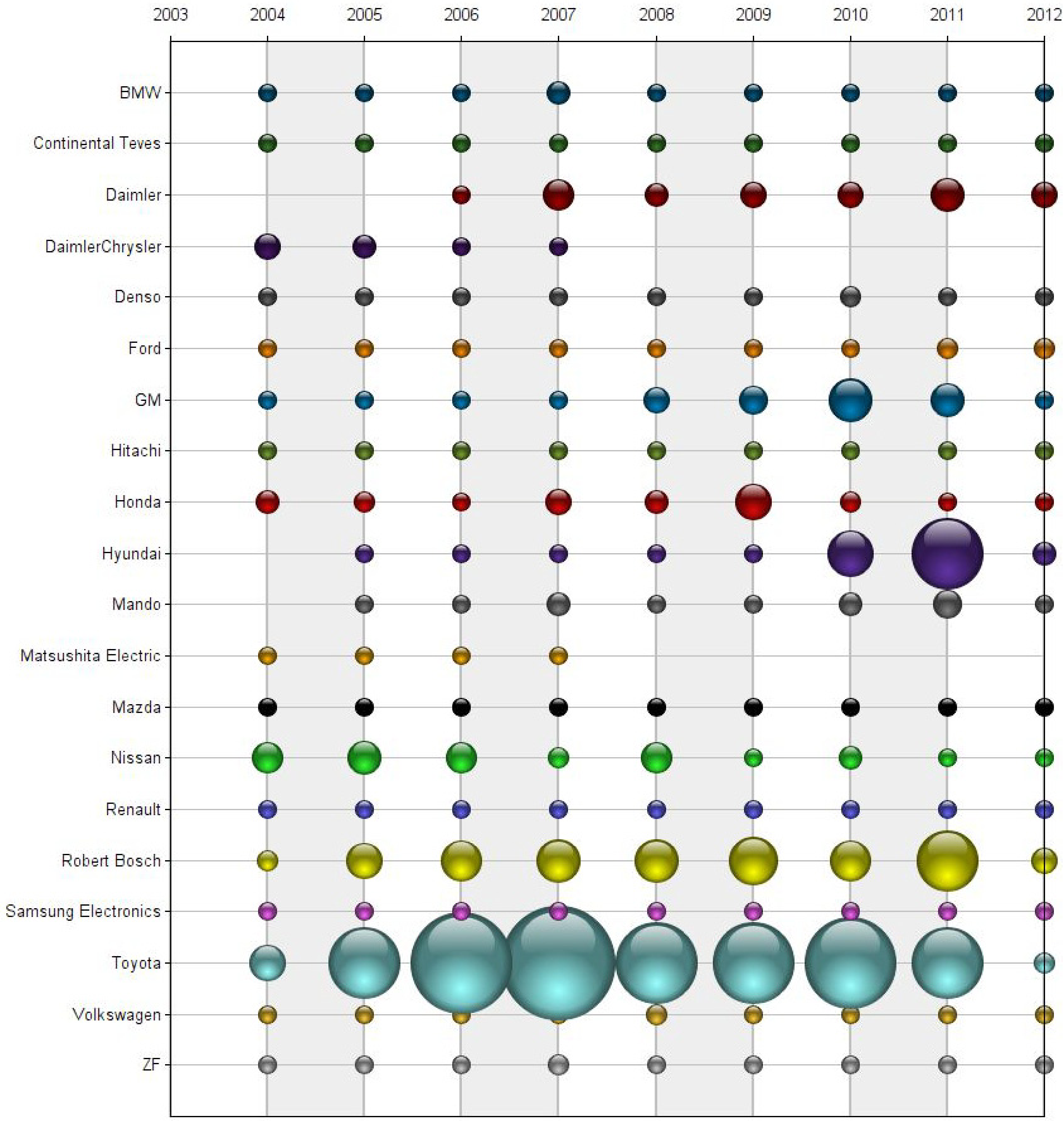

Figure 8: Applicant timeline of patent families by priority year

2.3 Collaboration

Figure 9 is a collaboration map showing main collaborations between the top ten applicants in the dataset (the top ten shown in Figure 7) and their collaborators. The collaborations form a network having a number of distinct clusters centred around the following major applicants:

- Hyundai with Kia
- Nissan
- GM, Chrysler, and Daimler, through Mando to BMW
- Audi, VW, Peugeot-Citroen, through Bosch to BMW
- BMW is then linked through Denso to a tight cluster of Toyota, Advics, Aisin Seiki, and other Japanese applicants

The top six applicants (Toyota Bosch, Nissan, Honda, Hyundai, Daimler) have no collaborations with each other, but automotive manufacturers do have indirect relationships with certain “enabling” organisations such as Bosch, Mando, and Denso, who each appear to be original equipment manufacturers (OEMs) to multiple automotive manufacturers. Honda stands out as it has no significant collaborators at all (and hence does not appear in Figure 9) and so is much more self-contained.

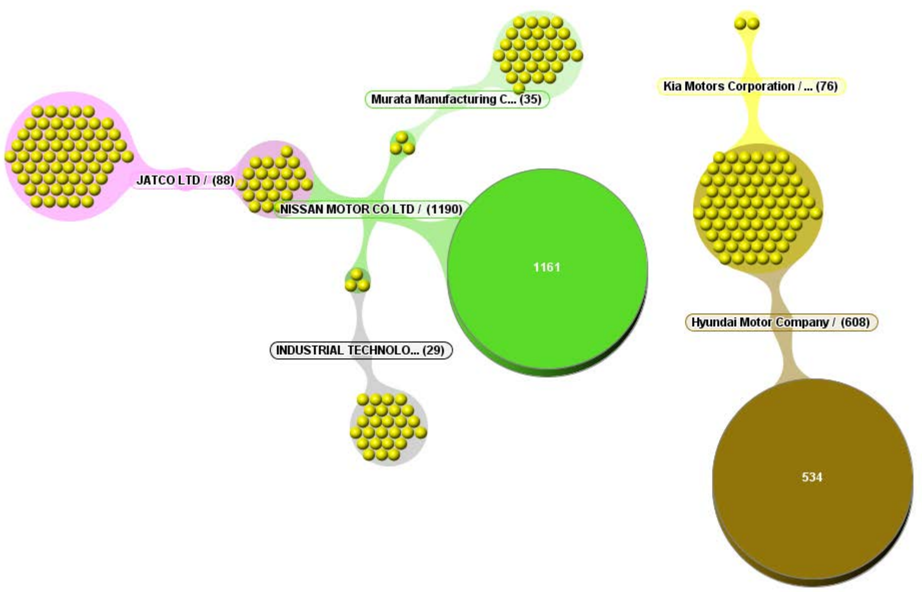

Figure 9 : Collaboration map showing collaborations of the top 10 applicants and their collaborators

