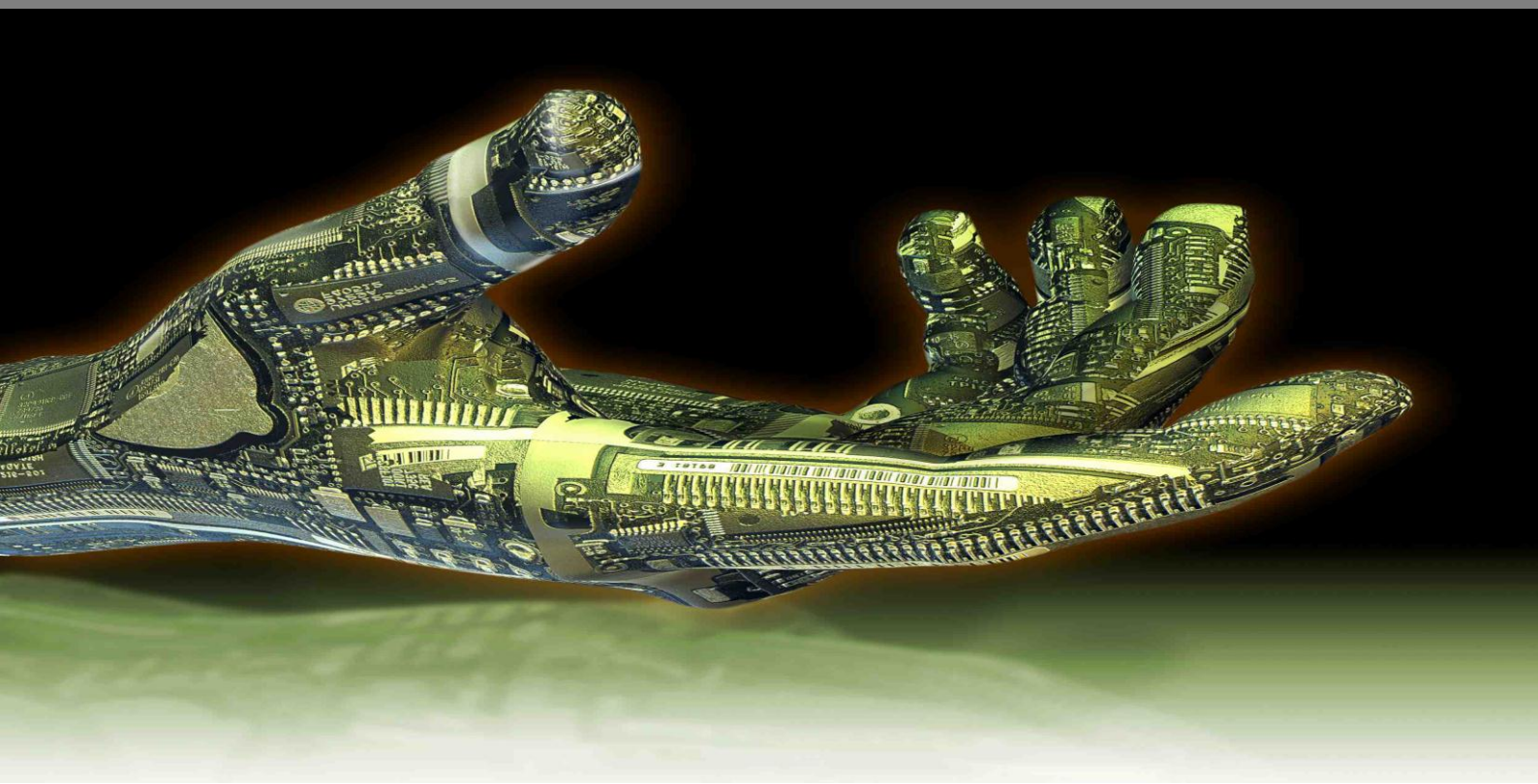


Technology Insight Report

ROBOTIC ARMS

Patent iNSIGHT Pro
Transform Patents to Intelligence

"Robotics is a field concerned with the intelligent connection of perception to action." A Robot is a reprogrammable manipulator designed to move material, parts, or specialized devices through various programmed motions for performing various tasks.

The most common manufacturing robot is the robotic arm. A typical robotic arm is made up of seven metal segments, joined by six joints. The computer controls the robot by rotating individual step motors connected to each joint (some larger arms use hydraulics or pneumatics)

This report takes a look into the patenting activity around robotic arms uncovering the key companies, inventors, and different sub categories.

Introduction to Robotic Arm

Arms are types of jointed robot manipulator that allow robots to interact with their environment. Many have onboard controllers or translators to simplify communication, though they may be controlled directly or in any number of ways. Due to this fact, standalone arms are often classified as full robots. The robot arms can be autonomous or controlled manually and can be used to perform a variety of tasks with great accuracy. The robotic arm can be fixed or mobile (i.e. wheeled) and can be designed for industrial or home applications.

There are many different types of robotic arms, but most can be characterized by their mechanical structure. Cartesian (also known as Gantry) robots have three joints that are coincident with the standard X-Y-Z Cartesian axes. Cylindrical arms have any number of joints that operate on a cylindrical axis, normally rotating about one fixed rod. Spherical (polar) arms are those with joints that allow it full rotation throughout a spherical range. SCARA robots have two parallel rotary joints to allow full movement throughout a plane, typically for pick-and-place work. Articulated robots are used for complex assembly operations, and consist of three or more rotary joints. Parallel robots have three concurrent prismatic or rotary joints, and allow for tilting of heavy or sensitive platforms.

Overview

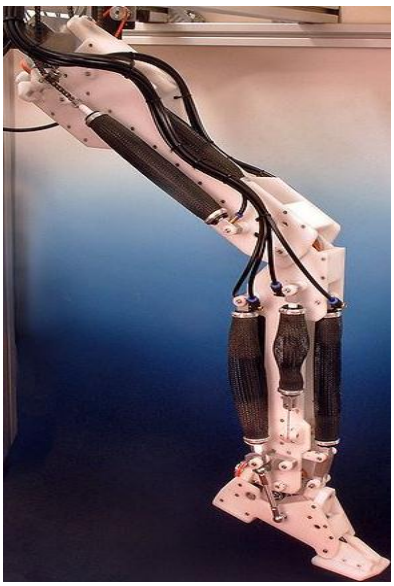
With the help of Patent iNSIGHT Pro, we will analyze the patent data around Robotic Arm to find answers to the following:

- What does the IP publication trend for Robotic Arm look like and how have the filings evolved?
- Who are the top assignees or key players in Robotic Arm and what are their technology wise trends?
- How is research in Robotic Arm spread across different countries?
- How is the Assignee portfolio spread across different robot types?
- How are Key Assignees filing across different IPC?
- Which parts are used across different types of robots?

To get deeper insights the patent set has been classified as follows:

By Robot Types

- Anthropomorphic Robots
- Articulated Robots
- Cartesian/ Gantry Robots
- Cylindrical Robots
- Industrial Robots
- Parallel Robots
- SCARA Robots
- Spherical/ Polar Robots



Shadow Leg

By Applications of Robotic Arms

- Agriculture
- Defense
- Material Handling
- Medical
- Other Industrial Applications
- Welding

Note: Other Industrial Applications include: bonding/sealing, deburring , spraying, grinding, milling, polishing, waterjet, cleanroom, drilling, foundry, assembling

Image Source:
http://www.google.co.in/search?q=robotics+agriculture&hl=en&prmd=imvns&source=lnms&tbm=isch&ei=0ndLT4zbKYHWrQekzNi3Dw&sa=X&oi=mode_link&ct=mode&cd=2&sqi=2&ved=0CDYQ_AUoAQ&biw=1600&bih=756

