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Open Innovation in Robotic Software—Pattern and Implications

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Abstract

This paper discusses the pattern of open innovation in robotic software (RSW) with both qualitative and quantitative data such as those from industrial statistics, news and the Sourceforge Open Source Software (OSS) projects. At the firm level, open innovation can be discussed in terms of inbound sourcing and acquiring and outbound revealing and selling classified by Dahlander and Gann (2010). Open innovation in RSW also involves open activities such as movement in open architecture for software and OSS. This paper also illustrates each of these patterns of open innovation in RSW and the role of significant actors. It especially analyzes OSS in robotics in terms of development status, intended users, operating systems, programming languages, etc. Finally, this paper gives some implications.

Keywords: open innovation, robotic software (RSW), open architecture, open source software (OSS)

1. Introduction

"Open innovation is a paradigm that assumes that firms can and should use external ideas as well as internal ideas, and internal and external paths to market, as the firms look to advance their technology" (Chesbrough, 2003). Currently, open innovation has been already considered as an important factor for a company's success in many sectors, especially these sectors with characteristics of complexity and embeddedness, like robotic software (RSW). However, there has been no research done on open innovation in RSW, while there has been little research done on open innovation in embedded software (Henkel, 2006), and a few research on open innovation in general PC software, such as open source software (OSS) research (see literature view on OSS in von Krogh and von Hippel (2006)) has been carried out. Under this context, this paper will discuss open innovation in RSW by focusing on the pattern and implications.

The first question is what forms of openness happen in RSW. We will answer this question based on the classification of openness by Dahlander and Gann (2010) as shown in Table 1.

Table 1 Different Forms of Openness

	Inbound innovation	Outbound innovation
Pecuniary	Acquiring	Selling
Non-Pecuniary	Sourcing	Revealing

Source: Dahlander and Gann (2010)

The second question is what the pattern of open innovation in RSW is. Based on the definition of open innovation by Chesbrough (2003), we argue that open innovation in RSW involves open activities in development of RSW where the actors look for external ideas and sources such as open architecture movement and OSS movement. Open architecture is a type of architecture that allows adding, upgrading and swapping components. To make robotic technology (RT) widely used, and to make various robots appear in the market for commercial use, robotic parts (mechanism, hardware, and software) should be reproduced, reused and integrated with an open structure. OSS is always used as an example of open innovation in software. This happens not only in general PC, but also in RSW. These definitions are the basic framework for our later analysis to answer the second research question.

We will use both qualitative and quantitative data such as those from industrial statistics, news and the Sourceforge Open Source Software (OSS) projects to discuss open innovation in RSW.

In the final section, we will discuss some implications. Before analyzing the pattern of open innovation in RSW in section three, we will first argue the significance of open innovation in RSW in section two.

2. Significance of open innovation in RSW

As a typical example of highly complex embedded software and the brain of robot, RSW plays a significant role in RT, especially for the next generation robots. There is an increasing need for integrating many kinds of technologies into a robot, as seen in Fig. 1 where robot related patents cover more than 100 4-code classes in USPTO database since 1985 and about 50 4-code classes on average in JPO database. Among these technologies, RSW plays a key role as the intelligence and the mechanism of integration. Meanwhile, with the characteristics of being distributed, data-intensive and real-time, RSW is becoming more difficult and complicated to develop and requires high quality, safety, reliability and intelligence. Nowadays, robot industry is undergoing a shift from industrial to non-industrial robot (Kumaresan and Miyazaki, 1999). For example, the market size of service robots in Japan has increased

from 1.9 billion yen in 2002 to 4.5 billion yen in 2004 and 6.7 billion yen in 2006 (Seedplanning, 2008) and then to 7.7 billion in 2008, and expected to reach 23.1 billion in 2012 (Fuji Keizai, 2009) (see Fig. 2). According to the forecast from METI (2004), in 2025, the market size of next generation robot may reach 4,785 billion yen (bigger than the market size of industrial robots), and RSW market size may reach 1507 billion yen (about 31.5% of the robot market). RSW will become more and more important for the next generation robot and future robot market.