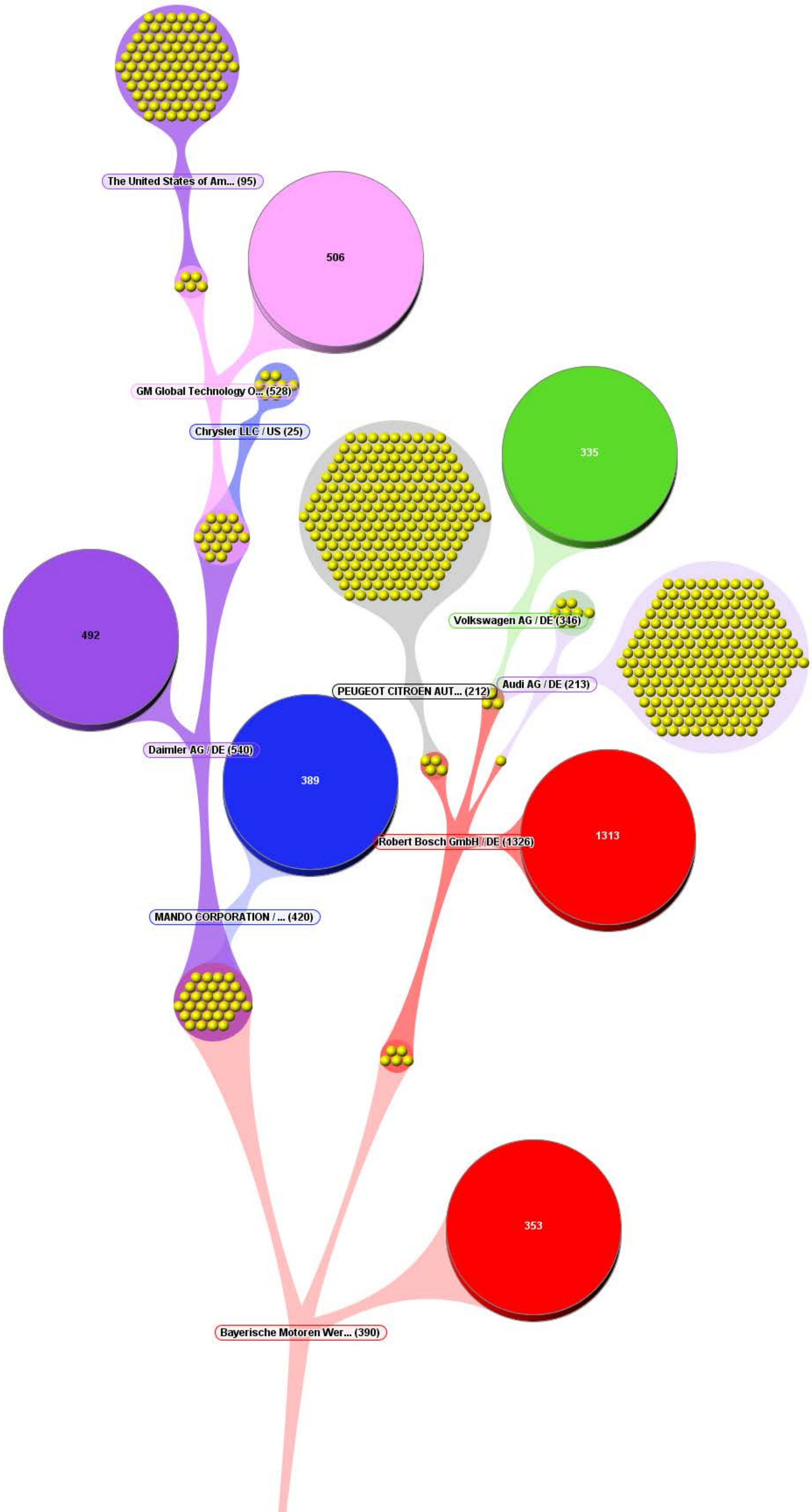

Figure 9 (cont.): Collaboration map showing collaborations of the top 10 applicants and their collaborators

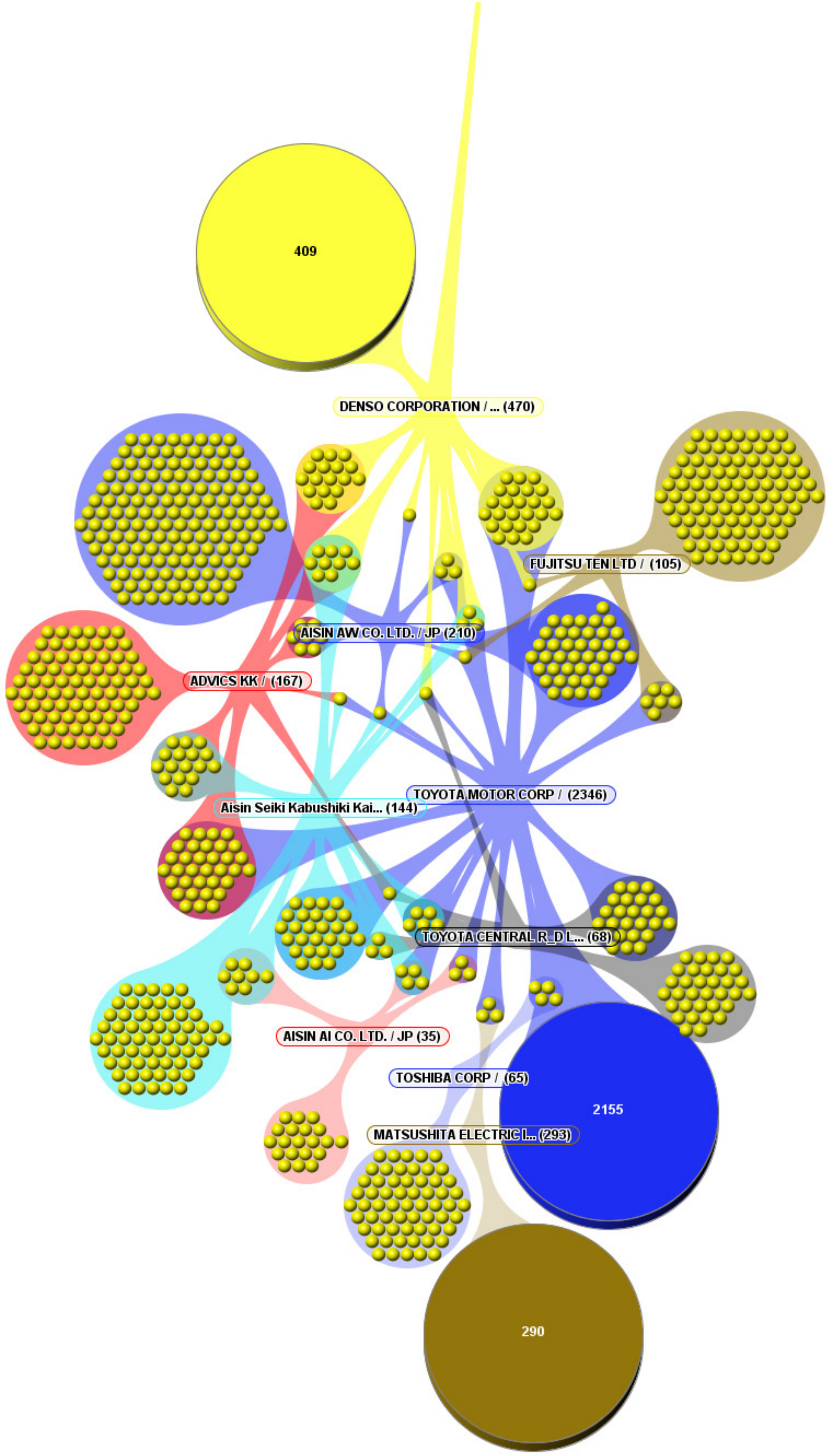

Figure 9 (cont.): Collaboration map showing collaborations of the top 10 applicants and their collaborators