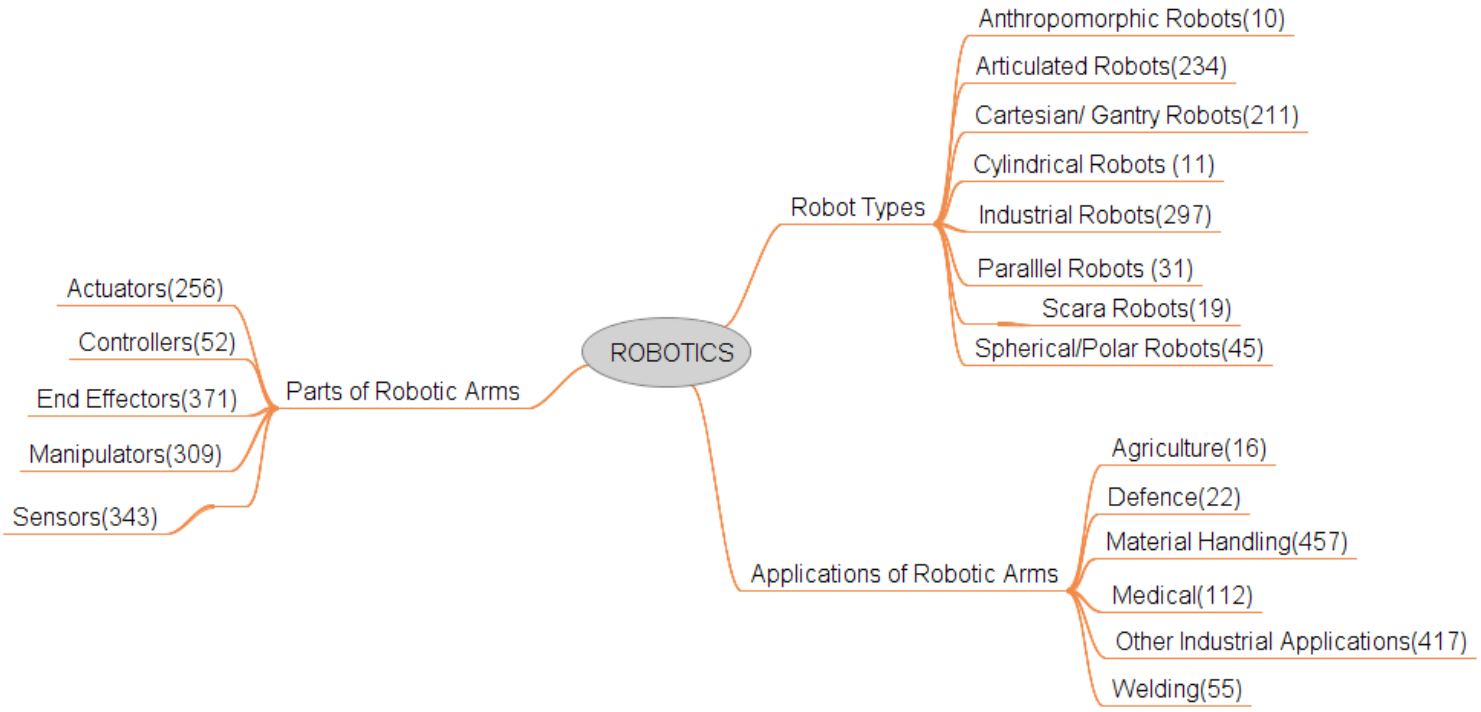
By Parts of Robotic Arms

- Actuators
- Controllers
- End Effectors
- Sensors

Image Source :
http://www.engineersgarage.com/articles/robotics-tutorial-introduction-robots

The illustration below shows the different categories prepared and the number of records in each. The categorization involved defining a search strategy for each topic and then conducting the search using the Advanced Searching capability in Patent iNSIGHT Pro. Details of search strings used for each category are given in Appendix B.

ROBOTICS CATEGORIZATION TREE



The Search Strategy

Note: This report excludes programming facets of robotics.

Using the commercial patent database PatBase as our data source we used the following search query to create our patent set.

FT- Full Text
TAC – Title Abstract Claims
IC – International Class
UC- US Class

(FT=(robot* or (artificial w/2 intelligence) or android or cyborg or humanoid*)) or (TAC= (manipulator* or manipulater* or actuator* or actuater* or drives or joint or joints or actuation or ("end effector" or "end effecter") or ((pneumatic* or air) w/2 muscle*))) and ((IC= B25J9/02 or B25J9/04 or B25J9/06 or B25J13/02 or B25J13/08 or B25J17 or B25J18) or (UC=901/2 or 901/14 or 901/19 or 901/27 or 901/31 or 901/39 or 700/245 or 700/248 or 700/261))

The queries were combined using the 'OR' operator to search in full text and title, abstract, claims and a patent set of 2352 records with one publication per family was generated.

The publications included in the report are updated as of 6th February, 2012.

Class Descriptions of Classes used in Search Strategy

B25J 9/02: characterised by movement of the arms, e.g. cartesian co-ordinate type (B25J 9/06 takes precedence) [4]

B25J 9/04: by rotating at least one arm, excluding the head movement itself, e.g. cylindrical co-ordinate type or polar co-ordinate type [4]

B25J 9/06: characterised by multi-articulated arms [4]

B25J 13/02: Hand grip control means

B25J 13/08: by means of sensing devices, e.g. viewing or touching devices [4]

B25J 17/00: Joints

B25J18/00: Arms [4]

Class Descriptions Continued…

901/2: ARM MOTION CONTROLLER

901/14: ARM MOVEMENT (SPATIAL)

901/19: DRIVE SYSTEM FOR ARM

901/27: ARM PART

901/31: Gripping Jaw

901/39: Jaw Structure

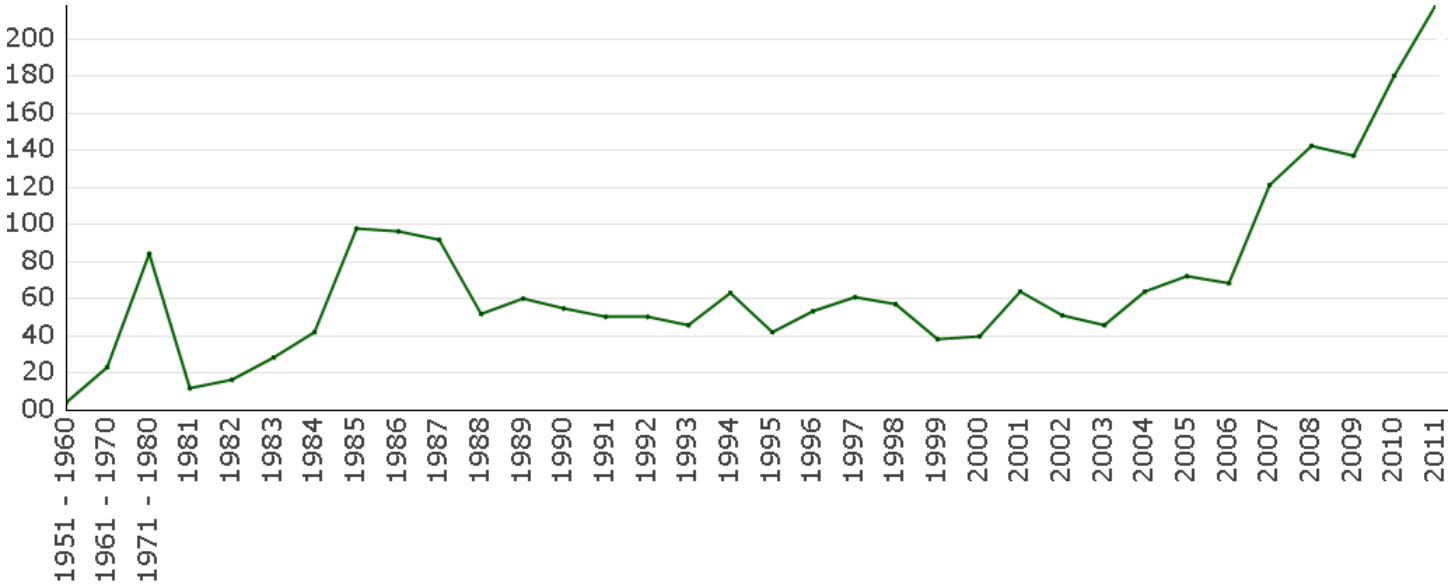
700/245: Robot control

700/248: Plural robots

700/261: Having control of robot torque

Publication Trend

What has been the IP publication trend for Robotic Arms?



Patents related to robotic arms can be traced back to 1951 and the real surge in the activity around this technology has happened in the last 5 to 6 years. Noticeably there was an increase in publications from 2007 onwards.

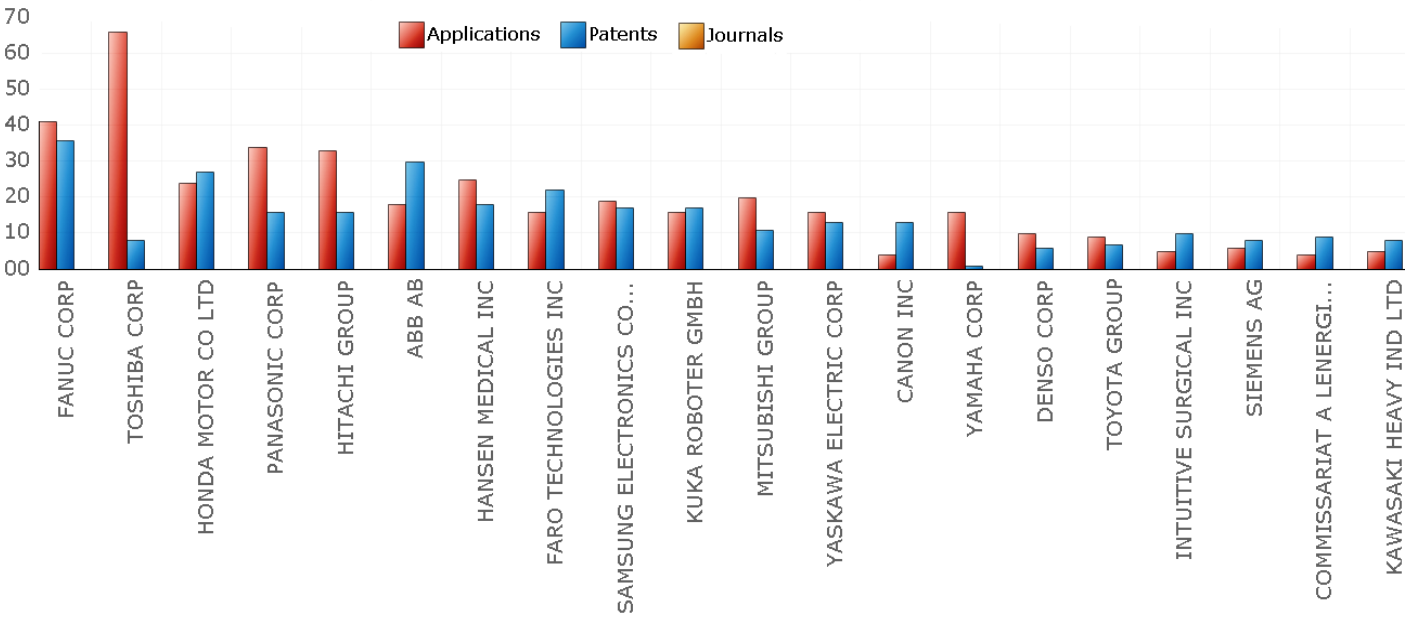
It's clear the current activity around these technologies is likely to continue seeing more innovation in the near future.