However, RSW faces challenges currently, as pointed out by Bruyninckx (2008) the key problems in robotics software in the industrial and the academic practice are a chronic lack of standardization, interoperability and reuse of software libraries, both proprietary and open source; therefore, for RSW, "the future should be open". We also already discussed that opening up is very important for the innovation in RSW sector (Xie and Miyazaki, 2009). Because of the characteristics of complexity and being like glue for integration of many technologies, open innovation becomes extremely significant in the RSW sector.

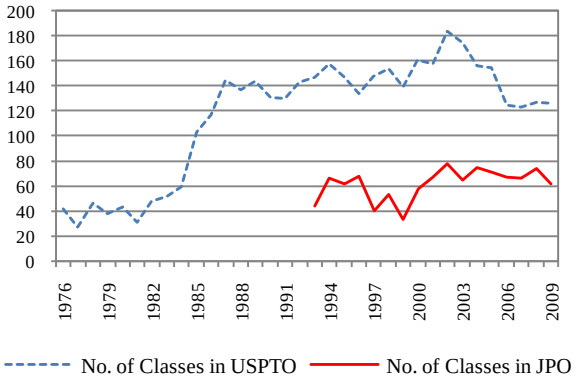

Fig. 1 Number of IPC classes of Robot Related Patents by Publication Year

Note: 4-code subclasses (e.g. "B25J") are analysis target
Source: Based on our patent database searched from USPTO and JPO

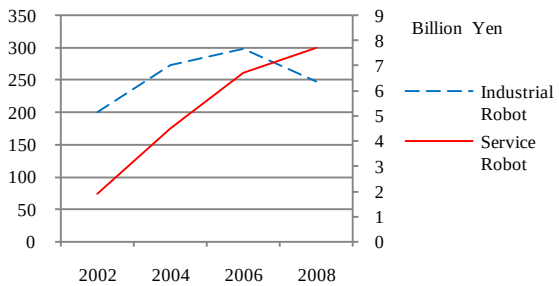

Fig. 2 The shift of Robot from Industrial to Non-Industrial in Recent Years

Note: Based on Japanese Robot Market Data
Source: JARA's statistics data and Fuji Keizai's Survey

3. Patterns of Open Innovation in RSW

3.1 Forms of Openness in RSW

Based on Dahlander and Gann (2010)'s classification of different forms of openness, we illustrate them in the RSW case as shown in Table 2. Firms are not the only actors in open innovation activities, but also other organizations, such as national research institutions in Japan. Therefore, we changed some concept of different forms of openness in a broader sense of actors.

Table 2 Different Forms of Openness in RSW

	Definition	RSW Cases
Revealing: outbound innovation-non-pecuniary	How internal resources are revealed to the external environment free of charge	Actors publish their RSW as OSS, such as OpenHRP-aist by AIST in Japan
Selling: outbound innovation-pecuniary	How actors commercialize their inventions and technologies through selling or licensing out resources developed in other organizations	Vendors sell RSW tools to RSW developers for further development of RSW, such as VxWorks being sold to Honda for ASIMO's software platform
Sourcing: inbound innovation-non-pecuniary	How actors can use external sources of innovation free of charge	RSW developers use OSS or free Middleware, such as Fujisoft published "Palro" robot by using RT Middleware by AIST and Linux-ubuntu 8.04 LTS as its operating system
Acquiring: inbound innovation-pecuniary	Acquiring input to the innovation process through the market place	RSW developer buying special tool or OS for RSW development, e.g. Honda bought VxWorks for ASIMO's platform

We can see that inbound and outbound innovations are opposite, because of the viewpoint where one is based. For example in case of ASIMO (a humanoid robot by Honda), Wind River (Merged by IBM in 2009)'s selling license of Vxworks to Honda is outbound-innovation, while Honda's buying VxWorks from Wind River is inbound-innovation.

As discussed by Dahlander and Gann (2010), there exists combination of different forms. Let's look at the case of Fujisoft's service robot "Palro". Based on the RT Middleware—OpenRTM-aist by National Institute of Advanced Industrial Science and Technology (AIST), Fujisoft, a big Japanese software company, has begun to sell "Palro" priced 298,000 yen from 2nd February, 2010. Its RSW system "Sapie" includes Linux OS (changed ubuntu 8.04 LTS in order to have real-time characteristic), OpenRTM-aist, Device Communication Library, Sapie Resource Allocator, Sapie Demand Multiplexer, Palro Application Programming Interface (PAPI), Sapie API, Palro Applications (PARPS), Service Applications (SAPPS), Sapie Cell, and Sapie Cell Slot. Using Linux OS and RT Middleware is considered as sourcing. Specially, some of Palro Applications (PAPPS) is published to public as OSS, which is a non-pecuniary outbound

innovation—revealing.