Figure 10 shows collaborations for UK applicants and their collaborators. Most of the partnerships shown appear to reflect acquisitions or related companies within a group. The only genuine collaboration appears to that between BAE Systems and the University of Leicester.

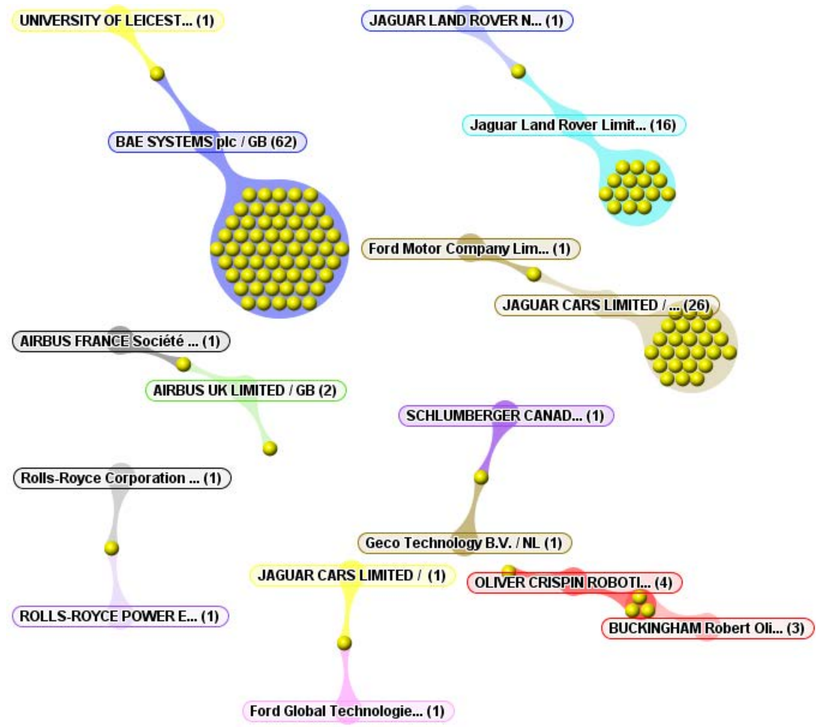

Figure 10 : Collaboration map showing collaborations of UK applicants and their collaborators

2.4 Technology breakdown

Figure 11 shows the top IPC subgroups, and Table 2 lists the description of each of these subgroups. It can be seen that many of these subgroups relate to navigation and control technologies for vehicles, or other aspects of autonomous vehicles. Other autonomous systems and robotics aspects form a much smaller part of the dataset.