How we did it?

Once the patents were populated in Patent iNSIGHT Pro, the publication trend chart was generated on a single click using the dashboard tool.

Top Assignees

Who have been the top assignees or the key players within this industry?



The top assignees are:

1. FANUC CORP
2. TOSHIBA CORP
3. HONDA MOTOR CO LTD
4. PANASONIC CORP
4. HITACHI GROUP
5. ABB AB
6. HANSEN MEDICAL INC
7. FARO TECHNOLOGIES INC
9. SAMSUNG ELECTRONICS CO LTD
10. KUKA ROBOTER GMBH
11. MITSUBISHI GROUP
12. YASAKAWA ELECTRIC CORP
13. CANON INC
14. YAMAHA CORP
15. DENSO CORP
16. TOYOTA GROUP
17. INTUTITIVE SURGICAL INC
18. SIEMENS AG
19. COMMISSARIAT ALENERGIE ATOMIQUE
20. KAWASAKI HEAVY IND LTD

How we did it?

Once the patents were populated in Patent iNSIGHT Pro, the assignee clean- up tools were used to normalize the names. Different cleanup tools were leveraged:

- To locate assignees for unassigned records
- To clean up records having multiple assignees
- To locate the correct assignee names for US records using the US assignments database
- To merge assignees that resulted from a merger or acquisition or name change.

Please refer Appendix A for more details on Assignee merging.

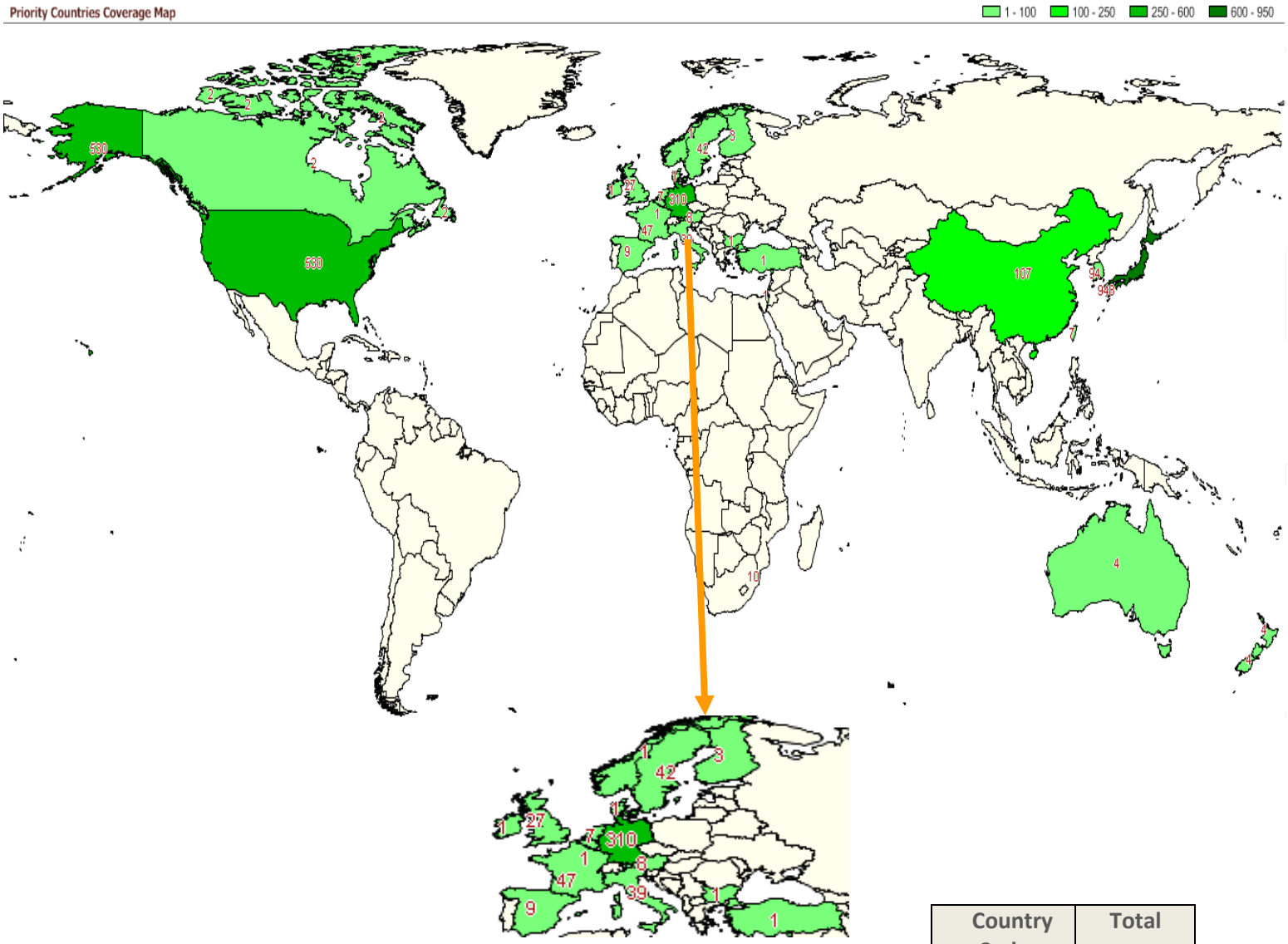
Once the Assignee names were cleaned up, the dashboard tool within Patent iNSIGHT Pro was used to find the top 20 assignees within the given patent set. A visual graph was created based on the results of the top assignees with the number of patents alongside each one.

The complete Assignee table in available in the following Excel file:
http://www.patentinsightpro.com/techreports/0312/List%20of%20Assignees.xls

Top Countries

How is research in Robotic arm spread across different countries?

In terms of regional pockets where patent protection is being sought most frequently for these technologies, JP leads the count, followed by the US and DE. The table below ranks top priority countries and helps provide an indication of where innovation in this area is originating:



Country Code	Total
JP	948
US	530
DE	310
CN	107
KR	94

How we did it?

The map was generated using the Priority country coverage map option provided in the dashboard tool within Patent iNSIGHT Pro.

Assignee - Key Statistics

Here we summarize key parameters of Top 15 Assignees such as filing trend, Avg. number of Forward citations per record, Top inventors in each Assignee, Top Co-Assignees and Coverage of underlying patent families

Assignee	Total No. of Records	Avg. No. of Fwd Cites per Patents	Filing Trend (Absolute)	Filing Year Range	Key Inventor (Top 5)	Coverage (Includes families)						
						US	EP	WO	JP	DE	CN	KR
FANUC CORP	77 (3.3%)	4.21		1983-2011	ITO SUSUMU(10) HAMURA MASAYUKI(9) NAKAJIMA SEIICHIROU(5) TANAKA AKIRA(5) TORII NOBUTOSHI(5)	47	1	1	25	1	0	0
TOSHIBA CORP	74 (3.1%)	2.73		1969-2011	KITAGAWA TSUGUYOSHI(7) MUNAKATA TADASHI(6) MIYAZAKI KIYOSHI(5) ISHINO KATSUZOU(5) MUROTANI TETSUO(3)	11	0	0	67	0	0	0
HONDA MOTOR CO LTD	51 (2.2%)	4.59		1985-2011	HASEGAWA TADAAKI(6) SUGIYAMA KENICHIRO(4) SANO SHIGEO(3) MAKI KOJI(3) MIKURUBE ATSUSHI(3)	36	0	2	10	0	2	1
PANASONIC CORP	50 (2.1%)	3.36		1980-2011	OKAZAKI YASUNAO(6) JIN KEIICHI(6) JIYOU YASUNORI(4) TAKEMOTO YOSHIROU(2) YAMASHITA KAZUICHI(2)	31	6	13	53	3	7	2

HITACHI GROUP	49 (2.1%)	10.96		1975-2009	KONO MICHINAGA(4) NAKAYAMA SUSUMU(3) ISHIKAWA YOSHIO(2) SUGIYAMA SAKAE(2) SUZUKI MASANORI(2)	16	5	0	60	2	0	2
ABB AB	48 (2%)	7.58		1980-2011	BROGARDH TORGNY(7) KOCK SOENKE(5) BRANTMARK HAKAN(2) WINTERHALTER CHRISTOPH(2)HAAGE MATHIAS(2)	50	22	14	6	17	9	1
HANSEN MEDICAL INC	43 (1.8%)	8.77		2000-2011	LEE WOOJIN(28) ROGERS GARY(9) BROCK DAVID L(7) SOLBJOR ALBERT(5) AILENGER ROBERT(3)	19	2	2	0	1	1	0
FARO TECHNOLOGIES INC	38 (1.6%)	3.61		1998-2011	BARBER MARC(22) SAJEDI SEYED ALI(22) RAAB SIMON(13) ATWELL PAUL CHRISTOPHER(4) BARBA JACINT R(3)	12	0	0	0	3	3	0
SAMSUNG ELECTRONICS CO LTD	36 (1.5%)	1.33		1985-2010	LIM BOK MAN(4) KIM MYUNG HEE(4) CHOI YONG WON(3) KANG KYUNG WON(2) HONG KWANG JIN(2)	17	0	0	2	0	0	16
KUKA ROBOTER GMBH	33 (1.4%)	5.27		1977-2011	HIETMANN GERHARD(3) ZIMMER ERNST(3) KARLINGER STEFAN(2) STURM STEFAN(2) MARTIN DAVID(2)	18	17	3	2	44	2	4
MITSUBISHI GROUP	31 (1.3%)	6.06		1983-1997	TANAKA MINORU(7) YAMAMOTO MASAYUKI(7) KATO HISAO(6) TAKAMURA YOUSUKE(4) FUJIMURA HIROSHI(2)	10	0	0	36	0	0	1

YASKAWA ELECTRIC CORP	29 (1.2%)	4.72		1982-2011	TANAKA KENTARO(4) SUEYOSHI SATOSHI(3) TANAKA MICHIHARU(2) FUKUDOME KAZUHIRO(2) MATSUKUMA KENJI(2)	17	1	3	18	0	1	2
CANON INC	17 (0.7%)	10.29		1988-2009	AZUMA YUSAKU(7) ISHIHARA KATSUMI(3) KIGAMI HIROYUKI(2) MACHINO MASAKI(2) YAMAMOTO TOSHIHIRO(2)	18	2	0	14	0	0	0
YAMAHA CORP	17 (0.7%)	0.41		1976-2008	KAWADA KOJI(4) KAIEDA TAKASHI(3) SHINDO HIROSHI(3) IWAI KAZUO(2) SUZUKI KOJIRO(1)	1	0	0	16	0	0	0
DENSO CORP	16 (0.7%)	0.5		2002-2009	TAKEDA SHIGERU(5) KAMIYA KOJI(3) UEYAMA TSUYOSHI(2) TANIGUCHI EISUKE(1) SANEKATA YUICHI(1)	9	0	0	8	0	0	0

How we did it?