3.2 Open Activities

If we just analyze open innovation in the form of openness, we cannot know the whole view of open innovation in RSW, especially what kind of activities are used to promote open innovation. For this purpose, we chose Japanese RSW to see open activities in RSW.

Open innovation is always in conflict with intellectual property (IP), such as patent protection. So how is the situation in RSW? How are the open activities in RSW carried out by significant actors? Let's look at the case of Japan. Firstly, we checked RSW and RT related patents in JPO to find out the most important actors in RSW patenting and RT patenting. In JPO, top 20 Japanese applicants possess 1006 RSW related applications (70.70% of 1423 RSW related applications by firms) and 212 issued RSW related patents (92.58% of 229 issued RSW patents by firms) in JPO database. We can see that these top applicants play a significant role in patenting RSW related claims and patents. Table 3 shows the top 20 Japanese applicants in RSW and RT patenting in both JPO. Among the top 10 applicants with issued RSW related patents, 9 of them (90%) as shown in Table 3 with bold and italic fonts, ranked in top 10 applicants with issued robot patents. Among the top 20 applicants with issued RSW related patents, 15 of them (75%) as shown in Table 3 with italic fonts (including both bold and non-bold fonts), ranked in top 20 applicants with issued RT robot patents. Therefore, there has been a very high consistence in patenting of RSW and robot related patents for the significant actors.

Table 3 Top 20 Japanese Applicants in RSW and Robot Related Patenting in JPO

Rank	JPO			
	Issued Robot Patents		Issued RSW Related Patents	
	Applicant Name	NO.	Applicant Name	NO.
1	***Fanuc Ltd.***	292	***Fanuc Ltd.***	56
2	***Kawasaki Heavy Industries (KHI)***	197	***NEC Corp.***	30
3	***NEC Corp.***	137	***Sony Corp.***	20
4	***Honda Motor***	92	***Kawasaki Heavy Industries (KHI)***	17
5	***Toshiba, Corp.***	83	*NTT, Corp.*	14
6	***AIST***	61	***Toshiba, Corp.***	12
7	***Sony Corp.***	56	***AIST***	9
8	*Toyota Motor*	47	***Seiko Epson***	8
9	***Panasonic Corp.***	47	***Panasonic Corp.***	7
10	***Seiko Epson***	31	***Honda Motor***	7
11	Hitachi, Ltd.	28	LG Japan	4
12	Yaskawa Electric	23	*Toyota Motor*	4
13	Funai Electric	21	*Fujitsu Ltd.*	4
14	Dainippon Screen Mfg.	21	*Omron, Corp.*	3
15	*NTT, Corp.*	19	JAXA	3
16	*Kanto Auto Works*	19	*Kanto Auto Works*	3
17	Murata Machinery	18	Tokyo Electron	2
18	*Omron, Corp.*	17	Konami Corp.	2
19	Japan Science and Technology Corp.	17	*Mitsubishi Heavy Industries (MHI)*	2
20	*Mitsubishi Heavy Industries (MHI)*	16	CAI Media Joint Dev. Co., Ltd.	2
	Fujitsu Ltd.	16		

Source: Our own database analyzed from JPO. Data include all Japanese patents published until 31st Dec., 2009.