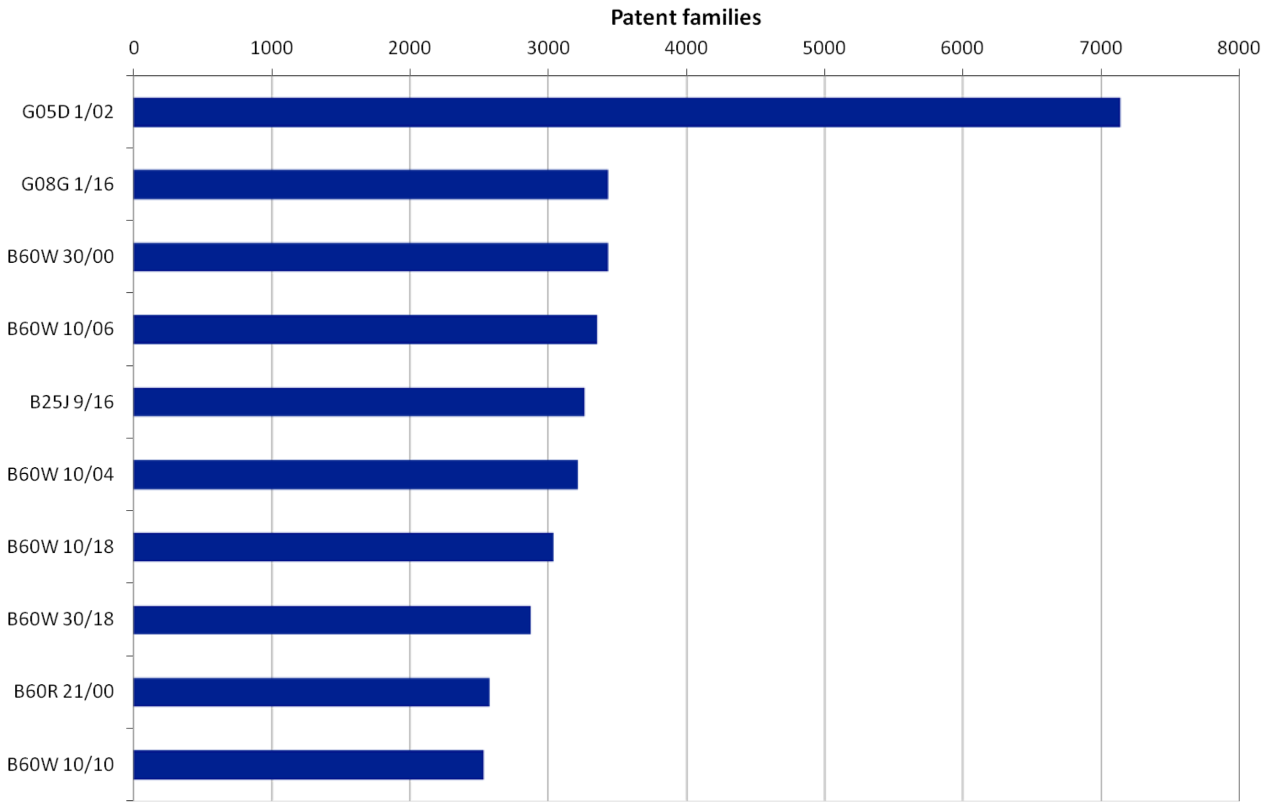

Figure 11: Top IPC sub-groups

Table 2: Key to IPC sub-groups referred to in Figure 11

G05D 1/02	Control of position, course or altitude of land, water, air, or space vehicles, e.g. automatic pilot: Control of position or course in two dimensions
G08G 1/16	Traffic control systems for road vehicles (arrangement of road signs or traffic signals: Anti-collision systems - road vehicle drive control systems for predicting or avoiding probable or impending collision otherwise than by control of a particular sub-unit
B60W 30/00	Purposes of road vehicle drive control systems not related to the control of a particular sub-unit, e.g. of systems using conjoint control of vehicle sub-units, { or advanced driver assistance systems for ensuring comfort, stability and safety or drive control systems for propelling or retarding the vehicle
B60W 10/06	Conjoint control of vehicle sub-units of different type or different function (for propulsion of purely electrically-propelled vehicles with power supplied within the vehicle: including control of propulsion units
B25J 9/16	Programme-controlled manipulators: Programme Controls
B60W 10/04	Conjoint control of vehicle sub-units of different type or different function for propulsion of purely electrically-propelled vehicles with power supplied within the vehicle: including control of propulsion units
B60W 10/18	Conjoint control of vehicle sub-units of different type or different function for propulsion of purely electrically-propelled vehicles with power supplied within the vehicle: including control of braking systems
B60W 30/18	Purposes of road vehicle drive control systems not related to the control of a particular sub-unit, e.g. of systems using conjoint control of vehicle sub-units: Propelling the vehicle
B60R 21/00	Arrangements or fittings on vehicles for protecting or preventing injuries to occupants or pedestrians in case of accidents or other traffic risks
B60W 10/10	Conjoint control of vehicle sub-units of different type or different function (...)(for propulsion of purely electrically-propelled vehicles with power supplied within the vehicle: including control of change-speed gearings

3 The UK landscape

3.1 Top UK applicants

Figure 12 shows the top UK-based applicants within the robotics and autonomous systems dataset. BAE Systems leads, but if the Jaguar and Land Rover companies were to be consolidated then their combined total families would be 76, placing them in the lead.

Most of the patents in the UK dataset are in the field of autonomous vehicles, including road vehicles, unmanned aerial vehicles, and unmanned underwater vehicles. Robotics companies in the UK dataset have very small portfolios, with the largest being Notetry (5 families), which is apparently a division of Dyson Ltd focussing on robotic vacuum cleaners. Other companies are Oliver Crispin Robotics Limited (industrial robotics), Absolute Robotics Limited (industrial robotics), Armstrong Healthcare Limited (robotics for surgeons), Isis Innovation Limited, QinetiQ Limited, and Rolls-Royce Plc.

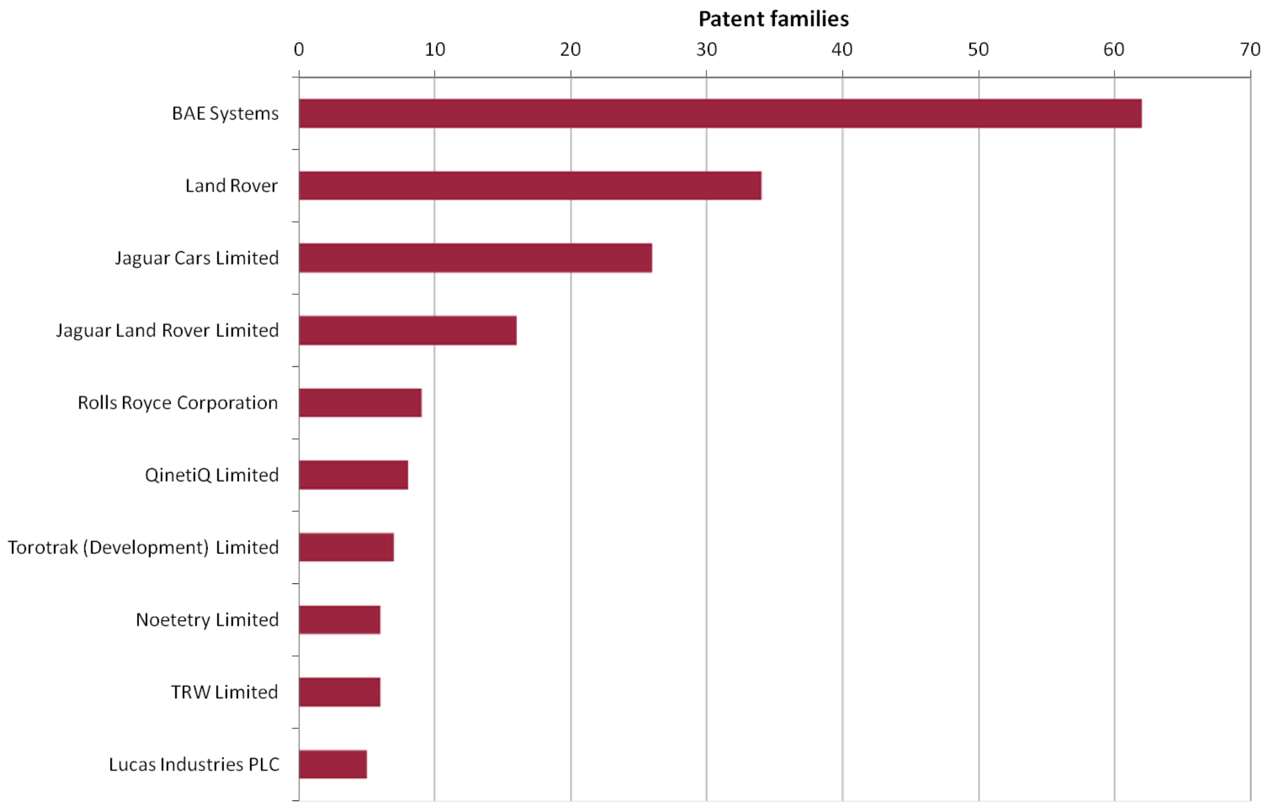

Figure 12: Top UK applicants

3.2 UK inventor mobility

Figure 13 shows the top worldwide applicants with named UK inventors on their published patents with several non-UK based firms appearing in this list.