From the Assignee 360° report options, we selected Top 15 Assignees and the different pieces of information we wanted to include in the singular display and then ran the report. The generated report was then exported to Excel using the option provided for the same.

Inventor - Key Statistics

Here we summarize key parameters of Top 15 Inventors such as filing trend, average number of forward citations per record, key associated companies and top 5 co-inventors.

Inventor	Total No. of Records	Average No. of Fwd Cites per Patents	Filing Trend (Absolute)	Filing Year Range	Key Assignees (Top 5)	Co-Inventors
LEE WOOJIN	32 (1.4%)	11.59		2000-2010	HANSEN MEDICAL INC(28) LEE WOOJIN(4) ROGERS GARY(3)	ROGERS GARY(7) CHAMORRO ANDRES(3) AILENGER ROBERT(2) CHAMORRO III ANDRES(2)
BARBER MARC	22 (0.9%)	3.68		2003-2007	FARO TECHNOLOGIES INC(22)	SAJEDI SEYED ALI(18) HASLOECHER KENNETH J(2) RAAB SIMON(2) HELM C ANDREW(1) SAJEDI ALLEN(1)
SAJEDI SEYED ALI	22 (0.9%)	3.68		2003-2006	FARO TECHNOLOGIES INC(22)	BARBER MARC(18) RAAB SIMON(3) HASLOECHER KENNETH J(1)
RAAB SIMON	13 (0.6%)	10.15		1998-2007	FARO TECHNOLOGIES INC(13)	SAJEDI SEYED ALI(3) BARBA JACINT R(2) BARBER MARC(2) ATWELL PAUL CHRISTOPHER(1) HASLOECHER KENNETH J(1)
HASHIMOTO YASUHIKO	12 (0.5%)	3		1992-2011	KAWASAKI HEAVY IND LTD(8)	KUBO YOSHIYUKI(1) OHYA TOMOKI(1)

					FANUC CORP(3) HITACHI GROUP(1)	YOSHIDA TETSUYA(1) YOSHIDA TOSHIAKI(1)
ROGERS GARY	12 (0.5%)	30.92		2001- 2008	HANSEN MEDICAL INC(9) LEE WOOJIN(3) ROGERS GARY(3)	LEE WOOJIN(7) SOLBJOR ALBERT(5) AILENGER ROBERT(1)
ITO SUSUMU	11 (0.5%)	9.09		1981- 1990	FANUC CORP(10) FUJITSU FANUC LIMITED(1)	TANAKA AKIRA(5) TERADA AKIHIRO(2) HAMURA MASAYUKI(1) INABA HAJIMU(1) IWASAKI KYOJI(1)
SOLOMON NEAL	11 (0.5%)	7.55		2003- 2008	SOLOMON RESEARCH LLC(11)	No Co-Inventor Present
HAMURA MASAYUKI	9 (0.4%)	1.33		1984- 1995	FANUC CORP(9)	TOYODA KENICHI(2) WAKIO HIROSHI(2) ITO SUSUMU(1) SAKAMOTO SHINSUKE(1)
RONEN AMIR	8 (0.3%)	5.25		2003- 2011	SANDISK IL LTD.(7) M SYSTEMS FLASH DISK PIONEERS LTD(1)	No Co-Inventor Present
YAZAWA TAKAYUKI	8 (0.3%)	0.25		2004- 2008	NIDEC SANKYO CORP(8)	ARAKAWA HIROSHI(2) NAKAJIMA HIROTO(1) SATO SHIRO(1)
AZUMA YUSAKU	7 (0.3%)	18.29		1990- 1994	CANON INC(7)	ISHIHARA KATSUMI(2) KIGAMI HIROYUKI(2) KARUBE YASUO(1) KASAI SHOZO(1) OOSAKA TEIJI(1)

BROCK DAVID L	7 (0.3%)	53		2002-2007	HANSEN MEDICAL INC(7)	AILENGER ROBERT(1) WEITZNER BARRY(1)
BROGARDH TORGNY	7 (0.3%)	4		2000-2007	ABB AB(7)	KOCK SOENKE(1) OLEVIK ANDREAS(1)
KATO HISAO	7 (0.3%)	10.71		1986-1989	MITSUBISHI GROUP(6) SHIN MEIWA IND CO LTD(1)	YOSHIMURA MAYUMI(1)

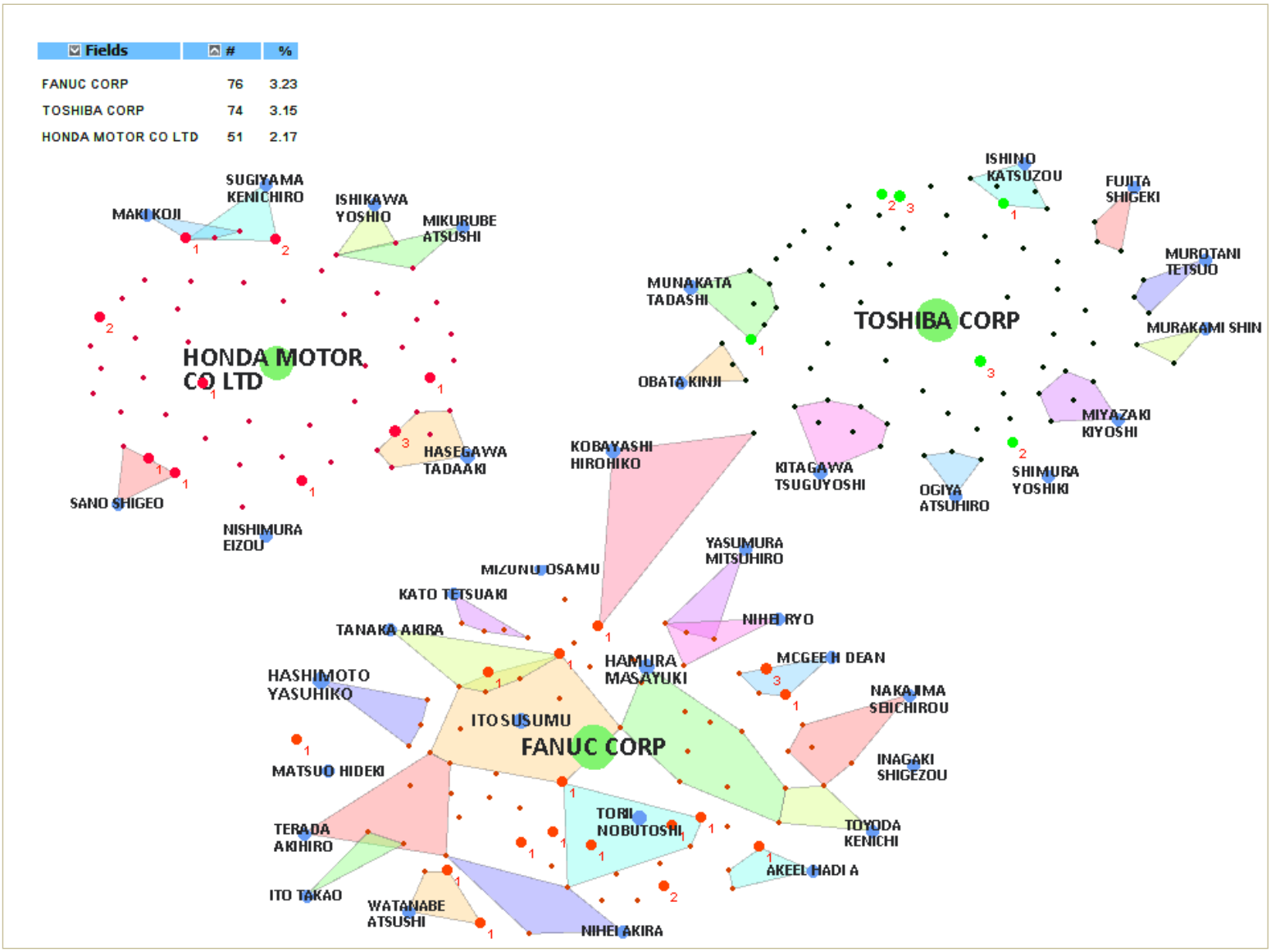
How we did it?

From the Inventor 360° report options, we selected the different pieces of information we wanted to include in the singular display and then ran the report. The generated report was then exported to Excel using the option provided for the same.