Table 4 RSW information and open activities of significant actors in RSW patenting

	Robot Type	RSW Info	Open	Architecture
Fanuc	Industrial	iRVision; FANUC ROBOGUIDE; many software tools for industrial robot	No	—
NEC	Service; Humanoid	RoboStudio	No	—
Sony	Amusement Humanoid	OPEN-R SDK	Yes	OPEN-R
KHI	Industrial	K-CONG and many other software tools	No	Some based on ORiN
NTT	Service	—	No	—
Toshiba	Service	—	No	ORCA
AIST	humanoid	OpenHRP; OpenRTM-aist	Yes	OpenHRP
Seiko Epson	Industrial	Image Processing tool--Vision Guide	No	—
Panasonic	Industrial	Panasonic DTPS 3D Simulation; G2 PC Tools Software	No	—
Honda Motor	Humanoid Service	VxWorks based complex system	No	—
Toyota Motor	Industrial Service Humanoid	—	No	—
Fujitsu Ltd.	Service Humanoid	—	No	—
Omron	Industrial Service	—	No	—
Kanto Auto	Industrial	—	No	—
MHI.	Industrial; Humanoid	"Wakamaru" is based on "MontaVista Linux"	No	—

Source: Based on information we collected from diversifying sources like news papers, companies website and report, etc. "—" represents that we cannot find any information, or that there is no public information in this term.

However, these significant actors behave differently in open innovation. Table 4 shows the related RSW information and open activities of these significant actors. From table 4 we can see that most significant robot manufactures keep their RSW inside and closed and develop their own RSW system to control their capabilities in the robot sector, especially in the industrial robot sector, such as Fanuc, Kawasaki Heavy Industries (KHI), etc. For non-industrial robot sector, some companies chose to make RSW closed while some opened their RSW to public. For example, Honda, known for successful and innovative

motorcycles, cars and other power products, first began to examine the principals of two-legged robotic locomotion in 1986, and in 1989 decided to develop their own RSW by relying on operating system software—VxWorks from Wind River as the heart of their robot projects, but kept their software system locked.

On the other hand, some robot manufacturers, especially those which produce service robots, tended to use open architecture or open their RSW up; especially, Toshiba put forward Open Robot Controller Architecture (ORCA) and Sony promoted Open-R and provide free download of Open-R SDK. Robot has been developed and manufactured using an integrated system; therefore different firms have different concepts of robot and heterogeneous concepts of RSW. Due to the highly proprietary nature of RSW and heterogeneities in RSW, there is a serious lack of cross-platform industry standard, subsequently affecting the development of software tools for robots. Therefore, a new concept of robot thereafter RSW is significant for the whole RSW sector. With a new architecture, RSW development may be changed and become relatively easy. Innovation in architecture is more related to open architecture, which is easy to connect with other organizations and fields and a new way to implement open innovation. Open architecture and platform are two possible ways to promote open innovation, because they may promote collaboration between different actors, resulting in revealing and sourcing, even selling and acquiring. Toshiba put forward ORCA because they believed that with the ORCA architecture, it may become faster to develop RSW, easy to connect with other robot controllers/peripheral equipment, easy to change algorithm, rapid to introduce new technologies, to accumulate and reuse RSW codes and even to create a new market (Ozaki, 2004). Sony put forward its own open architecture OPEN-R, because they believed that it is easy to change software module as illustrated in their description of Open-R.

AIST, as a special national institute, made a great effort not only in RSW and robot patenting, but also in promoting open activities. AIST also took the responsibility of developing common technologies for the whole robot sector, especially for the next generation robots in Japan. Open Architecture Human-centered Robotics Platform (Open HRP) and Open RTM-aist are significant results by AIST. These two open software projects are important open innovation activities in RSW. During the processes of these two projects, AIST innovated in an open way by which they collaborated with companies and universities shaping the relationship of triple helix.

Middleware concept recently attracted lots of attention especially open and common middleware. These organizations (institutions, universities and companies) got involved because they hoped that by using middleware, it is possible to reuse software codes, to enter the robot industry more easily and easy to integrate software components. Therefore in Japan, several related projects were implemented. Especially, there are three important projects, RT-Middleware, ORiN and RSi. Usually, these projects were implemented by different types of organizations (government, companies, institutions and universities) and collaboration became a common model in Japanese RSW sector. For example, in the case of ORiN (Open Robot Interface for the Network), this project was being conducted in the program "Standardization of Communication Interface for Open Robot" signed to JARA by NEDO (New Energy and Industrial Technology Development Organization) from 1999 to 2002. JARA was the secretariat of this project; members included robot makers such as Denso Corp., Yaskawa Electric Corp., Kawasaki Heavy Industries, ltd., Mitsubishi Electric Corp., Fanuc Ltd., and Kobe Steel, Ltd., and some other institutions, like University of Tokyo, NTT, etc.. This kind of organization is usual in the common platform projects, such as in RT-Middleware and RSi projects. Under these organizations, common technologies were developed and collaboration between different organizations promoted innovations. This is a form of collaboration among government, research institutes, universities and companies. Because of their efforts, RT-Middleware was already adopted as Object Management Group (OMG) standard framework in 2007. As mentioned before, Fujisoft already begun to sell RT-Middleware based robots. In these projects, the research groups were close. However, for each participant in these projects, it was an effective way to collaborate with others, therefore acquiring and sourcing information, resulting in open innovation. Based on this fact, we argue that collaborative projects between different organizations promote open innovation.