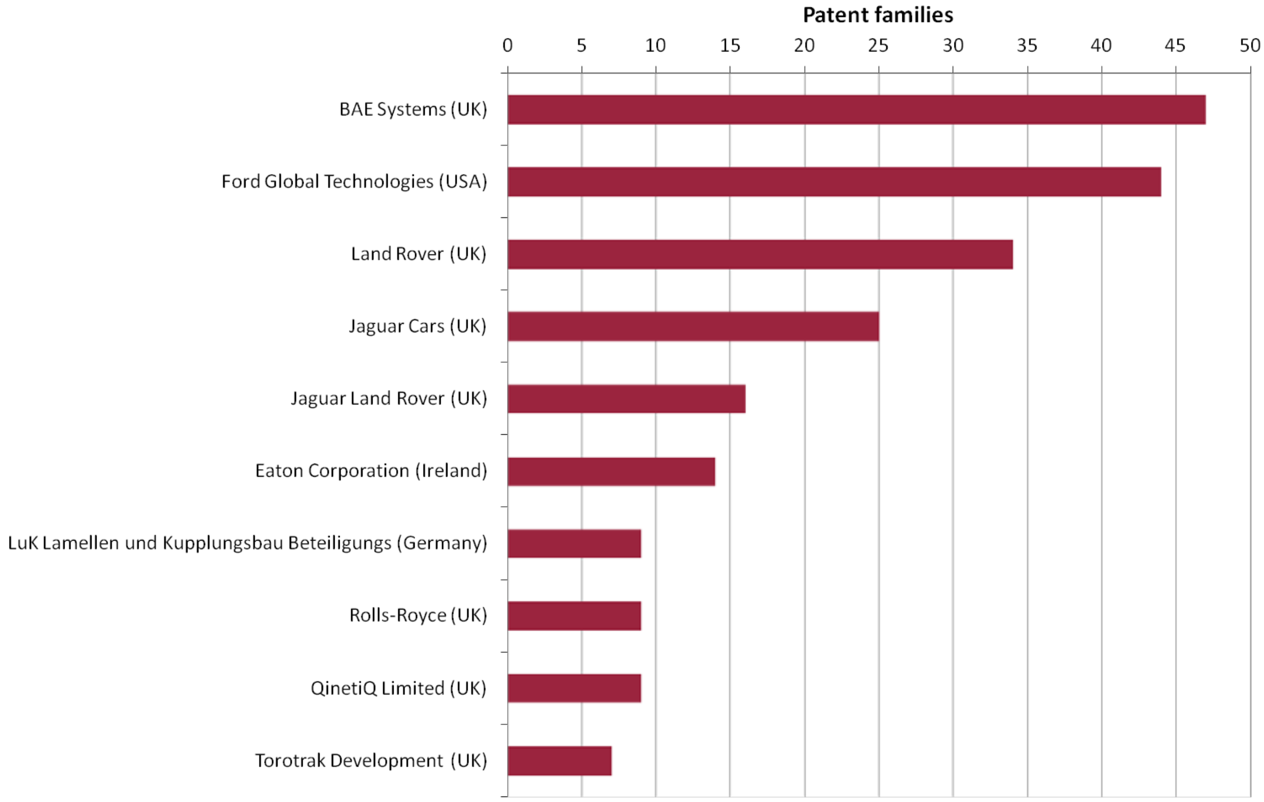

Figure 13: Top worldwide applicants with named UK-based inventors

3.3 How active is the UK?

A subset of the main worldwide dataset designed to reflect all UK patenting activity was selected. Figure 14 shows the year-on-year change in UK patenting activity against the worldwide year-on-year change in robotics and autonomous systems patenting shown in Figure 2; this shows that changes in UK patenting activity in robotics and autonomous systems have exceeded changes worldwide over the period 2007-2012, demonstrating that the industry is small but growing in the UK.

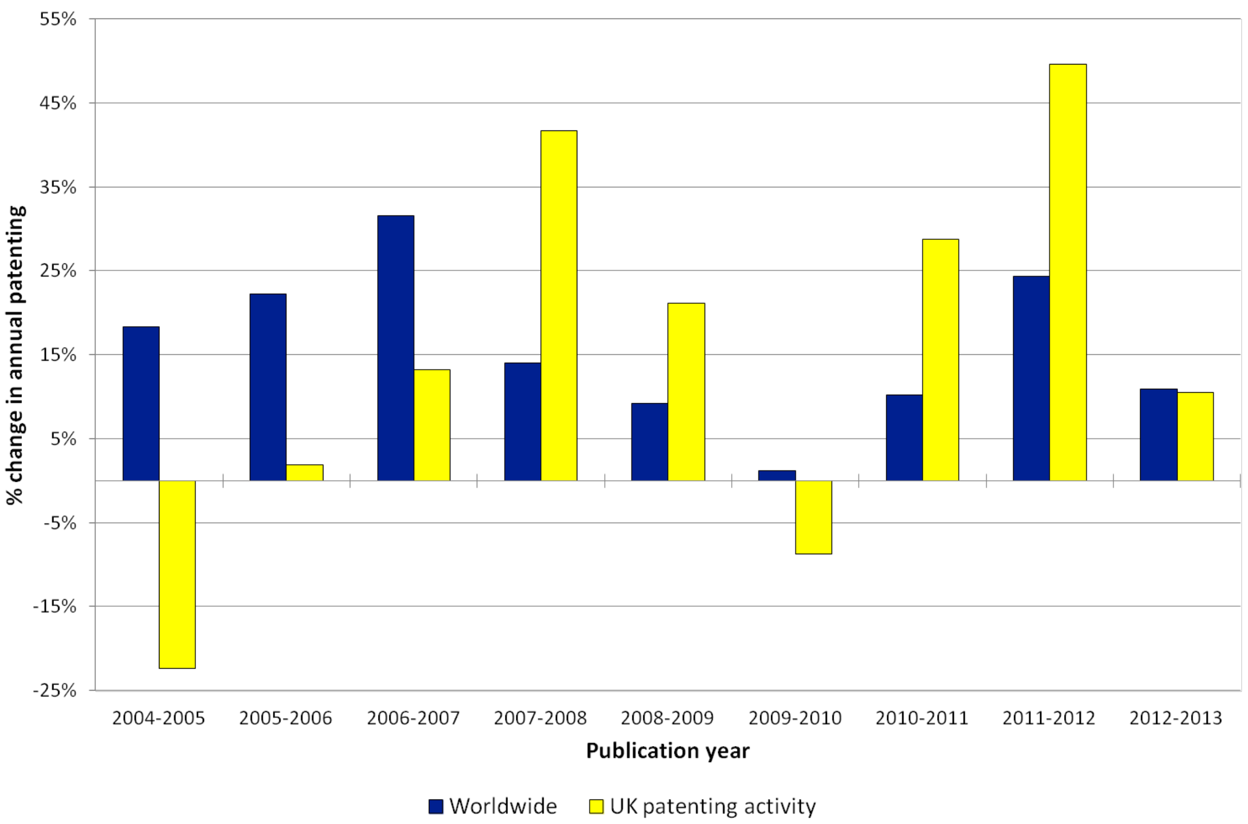

Figure 14: Year-on-year change in UK and worldwide robotics and autonomous systems patenting

Similar patent subsets were created to reflect patenting activity taking place in several comparator countries (France, Germany, USA, Japan, China, and Korea) to produce the comparison chart shown in Figure 15.

China has seen extraordinary rates of growth from a negligible baseline to one of the most significant sources of inventions. This is consistent with the positive specialisation seen earlier, although as yet none of the leading applicants is based in China. The UK has had some strong years of growth, particularly since 2007, but the overall size is still small.