Analysis of key inventor groups of top three assignees

The generated map below highlights the key inventor groups of top three assignees. The numbers besides the nodes represent citation count for respective inventors.

Key inventors present in the map, for instance, Hasegawa Tadaaki for Honda Motor Co Ltd has total 3 citations. Also groups of inventors who file together appear clustered together.



How we did it?

Using the VizMAP tool, patents of top three assignees, namely, Fanuc Corp, Toshiba Corp and Honda Motor Co Ltd were loaded. These were then expanded by their respective inventor names. The VizShade option was used to shade the inventors with potential overlapping patents between them and citation count from the current data set is displayed.

Robotic Arm: Applications vs Assignees

Which assignees hold the maximum inventions across different application areas of robotic arms?

In the below matrix leading patent holdings with each applications have been highlighted with stronger shades of green for large number of patents within that category. Solomon Research LLC concentrates on Defense applications. Hansen Medical Inc with 36 records heads the Medical application field closely followed by Intuitive Surgical Inc with 15 records.

Applications(Row) / Key Assignees (Column)	Total	Material Handling	Medical	Other Industrial Applications	Welding	Defense	Agriculture
Total	283	122	64	129	26	11	6
HANSEN MEDICAL INC	36		36	14			
ABB AB	25	16		13	5		
FANUC CORP	23	9		14	2	1	
INTUITIVE SURGICAL INC	15	7	15	3			
TOSHIBA CORP	14	4		11			
HONDA MOTOR CO LTD	12	6		3	4		
YASKAWA ELECTRIC CORP	11	5	1	4	1		
PANASONIC CORP	11	6		4	1		
HITACHI GROUP	10	4		5	3		
BROOKS AUTOMATION INC	10	7	1	5			
SOLOMON RESEARCH LLC	9					9	

KUKA ROBOTER GMBH	9	4	1	2	2		
SAMSUNG ELECTRONICS CO LTD	8	6		2		1	
MITSUBISHI GROUP	7	2		2	4		
LEMELSON JEROME H	7	6	2	7	1		
SIEMENS AG	6	3	2	2			
IBM CORP	6	4	1	3			
GENERAL MILLS INC	6	6					
FARO TECHNOLOGIES INC	6	1		6			
APPLIED MATERIALS INC	6	4		6			
YAMAHA CORP	5	1		5			
UNIMATION INC	5	2		2	2		
TOYOTA GROUP	5	3		1	1		
SRI INTERNATIONAL	5	2	5				2
GENERAL MOTORS CORP	5	3		4			
DELAVAL HOLDING AB	5	1					4
FUJITSU LTD	4	1		4			
DEVOL GEORGE C	4	4					
DAIHEN CORP	4	4		3			
CANON INC	4	1		4			

How we did it?

First the various applications of robot arms were identified by manual research. Then by using a combination of semantic analysis tools such as clustering tools and searching tools available in Patent iNSIGHT Pro, patents were categorized under different applications. Finally, a co-occurrence matrix was generated and exported to excel.

Robotic Parts vs Application

The below matrix shows which parts are being used in different applications areas.

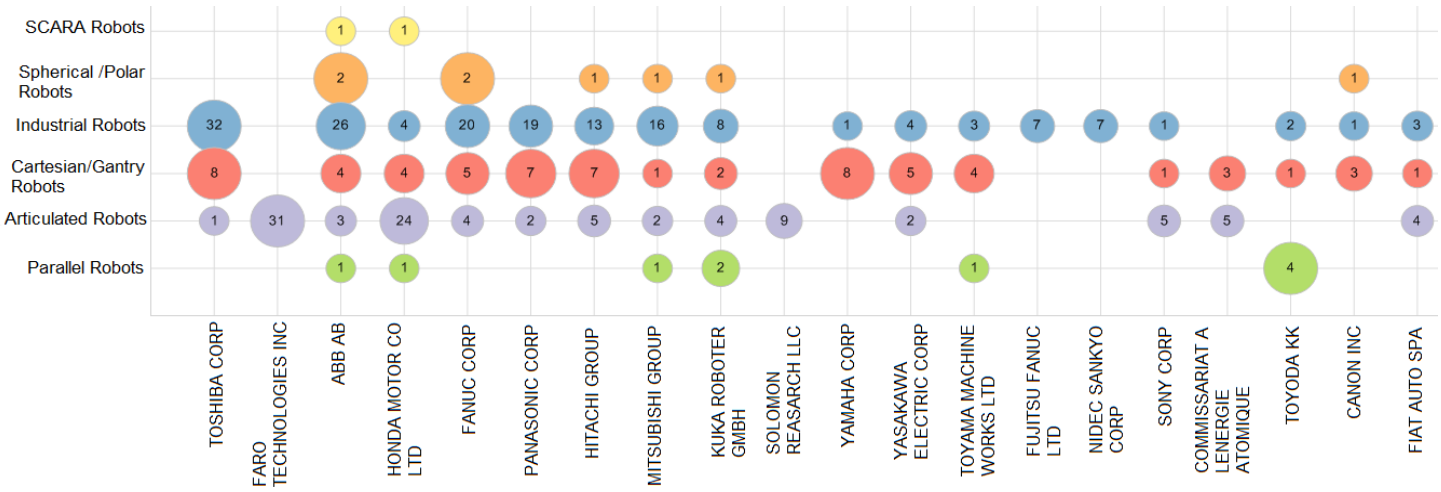
Parts (Rows) / Applications (Columns)	Total	Material Handling	Medical	Other Industrial Applications	Welding	Defence	Agriculture
Total	502	294	65	238	28	13	10
End Effectors	255	179	25	120	11	2	5
Sensors	180	105	30	85	11	7	9
Manipulators	160	85	27	81	8	3	5
Actuators	133	71	21	74	5	3	1
Controllers	25	15	5	10	4	1	

How we did it?

The clusters that were created for the analysis were correlated using the co-occurrence analyzer and then the resulting matrix was exported to Excel.

Robotic Types vs Assignees

How is the Assignee portfolio spread across different robot types?



Toshiba Corp is active across Industrial and Cartesian Robots. Faro Technologies dominates patent holdings for “Articulated Robots” with 31 patent records.

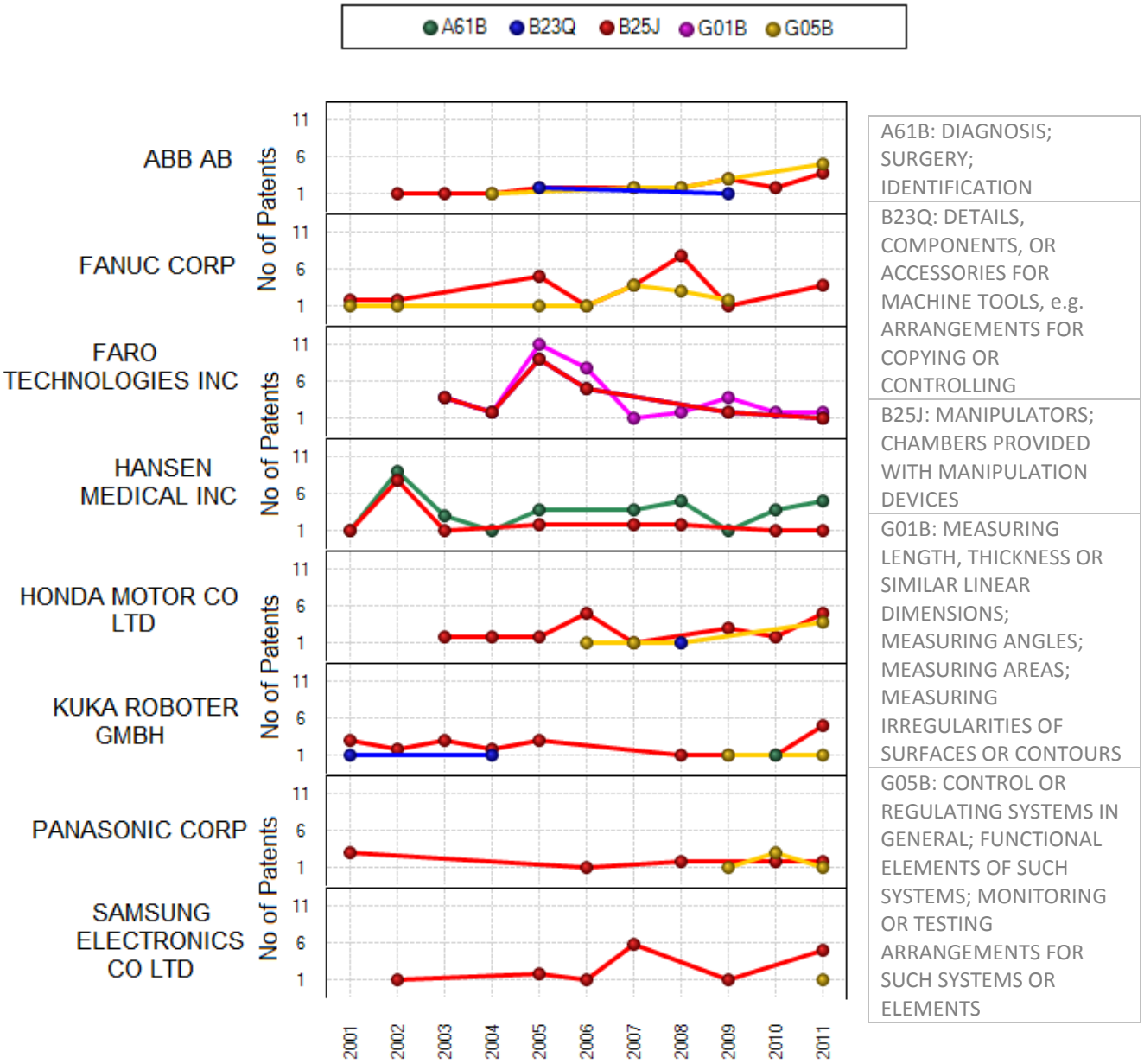
How we did it?