3.3 OSS

OSS is always considered as an important indicator of open innovation in the software sector. Therefore, this part will discuss OSS in robotics. SourceForge.net is the world's largest open source software development web site and has the largest collection of open source tools and applications. Xie and Miyazaki (2009)'s paper on "Openization, Standardization and Diversification—in the Case of Robotics Software Sector in Japan" shows the increasing trend in registration of OSSs on RSW in Sourceforge.net until 2008. However, our latest research in September 2010 shows that it has been decreasing since 2008, maybe for the reason of economic crisis, as shown in Fig. 3. Based on this new database that includes 890 RSW projects in Sourceforge.net, we analyzed open RSW in

the following aspects.

In terms of intended users, 414 (46.52%) of these projects are developed for science/research, 364 (40.90%) for developers, 219 (24.61%) for education, 146 (14.60%) for advanced end user, and others for end user/desktop, engineering, IT, manufacturing and aerospace, etc. As seen in Fig. 4, the share of OSS in science/research, developer and education decreased in recent years, while the total share of OSS in other fields, especially in engineering fields and other industries, increased. This illustrates the trend that OSS is going to be used in more robot related industries, not just for research and development.

Among these projects, Windows, all POSIX (Linux/BSD/UNIX-like OS), Linux and BSD are the main operating systems used for. From Fig. 5, we can see that the share of Windows increased and is still No.1, following all POSIX, Linux and then BSD. Unix series account more than half of the OS. During the past decade, Windows OS increased as a very significant supporting platform for robotics.

Concerning programming languages, C++ (387 projects), C (293), Java (193), Python (93), C# (67) and Assembly (42) account for the most following by Matlab (26), Basic (24), PHP (12), Perl (12) and others. In recent years, the shares of C++ and C were increasing while the share of Java decreased. Programming languages of RSW are still ruled by the C family.

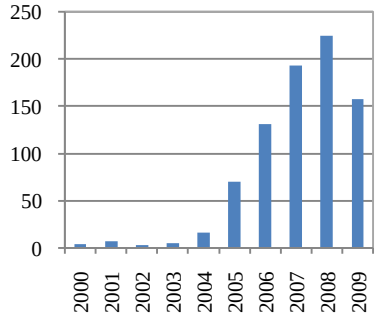

Fig. 3 Robotic Projects in Sourceforge.net (by Registration Year)
Source: Based on the Data Searched from Sourceforge.net

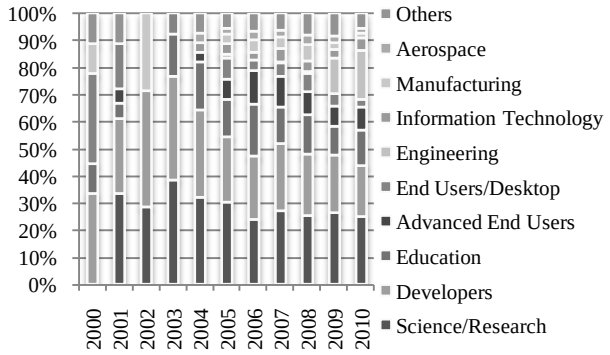

Fig. 4 Intended Users of RSW in Sourceforge.net
Source: Our database on RSW searched from Sourceforge.net