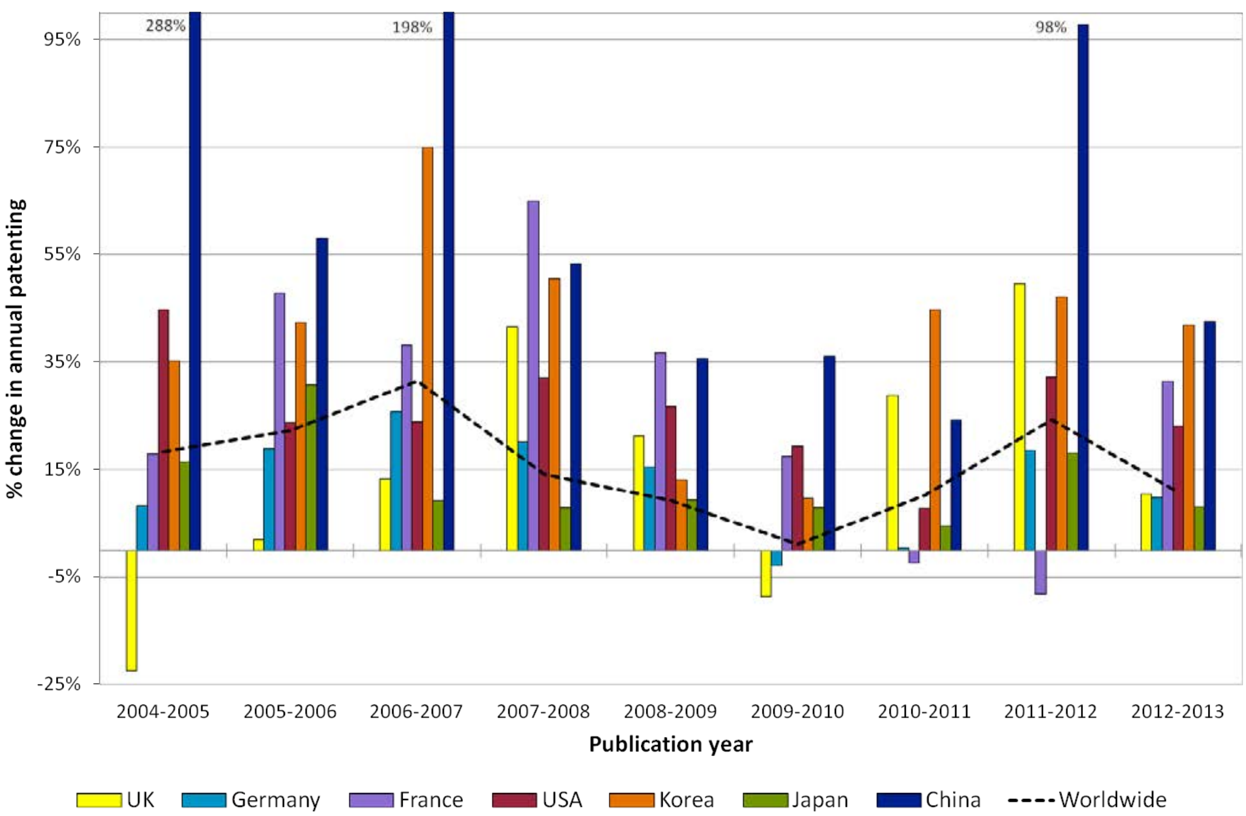

Figure 15: Year-on-year change in UK robotics and autonomous systems patenting activity against comparator countries

4 Patent landscape map analysis

In order to give a snapshot as to what the patent landscape looks like for this technology space, a patent map provides a visual representation of the dataset. Published patents (not patent families) are represented on a patent map by dots and the more intense the concentration of patents (*i.e.* the more closely related they are) the higher the topography as shown by contour lines. The patents are grouped according to the occurrence of keywords in the title and abstract and examples of the reoccurring keywords appear on the patent map[5].

The landscape map for robotics and autonomous systems is shown in Figure 16. Most of the map relates to vehicles, and much of it to road vehicles. The upper right region is focussed on unmanned aerial and underwater vehicles, whereas most of the topics in the lower half of the map are details of road vehicle aspects such as guiding, steering, lane changing, parking, collision avoidance, and engine and gearbox control. The upper central region shows robotics aspects, although there is some overlap with vehicles in the *Image, Camera, Data* region at the top of the map.

[5] Further details regarding how patent landscape maps are produced is given in Appendix C.