The clusters that were created for the previous analysis were correlated using the co-occurrence analyzer and then the resulting matrix was converted into a bubble chart.

Assignee activity across main IPC

How are Key Assignees filing across different IPC?

The generated map below highlights activity of some of the key assignees across top 5 IPC. From the chart we can see that FANUC CORP is consistent in B25J. So also Hansen Medical Inc is active through A61B.



How we did it?

We manually filtered some of the top IPC to analyze the publications for key assignees using co-occurrence analyser. Thereby a 4-D chart was generated to represent the data.

Robotic Arm: Parts vs Types

Which parts are used across different types of robots?

As can be seen in the table end effectors and manipulators are used in all the types of robots making them the most essential parts.

Types(Row) / Parts(Column)	Total	Manipulators	Actuators	Sensors	End Effectors	Controllers
Total	300	82	84	117	127	10
Articulated Robots	123	28	36	50	51	3
Cartesian/ Gantry Robots	93	28	23	37	45	3
Industrial Robots	77	14	23	33	25	5
Spherical/ Polar Robots	26	11	12	5	11	
Parallel Robots	19	9	5	3	7	1
SCARA Robots	17	5	5	4	12	
Cylindrical Robots	4	4	2		2	
Anthropomorphic Robots	3	2			2	

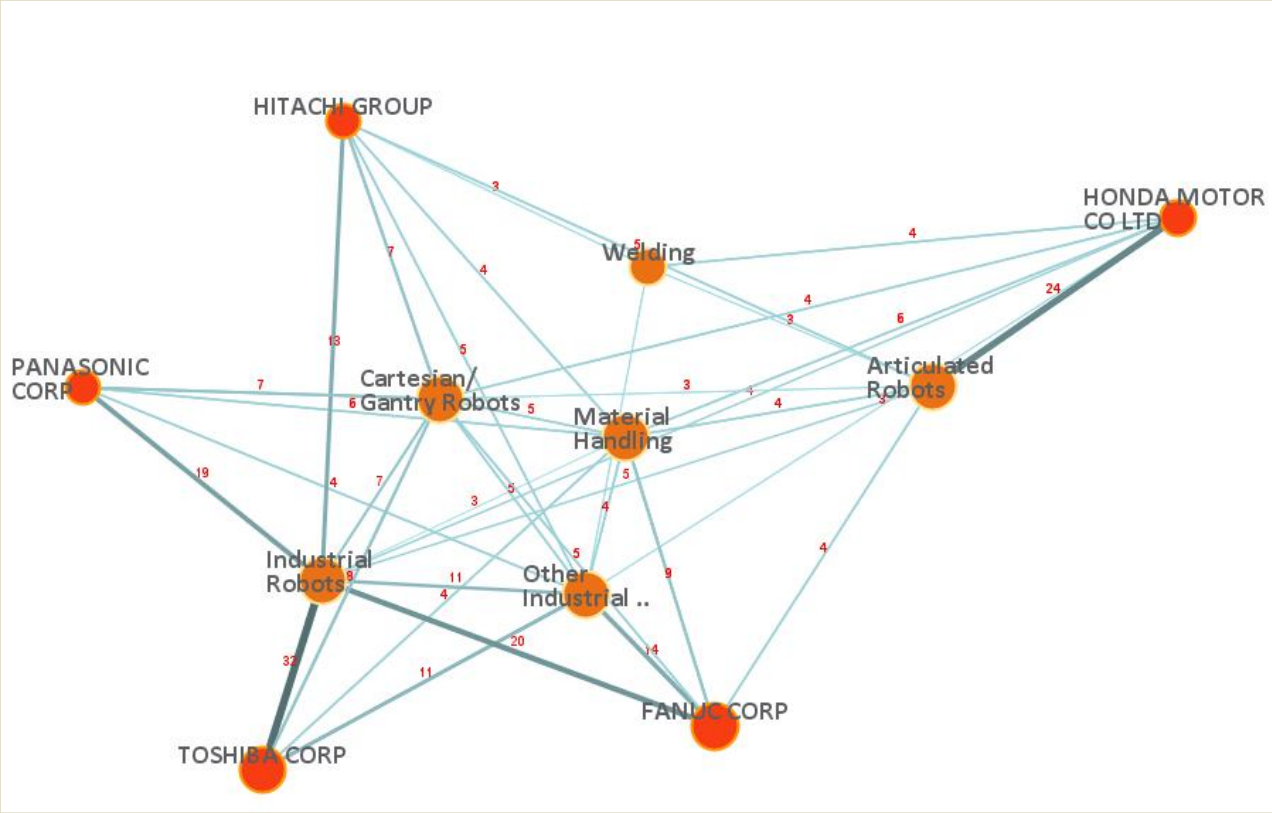
How we did it?

The clusters that were created for the previous analysis were correlated using the co-occurrence analyzer and then the resulting matrix was exported to Excel.

Assignee Portfolios spread across different robotics applications and types

In the map, each assignee is connected through links whose thickness and color intensity is directly proportional to the number of records relating them. The number (in red) next to each line represents the number of records held by the Assignee in the particular type and application for robotics.

Honda Motor Co Ltd leads the assignees for patents in Articulated type of robots. Fanuc Corp, Toshiba Corp and Panasonic Corp are actively involved in Industrial Robots.



How we did it?

Using VizMap, records of top 5 assignees were loaded. These assignees were then analyzed on the basis of applications and types. The map generated was finally represented as Correlation Map.

Assignee Portfolios spread across different Technologies

The tables below highlight key technology clusters of top assignees within different markets. The respective headers represent the main cluster, followed by their sub-cluster. We analysed companies in two verticals: Industrial Applications and Medical Applications.

How we did it?

We created patent groups of key assignees and using clustering tools key sub topics were generated. These were then exported to Excel.

Vertical: Industrial Applications

FANUC CORP

Robot control	Robot arm	Industrial robot	Drive means	Coordinate	Molded
▪ Robot system ▪ Robot mechanism ▪ Point ▪ Robot control apparatus ▪ Motor ▪ Means for storing ▪ Control device ▪ Robot hand ▪ Force ▪ Position and orientation ▪ Control unit ▪ Rotation drive means ▪ Coordinate system ▪ Control function ▪ Automatically setting ▪ Assembly ▪ Orientation data ▪ Visual sensor ▪ Setting section ▪ Screw shaft ▪ Processing section ▪ Output shaft ▪ Outer arm ▪ Arm tip ▪ Welding torch ▪ Spherical surface ▪ Mirror ▪ Linear motion ▪ Extracting device ▪ End effector ▪ Coordinate data ▪ Ball nut ▪ Wrist element	▪ Set ▪ Mounted ▪ Moving a workpiece ▪ Motion ▪ Drive ▪ Control operation ▪ Servo motor ▪ Rotary axis ▪ First point ▪ Element ▪ Line ▪ Installation ▪ Teaching ▪ System for handling ▪ Shaft ▪ Position and posture ▪ Joint ▪ Horizontal plane ▪ Holding the workpiece ▪ Arm assembly ▪ Reference position ▪ Includes a ball ▪ Configuration ▪ Body ▪ Force sensor ▪ External force ▪ Center point ▪ Ball screw ▪ Second pulley ▪ Laser beam ▪ Direct-acting actuator	▪ Means ▪ Member having ▪ First end ▪ Ball ▪ Screw ▪ First arm ▪ Drive unit ▪ Drive motor ▪ Rotary ▪ End face ▪ Control ▪ Movement of the robot ▪ Movable element ▪ Mechanism mounted ▪ Actuator ▪ Workpiece ▪ Turning ▪ Spline ▪ Joint type ▪ Input ▪ Distal end ▪ Molding machine ▪ Conditions ▪ Assembly	▪ Arm and the second ▪ Structure ▪ Side face ▪ Plate ▪ Output ▪ Holding means ▪ Nut ▪ Machine body ▪ Tool mounted ▪ Robot controller ▪ Pulley ▪ Three power transmission units ▪ Tensile ▪ Supply ▪ Pivot ▪ Mounted on a molding ▪ Horizontal ▪ Fifth arm ▪ Bearing unit ▪ Umbilical ▪ Passage ▪ Monitoring an operation ▪ Intermediate base member ▪ Handling ▪ Flange	▪ Supporting ▪ Plurality of robot ▪ Path ▪ Having a tool ▪ Coordinate type robot ▪ Arm includes ▪ Workpiece comprising ▪ Surface ▪ Section ▪ Second point ▪ Posture ▪ Movement of the tool ▪ Information processing ▪ Engaged ▪ Coordinate system set ▪ Axes ▪ Articulating ▪ Adjusting ▪ Respective robot arm ▪ Processing means ▪ Coating ▪ Center ▪ Angle	▪ Lift arm ▪ Robot arm having ▪ Portion ▪ Machine ▪ Front side ▪ First vertical motion arm ▪ Device comprising ▪ Axis of the robot ▪ Wrist ▪ Vertically disposed ▪ Operation ▪ Molded article ▪ Forward end thereof ▪ First surface ▪ Extending parallel ▪ Control system ▪ Axis perpendicular ▪ Supporting the workpiece ▪ Electric power ▪ Component ▪ Communicating