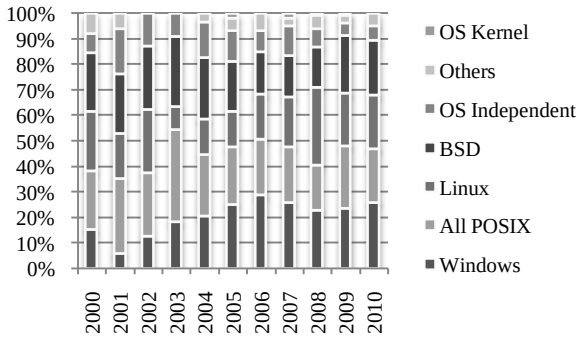

Fig. 5 Share of OS in Open RSW Projects
Source: Our database on RSW searched from in Sourceforge.net

Most of these projects are under the license of GNU General Public License (GPL) (560 projects), GNU Library or Lesser General Public License (LGPL) (138) and BSD License (108). Licenses which follow are Academic Free License (31), Public Domain (29), Apache License V2.0 (15) and others (50).

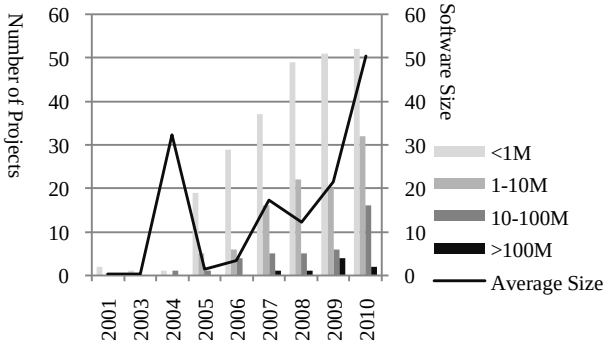

Fig. 6 Softwar size of downloadable RSW projects in Sourceforge.net
Source: Based on the Data Searched from Sourceforge.net

From Fig. 6, we can see the distribution and the evolutionary growth of software size of the downloadable RSW projects in Sourceforege.net by updated year. Although a big fraction of software was the software with size of less than 1M during the last decade, the number and share of bigger software increased. As a result, the average size of OSS in robotics is becoming bigger and bigger. This illustrates the increasing complexity of open source of RSW.

Among these OSS projects, there are some important projects, such as the OROCOS (Open Robot Control Software), Player/Stage platform, Orca, ROS, CARMEN, and Japanese OpenRTM-aist and OpenHRP 3. However, in the movement of OSS, most attractive OSS in Japan, OpenRTM-aist and OpenHRP3 cannot be found in sourceforge.net. OpenRTM-aist is based on Robotic Component Specification standard of OMG (Object Management Group), under LGPL. OpenHRP3 allows the users to inspect an original robot model and control the program by dynamic simulation under Eclipse Public License (EPL) v1.0.

4. Implications

Open innovation is a common type of innovation in the RSW sector. Open innovation in RSW involves all kinds of forms of openness both inbound and outbound. Because of the characteristics of heterogeneous concept in robot and architecture of RSW, and the embeddedness and complexity of RSW, RSW developers should be open to acquire and source all kinds of ideas and resources. RSW developers may choose to make their RSW closed, while they cannot avoid being open to look for outside sources. The results of openness may be products which is not open to the public. However, if the process is open to look for outside ideas and sources, it should be open innovation, based on the definition of open innovation by Chesbrough (2003).

This opening up process highly contradicts the fact that most robot manufacturers keep their software hidden, especially in the industrial robot sector to control their capabilities in the robot sector. However, for the next generation robot, opening up is a possible and good way to collaborate. For actors in the RSW sector, collaboration with others and outbound revealing and selling as well as inbound acquiring and sourcing will improve the development of RSW and robot sector. Furthermore, collaborative projects between different organizations may promote open innovation.

Open architecture and common platform technology are some examples of openness. With the open architecture and common platform, it may become easier to collaborate among different actors in the robot sectors. This is also why Japanese robot sector has been and is working on middleware oriented projects. Open architecture and common platforms provide the base for RSW actors to collaborate.

On the other hand, OSS has played a major role in computer, but its role has been much less significant in robotics. As time goes by, OSS will become much more important in RSW. Governments, agencies, hobbyists, and associations are the main contributors to the OSS in robotics, while lots of firms are unwilling to join this process because closed RSW is a way to control their capabilities in the robot sector. Undoubtedly, opening up makes reuse of RSW possible, which may reduce large repeated work in the development of RSW. Open innovation may be very significant for the next generation robot.

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