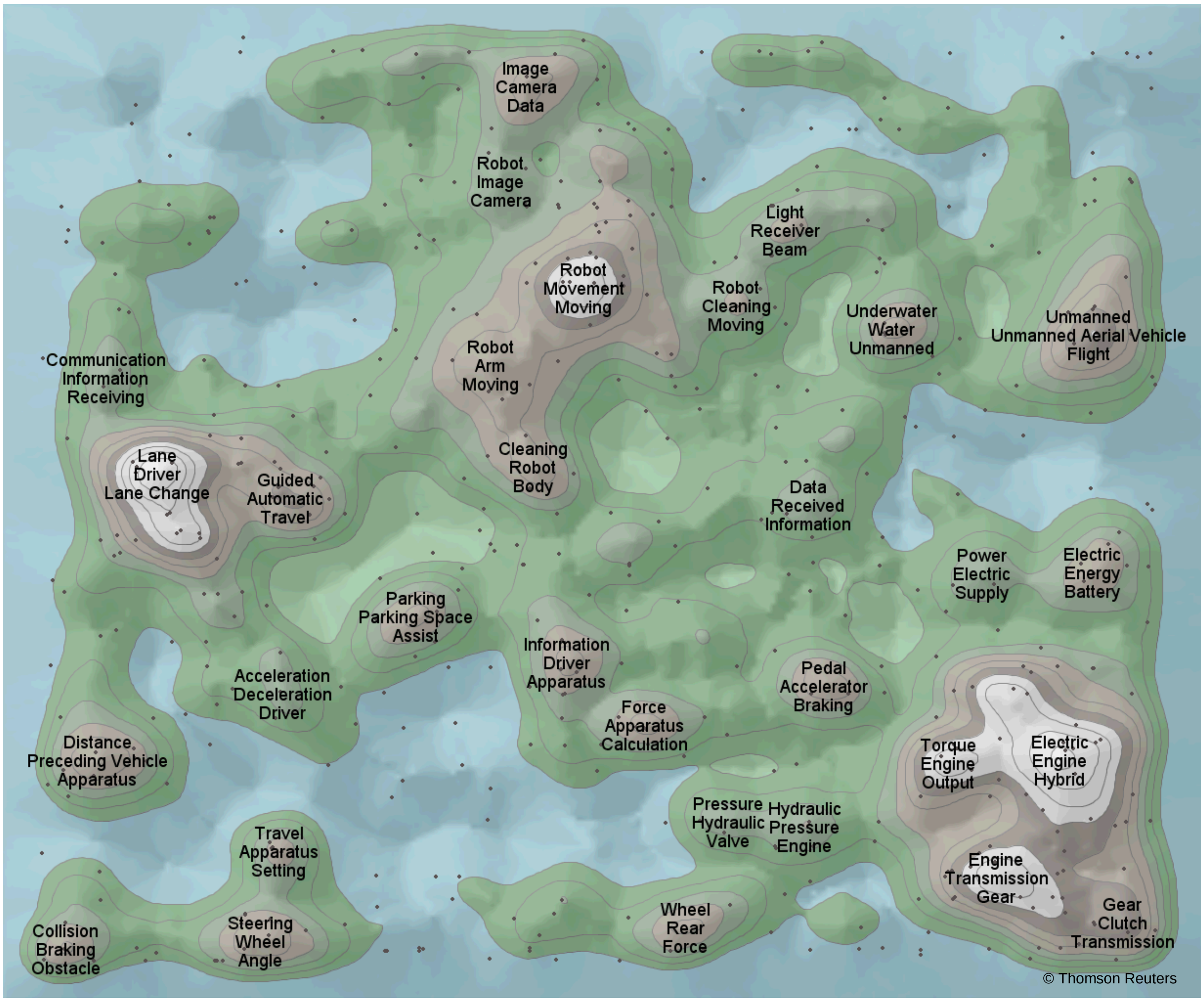

Figure 16: Patent landscape map of robotics and autonomous systems

The distribution of leading applicants throughout the map can be shown by colouring the patents of each applicant, as shown in Figure 17.

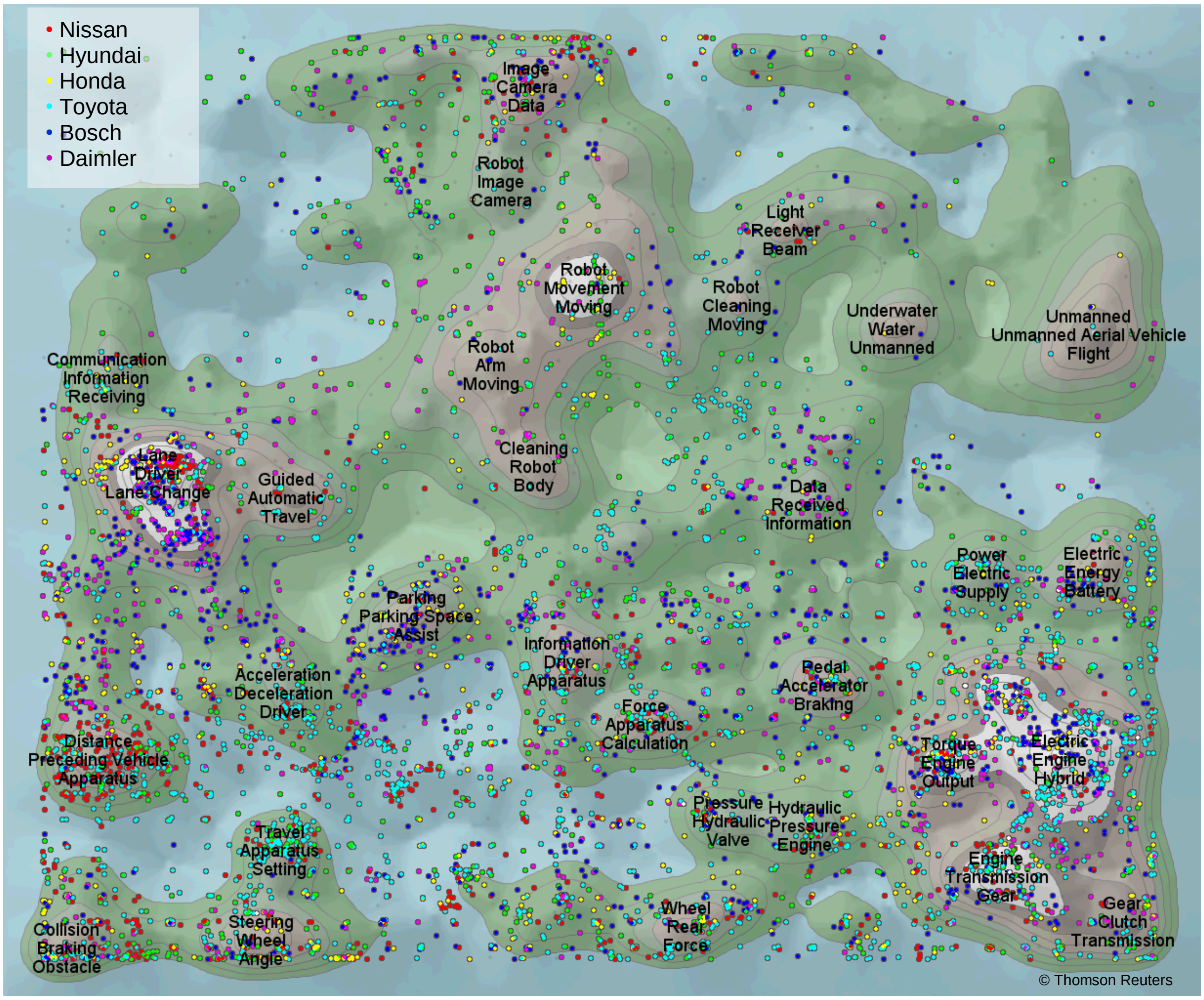

Figure 17: Patent landscape map of robotics and autonomous systems with leading applicants' patents coloured

Each of these major applicants appears to be active over the majority of the vehicles areas of the map. Since the degree of collaboration between the leading automotive manufacturers is low (as established earlier in section 2.3) the collocation of applicants into the peaks indicates a lot of competition in those areas. In particular, *Lane, Driver, Lane change* shows competition between all of the leading applicants, and *Distance, Preceding Vehicle, Apparatus* shows competition between Nissan, Honda, and Toyota. Toyota is very active additionally in *Electric, Engine, Hybrid* and in the region from the centre-upper right of the map, where the major topics are associated with the positioning and navigation of a robot.

5 Conclusions

Robotics and autonomous systems patenting has grown consistently over the ten year period that has been studied, with a tripling of patent publications over this period altogether. This growth exceeds the general growth in patenting by a large margin.

Japan is the clear leader worldwide in robotics and autonomous systems, both by the country in which patent applicants are based and the country in which patent applications are first made. The USA, Germany, China, and Korea are other significant innovators.

The bulk of the dataset relates to autonomous vehicles, and so countries having large automotive sectors feature. An index of relative specialisation of applicant countries indicates that Japan, Germany, and China have positive specialisations, but that USA has a negative specialisation, indicating that although raw numbers of USA patents in robotics and autonomous systems are large, they are not as large as expected. The UK also has a significantly negative specialisation and so robotics and autonomous systems is not currently a focus for UK inventors. Nevertheless, there appears to be increasing interest since the percentage growth of robotics and autonomous systems patents in the UK is larger than the worldwide average, especially in recent years (since 2007).