TOSHIBA CORP

Moving robot	Slider	Driving	Control	Robot device	Industrial robot
▪ Linear moving ▪ Speed ▪ Robot ▪ Control section ▪ Body ▪ Signal ▪ Linear movement type robot ▪ Straight moving robot ▪ Coordinate ▪ Control unit ▪ Gripping ▪ Rotation angle ▪ Original point ▪ Mass of a moving ▪ Manipulator device ▪ Joint ▪ Hand ▪ Actuator means ▪ Robot system ▪ Axes ▪ Longitudinal	▪ Pulley ▪ Motor ▪ Moved linearly ▪ Slider ▪ Moving type robot ▪ Belt ▪ Face ▪ Ball nut ▪ Longitudinal direction of the frame ▪ Driven ▪ Y-axis driving member 3 ▪ Spline bush ▪ Sensor ▪ Rectangular parallelepiped ▪ Peripheral surface ▪ Turning angle ▪ Single axis	▪ Second drive ▪ Force ▪ Linear ▪ Line ▪ Rotatably supported ▪ Case ▪ Arranged ▪ Transmitting ▪ Pair ▪ Working head ▪ Signal processing means ▪ Shaft extending ▪ Rectilinear motion ▪ Position signal ▪ Gear ▪ Cylindrical ▪ Angular ▪ Swingable ▪ Spline shaft ▪ Rocking	▪ Motor ▪ Controller for industrial robot ▪ Surface ▪ Storage ▪ Pulse ▪ Terms ▪ Straight line ▪ Signal processing means responsive ▪ Signal indicative ▪ Section calculates ▪ Linear movement ▪ Horizontal ▪ Feed ▪ Specified position ▪ Single axis robot ▪ Means for transmitting ▪ Face of the arm ▪ Center	▪ Rear ▪ Vibration ▪ Moving an arm ▪ Intermediate ▪ Block ▪ Attitude ▪ Action ▪ Movement ▪ Tool shaft ▪ Imparting ▪ Guide ▪ Bending ▪ Switch ▪ Pinion ▪ Cutting ▪ Orthogonal robot ▪ Air ▪ Manipulator	▪ Frame ▪ Operation ▪ Connected ▪ Industrial robot ▪ Ball screw ▪ Belt ▪ Shaft ▪ Robot actuator ▪ Turning ▪ Motion ▪ Means ▪ Acceleration ▪ Moving member ▪ Hydraulic cylinder

HONDA MOTOR CO LTD

Control system
- Controlled object
- Space
- Motion
- Leg bodies
- Robot
- Posture
- Plurality of legs
- Moving an object
- Holding
- Force
- Control program
- Module
- Means for determining
- Vertical
- Reference
- Information the position
- Grasping
- First coordinate system
- Extended from the body
- Configured to perform
- Condition
- Two legs
- Specified action
- Processor
- Vector
- Variable
- Rail
- Desired position
- Command
- Bolts

Legged mobile robot
- Motion of the robot
- Legged mobile robot control system
- Arm
- Virtual space
- Surface
- Robot for causing
- Portion thereof
- External force
- End portion
- Reference point
- Hand
- Gait
- Driving
- Desired motion
- Bipedal mobile robot
- Trajectory
- System for generating
- Ground contact
- Displacement
- Device comprising
- Bending angle
- Stable posture
- Result of the first
- Path
- Improving
- Coordinate system
- Center of gravity
- Bending and stretching
- Real space
- Plurality of finger mechanisms
- End effector
- Detection unit

Motion control
- Body
- System for controlling
- Second predetermined
- Motion of the object
- Motion state amount
- First means
- Disposed
- Contact
- Configured to control
- Center
- Virtual surface
- Model
- Leg type
- Basis
- Program
- Plane
- Movable
- Manner
- Sequence
- Second coordinate system
- Reducing
- Interfering
- Efficiency
- Desired gait
- Degree
- Action force
- Acquisition unit
- Workpiece
- Welding gun
- Linear guide
- Interpolation
- Configured to search
- Apexes

Robot arm
- Leg
- Robot control method
- Axis of rotation
- Apparatus comprising
- Guide rails
- External
- Wrist
- Joint
- Second robot
- Control
- Arm respectively
- Operation
- Leg portion
- Front end
- Cross
- Apparatus having
- Transmitting
- Right angles
- Pair of guide
- Moving the object
- Level
- Legged mobile robot
- Reduction gear
- Plate
- Movement
- Industrial robot
- Body into contact
- Applied
- Welding
- Recognized
- Prescribed
- Power
- Frame
- Elevating
- Actuator
- Machine
- Finger
- Articulated robot having

Signal
- Recognized by the second
- Force sensor
- Capable
- Applied to the object
- Sunroof
- Right arm
- Network
- Magnitude
- Front surface
- Depending
- Carried
- Acceleration

Joint
- Second robot
- Control
- Arm respectively
- Operation
- Leg portion
- Front end
- Cross
- Transmitting
- Right angles
- Pair of guide
- Moving the object
- Level
- Legged mobile robot
- Intermediary
- Equipped
- Electric motor
- Coupling
- Constant
- Bracket
- X-axial
- Swingable
- Shaft
- Preventing
- Plurality of welding
- Axes

PANASONIC CORP

Robot Arm	Industrial robot	Orthogonal robot
▪ Means ▪ First arm ▪ Control device ▪ First moving ▪ Driving ▪ Unit provided ▪ Portion ▪ Detecting ▪ Connected ▪ Horizontal ▪ Control apparatus ▪ Supporting ▪ Transporting ▪ Posture ▪ Pair of first ▪ Manipulator ▪ Input ▪ Capable of reducing ▪ Arm coupled ▪ Motion ▪ Recognizing ▪ Fourth arm ▪ Endless belt ▪ Center of gravity ▪ Arm is recorded	▪ Industrial robot having ▪ Control ▪ Respective first ▪ Turning ▪ Surface ▪ Sensor ▪ Movable ▪ Means includes ▪ Joint ▪ Horizontal articulated ▪ First arm having ▪ Driving device ▪ Opposite end ▪ Having one end connected ▪ Calculating means ▪ Block	▪ Robot system ▪ Mounted ▪ Housing ▪ Transfer system ▪ Robot capable ▪ Force ▪ Electronic ▪ Control device for controlling

ABB AB

Point	Orientation	Control unit	Control signals	Sensor
▪ Second position ▪ Robot coordinate system ▪ Tool Center point ▪ Arm ▪ Upper Arm ▪ Measuring point ▪ Rotation of the first ▪ Effecting motion ▪ Calibration object ▪ Orientation of the object ▪ Fixed point ▪ Start position ▪ Second plane ▪ Second drive means ▪ Longitudinal axis ▪ Amplitude signal ▪ Second carriage ▪ Error signal	▪ Arm system ▪ Distance ▪ Velocity ▪ Unit is arranged ▪ Wrist ▪ Reference position ▪ Range of the robot ▪ Defined by input signals ▪ Configured to move ▪ Robots and external axes ▪ Drive means ▪ Data processing	▪ Axes of movement ▪ Program ▪ Adapted to move ▪ Second arm ▪ First position ▪ Value ▪ Calculating ▪ Signal ▪ Robot tool ▪ Opposite sides ▪ Mounted ▪ Monitoring ▪ Locking member ▪ Gripper ▪ End element ▪ Carrying the object ▪ Adapted to measure forces ▪ Switch ▪ Spring ▪ Spray ▪ Perpendicular to the first ▪ Device for handling ▪ Coordinate	▪ Control signals representing ▪ Input signals ▪ Industrial robot having ▪ Graphical user interface ▪ Robot control unit ▪ Point associated ▪ Operating position ▪ Displacement ▪ Welding ▪ Rotation of the upper arm ▪ Intersects	▪ Surface of an object ▪ Arm of the robot ▪ Receive ▪ Operating ▪ Axis of rotation and translation ▪ Attached to the robot ▪ Workpiece ▪ Substantially parallel ▪ Element having ▪ Correction ▪ Communication

HITACHI GROUP

Arm	Drive means	Robot control	Industrial robot	Type robot
▪ Control method ▪ Motor ▪ Point ▪ Vertical ▪ Driving mechanism ▪ Output shaft ▪ Coordinate ▪ Control system ▪ Section ▪ Rotary member ▪ Command value ▪ Center axis ▪ Upper arm ▪ Memory means for storing ▪ Industrial robot ▪ Welding robot ▪ Articulated type ▪ Manual operation ▪ Manipulator ▪ Automatic welding ▪ Apparatus for an industrial robot ▪ Manipulator	▪ Operation control ▪ Rotation ▪ Connected ▪ Shaft positioned ▪ Movable ▪ Position detecting ▪ Supported ▪ Steps ▪ Second arm ▪ Fixed ▪ Detecting signal ▪ Value ▪ Horizontal ▪ Arm is moved ▪ Driven ▪ Vertical axis ▪ Memory means ▪ Coupled ▪ Actuator ▪ Holding ▪ Displacement ▪ Command ▪ Pair ▪ Function ▪ Cylinder ▪ Sprocket ▪ Slider ▪ Rectangular coordinate system ▪ Range ▪ Pulse ▪ Program ▪ Parameters representing ▪ Manual ▪ Forearm	▪ Angle ▪ Rotation movement ▪ Portion ▪ Robot mechanism ▪ Stopping ▪ Sequence ▪ Posture ▪ Motor mounted ▪ Articulated robot ▪ Adjusting ▪ Transformation ▪ Rotation about a vertical ▪ Pattern ▪ Head ▪ Gripper ▪ Counting ▪ Calculated ▪ Linkage	▪ Arm having ▪ Orientation ▪ Wrist mounted ▪ Shaft of said first ▪ Perpendicular ▪ Parallel ▪ Means for driving said arm ▪ Interpolation ▪ End of the lever ▪ Detector ▪ Arm of the robot ▪ X-Y ▪ Structure ▪ Member mounted ▪ Encoder ▪ Welding	▪ Orthogonal type robot ▪ Coordinate type ▪ Transmission ▪ Double arm type robot ▪ Cylindrical ▪ End effector ▪ Cable ▪ Robot system ▪ Robot operation ▪ Arm respectively ▪ Installed ▪ Drive motor ▪ Workpiece ▪ Linear ▪ Length ▪ Interface ▪ Joint ▪ Means ▪ Space ▪ Plate ▪ Periphery ▪ Machine ▪ Executed ▪ Track ▪ Parallelogram ▪ Improve ▪ Cooperation ▪ Belt ▪ Assembled