It is clear that automotive manufacturers have a large part to play in robotics and autonomous systems, and in fact autonomous vehicles form a large part of the dataset used in this study. Toyota, Bosch, Nissan, Honda, Hyundai, Daimler, GM, Denso, Ford, and Mando occupy the top positions in terms of patents. Many, if not all, of the major automotive manufacturers appear in the dataset, and manufacturers of other types of vehicles, such as Boeing, Fuji Heavy Industries, Scania, Caterpillar, Deere, and Volvo Trucks are also present. Developments are therefore not limited to road vehicles and also include aircraft, commercial vehicles, and agricultural vehicles.

Robotics and autonomous systems does not appear to carry the hallmarks of an emerging technology, because of the presence of many large organisations, lack of university and academic applicants, and lack of applicant turnover. Smaller companies who may be engaged in innovative work may be present but hidden by the larger companies. Robotics and autonomous systems appears to be developing mainly out of larger organisations in an incremental fashion. For example, fully autonomous vehicles become gradually enabled by the improvements to conventional vehicles to provide semi-automation of specific functions in the form of driver aids.

Collaboration exists within the robotics and autonomous systems field, but not between the leading applicants, who appear to be in competition with each other. The leading automotive applicants do, however, collaborate with original equipment manufacturers, smaller automotive manufacturers, or other companies. Honda, on the other hand, appears to be almost self-contained, with little collaboration at all. Google is not a leading patent applicant but is currently well known for its prototype autonomous vehicles, and is also found to work independently. Its patent portfolio is also growing at a significant rate.

Patent landscape analysis further demonstrates the competitive nature of robotics and autonomous systems patenting, with leading applicants active across the landscape.

Appendix A Interpretation notes

A.1 Patent databases used

The *Thomson Reuters* World Patent Index (WPI) was interrogated using *Thomson Innovation*[6], a web-based patent analytics tool produced by *Thomson Reuters*. This database holds bibliographic and abstract data of published patents and patent applications derived from the majority of leading industrialised countries and patent organisations, *e.g.* the World Intellectual Property Organisation (WIPO), European Patent Office (EPO) and the African Regional Industry Property Organisation (ARIPO). It should be noted that patents are generally classified and published 18 months after the priority date. This should be borne in mind when considering recent patent trends (within the last 18 months).

The WPI database contains one record for each patent family. A patent family is defined as all documents directly or indirectly linked via a priority document. This provides an indication of the number of inventions an applicant may hold, as opposed to how many individual patent applications they might have filed in different countries for the same invention.

A.2 Priority date, application date and publication date

Priority date: The earliest date of an associated patent application containing information about the invention.

Publication date: The date when the patent application is published (normally 18 months after the priority date or the application date, whichever is earlier).

Analysis by priority year gives the earliest indication of invention.

A.3 WO and EP patent applications

International patent applications (WO) and European patent applications (EP) may be made through the World Intellectual Property Organization (WIPO) and the European Patent Office (EPO) respectively.

International patent applications may designate any signatory states or regions to the Patent Cooperation Treaty (PCT) and will have the same effect as national or regional patent applications in each designated state or region, leading to a granted patent in each state or region.

European patent applications are regional patent applications which may designate any signatory state to the European Patent Convention (EPC), and lead to granted patents having the same effect as a bundle of national patents for the designated states.

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[6] *http://info.thomsoninnovation.com*

Figures for patent families with WO and EP as priority country have been included for completeness although no single attributable country is immediately apparent.

A.4 Patent documents analysed

The robotics and autonomous systems patent dataset for analysis was identified in conjunction with patent examiner technology-specific expertise. A search strategy was developed and the resulting dataset was extracted in April 2014 using International Patent Classification (IPC) codes, Co-operative Patent Classification (CPC) codes and keyword searching of titles and abstracts in the *Thomson Reuters* World Patent Index (WPI) and limited to patent families with publications from 2004 to 2013.

The applicant and inventor data was cleaned to remove duplicate entries arising from spelling errors, initialisation, international variation (Ltd, Pty, GmbH *etc*.), or equivalence (Ltd., Limited, *etc*.).

A.5 Analytics software used

The main computer software used for this report is a text mining and analytics package called *VantagePoint*[7] produced by *Search Technology* in the USA. The patent records exported from *Thomson Innovation* were imported into *VantagePoint* where the data is cleaned and analysed. The patent landscape maps used in this report were produced using *Thomson Innovation*.

[7] *http://www.thevantagepoint.com*

Appendix B Relative Specialisation Index

Relative Specialisation Index (RSI) was calculated as a correction to absolute numbers of patent families in order to account for the fact that some countries file more patent applications than others in all fields of technology. In particular, US and Japanese inventors are prolific patentees. RSI compares the fraction of robotics and autonomous systems patents found in each country to the fraction of patents found in that country overall. A logarithm is applied to scale the fractions more suitably. The formula is given below:

$$\log_{10}\left(\frac{n_i/n_{total}}{N_i/N_{total}}\right)$$

where

ni = number of robotics and autonomous systems patents in country i
ntotal = total number of robotics and autonomous systems patents in dataset
Ni = total number of patents in country i
Ntotal = total number of patents in dataset

The effect of this is to highlight countries (in this study, Israel and Australia in particular, as shown in Figure 5) which have a greater level of patenting in robotics and autonomous systems than expected from their overall level of patenting, and which would otherwise languish much further down in the lists, unnoticed.

Appendix C Patent landscape maps

A patent landscape map is a visual representation of a dataset and is generated by applying a complex algorithm with four stages:

i) **Harvesting documents** – When the software harvests the documents it reads the text from each document (ranging from titles through to the full text). Non-relevant words, known as stopwords, (e.g. “a”, “an”, “able”, “about” etc) are then discounted and words with common stems are then associated together (e.g. “measure”, “measures”, “measuring”, “measurement” etc).

ii) **Analysing documents** – Words are then analysed to see how many times they appear in each document in comparison with the words’ frequency in the overall dataset. During analysis, very frequently and very infrequently used words (i.e. words above and below a threshold) are eliminated from consideration. A topic list of statistically significant words is then created.

iii) **Clustering documents** – A Naive Bayes classifier is used to assign document vectors and Vector Space Modelling is applied to plot documents in n-dimensional space (i.e. documents with similar topics are clustered around a central coordinate). The application of different vectors (i.e. topics) enables the relative positions of documents in n-dimensional space to be varied.

iv) **Creating the patent map** – The final n-dimensional model is then rendered into a two-dimensional map using a self-organising mapping algorithm. Contours are created to simulate a depth dimension. The final map can sometimes be misleading because it is important to interpret the map as if it were formed on a three-dimensional sphere.

Thus, in summary, patents are represented on the patent map by dots and the more intense the concentration of patents (*i.e.* the more closely related they are) the higher the topography as shown by contour lines. The patents are grouped according to the occurrence of keywords in the title and abstract and examples of the reoccurring keywords appear on the patent map. Please remember there is no relationship between the patent landscape maps and any geographical map.

Please note that the patent maps shown in this report are snapshots of the patent landscape, and that patent maps are best used an interactive tool where analysis of specific areas, patents, applicants, inventors *etc* can be undertaken ‘on-the-fly’.

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