Vertical: Medical Applications

HANSEN MEDICAL INC

Drive unit	Robotic medical system	Catheter	Shaft	Drive mechanism
▪ Robotically controlled medical instrument ▪ Proximal end ▪ Flexible ▪ Operative ▪ Mechanical cabling ▪ Instrument driver ▪ Instrument assembly ▪ Guide assembly ▪ Elongated shaft ▪ Adapter ▪ Robotic medical system ▪ Surgeon manipulation ▪ Shaft and a driver ▪ Robotic surgery apparatus ▪ Minimally invasive ▪ Interchangeable surgical instrument ▪ Central axis ▪ Carriage assembly ▪ Outer and inner ▪ Medical implement ▪ Guide member ▪ End effector ▪ Flexible instrument ▪ Robotic ▪ Operatively coupled ▪ Instrument assembly ▪ Drive ▪ Proximal and distal ▪ Medical ▪ Interchangeable instrument ▪ Axis ▪ Sheath instrument ▪ Fluid-dispensing instruments	▪ Medical instrument assembly ▪ Coaxial catheter system ▪ Inner medical ▪ Electromechanical driver configured for being coup ▪ Surgical instrument ▪ Probe ▪ Controller configured for directing the motor ▪ Array ▪ Arrangement ▪ Anatomical vessel ▪ Storage ▪ Axially	▪ Instrument system ▪ Interface ▪ Outer ▪ Mechanically coupled ▪ Belt ▪ Single ▪ Plurality of actuating elements ▪ Delivery	▪ Medical procedure on a patient ▪ Input device ▪ Instrument driver ▪ Plurality of instruments ▪ Internal operative ▪ Plurality of instruments	▪ Mechanically drivable ▪ Subject is mounted ▪ Response to the at least one command ▪ Control movement ▪ Patient ▪ Jaw ▪ Controller ▪ Rigid support ▪ Position ▪ Lumen ▪ Drivably

INTUITIVE SURGICAL INC

Image display	Medical device	Joint
▪ Surgical end effector ▪ Medical system ▪ Image capture device ▪ Surgical procedure ▪ Generate ▪ Video ▪ System transmitting ▪ Point ▪ Minimally invasive ▪ Image corresponding ▪ Assembly ▪ Ultrasound image ▪ Surgical tool ▪ Section ▪ Machine readable code ▪ Instrument with respect ▪ Hand of an operator ▪ Configured to drive ▪ Cardiac ▪ Beating heart ▪ Threshold ▪ Display the image ▪ Adapted	▪ Response to movement ▪ Input device ▪ Sliding mode control ▪ Robotic surgical system ▪ Robotic surgery ▪ Parameter ▪ Operator manipulation ▪ End effector ▪ Configured to effect	▪ Robotic surgical ▪ Motions of the joint ▪ Surgical instrument ▪ Manipulation of the handle ▪ Robotic arm ▪ User manipulation of a master manipulator ▪ Surgery ▪ Arm to move ▪ Grip

Appendix A: Key Assignee Normalization Table

Note: The tables below include normalization from US Assignments database and so some assignees may appear under multiple normalized names.

HITACHI GROUP

HITACHI KOKI KK
HITACHI KEIYO ENG
HITACHI DENSHI ENJINIARINGU KK
HITACHI SHIPBUILDING ENG CO
HITACHI LTD
HITACHI TECHNO ENG
HITACHI METALS LTD
NISHIUCHI SHIGETO NONAKA YOUICHI
HITACHI HIGH TECH CORP

FANUC CORP

FANUC LTD
JHAVERI NISHANT ORR IAN H
KOBAYASHI HIROHIKO
GMF ROBOTICS CORP
FANUC ROBOTICS NORTH AMERICA
AKEEL HADI TSAI JASON
CLIFFORD SCOTT J GRACA RANDY NIEDERQUELL BRADLEY O

ABB AB

ABB TECHNOLOGY AG
ASEA AB
ABB ROBOTER GMBH
CINCINNATI MILACRON INC
GRACO ROBOTICS INC
ERIKSSON BENGT
KROGEDAL ARNULF
ASEA BROWN BOVERI

PANASONIC CORP

MATSUSHITA ELECTRIC IND CO LTD
MATSUSHITA DENKI SANGYO KK
MUKAI YASUSHI NAGAI TAKASHI TAKAHASHI WATARU

HONDA MOTOR CO. LTD.

HONDA ENGINEERING CO LTD
SANO SHIGEO
HASEGAWA TADAAKI
ASAMIZU KENICHI ISHIDA TAKETO SHIBAYAMA TAKAO

Appendix B: Search Strings Used for Categorization

Categorization: Types

1. Anthropomorphic Robots

Anthropomorphic Robots	
(TAC) contains (humanoid or android or anthropomorphic* or anthropomorfic*)	10 results

2. Articulated Robots

Articulated Robots	
(TAC) contains (articulated* or (mobile w/2 robot*) or legged or hexapod)	234 results

3. Cartesian / Gantry Robots

Cartesian / Gantry Robots	
(TAC) contains (cartesian* or gantry* or orthogonal* or (linear* w/2 robot*))	211 results

4. Cylindrical Robots

Cylindrical Robots	
(TAC) contains (((cylindrical or cylinder or circular) w/2 robot*) or (prismatic w/2 joint*))	11 results

5. Industrial Robots

Industrial Robots	
(TAC) contains ((industrial or industry or industrie w/3 robot*) or industrierobo*)	297 results

6. Parallel Robots

Parallel Robots	
(TAC) contains (parallel w/3 (robot* or manipulator* or manipulater*))	31 results

7. SCARA Robots

SCARA Robots	
(TAC) contains (scara or (parallel w/3 joint*) or (selective w/2 (compliance or compliant)))	19 results

8. Spherical/ Polar Robots

Spherical/Polar Robots	
(TAC) contains ((polar w/2 (coordinate* or robot*)) or dovetail or (linear w/2 bearing*) or spherical* or (prismatic w/2 joint*))	45 results

Categorization: Applications

1. Agriculture

Agriculture	
(TAC) contains (agricultur* or seed* or pluck* or farm* or agro* or herbi* or cultivat* or scouting or harvest* or crop or forage* or fertili* or insecti* or weed* or irrigat* or sow or sowing or plough* or horticultur* or pesti* or flower*or planting* or planta* or milk* or sprinkl*)	16 results

2. Defense

Defense	
(TAC) contains (defence* or defense* or combat* or aerospace or aeronautic* or aerodynamic* or navy or army or airforce or aircraft or airplane* or airline* or military or armo* or missile* or weapon* or sniper or copter* or artillery or surveillan*)	22 results

3. Material Handling

Material Handling	
(TAC) contains (dispensing or dispatch* or pallet* or packag* or handel* or handl* or ((transferring or moving) w/2 (object* or objekt* or material* or device* or devise* or article* or system* or substrate*)) or stack* or transport* or fetch*)	457 results

4. Medical

Medical	
(TAC) contains (medical* or surger* or medicin* or surgic* or stent* or cancer* or mitral* or laparoscop* or endoscop* or angioplast* or coronary* or biopsy or patient* or cathet* or radiat* or massage)	112 results

5. Other Industrial Applications

Other Industrial Applications	
(TAC) contains (bonding or sealing or polishing or coating or spray* or assembl* or foundry or drill* or waterjet* or (water w/2 jet*) or milling or grind* or deburr* or lacquer* or gelatin* or riveting or gluing or glue* or paint* or hemming or dust* or clean* or sludge or (waste* w/2 material*))	417 results

6. Welding

Welding	
(TAC) contains ((arc or mig or tig or spot or laser or resistance or seam or plasma or flux w/2 weld*) or welding or solder*)	55 results

Categorization: Parts

1. Actuators

Actuators	
(TAC contains (actuator* or driver*)	256 results

2. Controllers

Controllers	
(TAC) contains ((controller w/2 robot*) or "lead-through" or "record-playback")	52 results

3. End Effectors

End Effectors	
(TAC) contains (grip* or effecter* or effector* or (end w/2 effect*) or dextrous* or dexterous* or finger*)	371 results

4. Manipulators

Manipulators	
(TAC) contains (manipulater* or manipulator* or "micromanipulater" or "micromanipulator")	309 results

5. Sensors

Sensors	
(TAC) contains (sensor* or sensing* or detector*)	343 results

Summary

Robotics is a rapidly growing field, as we continue to research, design, and build new robots that serve various practical purposes, domestically, commercially, or defense. Robotic arms are used in most industries such as material handling, welding, medical fields, agricultural activities.

Companies such as Fanuc Corp, Hitachi Group, Honda Motor Co Ltd, Hansen Medical Inc. are amongst the leaders with the largest patent portfolios.

This report graphically analyzes robotic arm technologies from various perspectives, categorizes and highlights the key companies involved, defines unique categories.

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