Expert Systems with Applications 40 (2013) 7132–7140

Contents lists available at SciVerse ScienceDirect

Expert Systems with Applications

journal homepage: www.elsevier.com/locate/eswa

The ECHORD project proposals analysis – Research profiles, collaboration patterns and research topic trends ☆

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ARTICLE INFO

Keywords:
Pattern collaboration analysis
Research topic analysis
European robotics
Social network analysis

ABSTRACT

This paper investigates the research profiles, collaboration patterns and research topic trends which can be identified in the proposals submitted to the ECHORD (European Clearing House for Open Robotics Development) FP7 project. On a country level, clusters were identified and characterized by patterns of proposal production per inhabitant, score and international cooperation. Belgium and Sweden constitute a cluster characterized by high proposal production, with very high scores and extensive international collaboration. Belgium also excels from another cluster analysis, being as the only country where 100% of proposals involve industry–academia cooperation and obtain scores above 10. Other findings show that single partner proposals have significantly lower quality than multi-partner proposals but, on the other hand, the number of countries involved shows no influence on the quality of the proposals. Despite the high number of industrial participants present on the proposals, it is observed that they play secondary roles in the proposals, with a very low number projects leaded by companies. Also, it is observed that partnerships between research institutions (non-universities) are the most successful. Concerning topics of the proposals, the technology human–robot interface and the product vision robot for small-scale manufacturing are the most significant. Finally, the paper shows clusters of institutions extracted from the giant network of relations obtained from the ECHORD set of proposals.

1. Introduction

The European Clearing House for Open Robotics Development (ECHORD) ECHORD is an FP7 funded project, which is aimed at strengthening the cooperation between academia and industry. ECHORD works as the clearing house where universities and companies meet with the purpose of establishing clear paths for know–how transfer.

The ECHORD basic pillars are the funding of 51 experiments, i.e. small technical projects, and the structured dialogue concept established between academia and industry (Knoll, Siciliano, Pires, & Lafrenz, 2010). The structured dialogue mechanism is composed by 3 main instruments and services: (1) Experiment monitoring: aiming to assess, consolidate and publish the ongoing efforts and results of the financed experiments; (2) Data densification: aiming to build a database and design the necessary mechanisms to collect data on the interesting R&D areas and extract relevant information – the objective here is also on selecting the most relevant forums, events and publications to expose information and obtain feedback; (3) Dissemination of results among the research institutions and organizations and robot manufacturers: aiming to generate digests adapted to the type of individuals and efficiently distribute them through both types of organizations.

1.1. The experiment calls

Three calls for experiments were sent out and with duration from 12 to 18 months and a budget around €300.000. As guidelines for the proposers, three scenarios and four research foci were identified.

1.2. Scenarios and research foci

The range of research topics and subjects in the field of robotics is virtually unlimited. Thus, ECHORD defined a clear thematic orientation which is reflected in selected scenarios. Three scenarios were identified, which are both scientifically challenging and commercially relevant. They consist of challenges, which robotics experts can easily understand and use as a basis for their own

☆ This work was supported by the FP7 European project ECHORD – 231143.

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http://dx.doi.org/10.1016/j.eswa.2013.06.046

research. The selected scenarios, which build on each other, are: *human–robot co-worker*, *hyper-flexible manufacturing cells*, and the *cognitive factory*. Within these scenarios, different research foci have been identified. The research foci are reference points for the expected scientific progress of proposals for experiments. They combine mechanical design, controller technology developed by manufacturers, with the research community expertise in sensing, cognition, and behavior control. The research foci are *human–robot interfacing and safety*, *robot hands and complex manipulation*, *mobile manipulators and cooperation* and *networked robots*.

2. Data set and methodology

2.1. Data set

This paper is based on the data from ECHORD experiment proposals and from the correspondent revision and selection process. The reviews were made by at least 2 independent experts that classified the experiments according to (1) scientific and/or technological excellence, (2) the quality and efficiency of the implementation and (3) the potential impact through the development, dissemination and use of project results. For each criteria a 0–5 mark was given and technical and implementation criteria, resulting in a ranking of scores from 0 to 15 points (see ECHORD-GuideForApplicants for details).

For the classification of the experiments in terms of research and application topics presented in Section 5 we considered several different frameworks; namely, the one produced by World Technology Evaluation Center in 2006 (Bekey & Ambrose, 2006) together with an International assessment, the strategic research agenda (SRA) Bischoff et al., 2009 and the table of contents of the Springer Handbook of Robotics (Siciliano & Khatib, 2008). Due to the fact that up-to-date classifications are valuable and considering also the coverage of selected frameworks, we have chosen the SRA as the basic guideline. The SRA resulted from the efforts developed in the Coordination Action for Robotics in Europe (CARE), which was a European cooperative effort of academic and industrial stakeholders to design a join strategy aiming to strengthen Europe's competitiveness in robotics R&D, as well as global markets, and to improve quality of life. CARE is also closely related with the European Robotics Platform (EUROP) initiative. This agenda forecasts the future of robotics in Europe until 2020 defines a group of technologies with significant impact in the robotics development and foresees a set of product visions and application scenarios for future robots.

2.2. Methodology

The analysis of the international character of the ECHORD experiments presented in Section 3 uses the concept of international partnership, which is a one-to-one relationship between institutions, instead of the simple global concept of international project. In this way, we clearly distinguish between experiments based on the number of countries present in the proponents. Consequently, the results presented here are proponent-wise and can be seen as the prospective possibilities of a hypothetic proponent considering options like international collaboration, or industry–academia collaboration.

To classify and group countries in terms of success rate, international collaboration patterns and industry academia cooperation patterns (Sections 3 and 4) we employed a well known data-mining algorithm, simple-K-means, which is fast and provides quality results when compared with hierarchical clustering techniques (Steinbach, Karypis, & Kumar, 2000). K-means clustering consists in determining a set of K points, called cluster centers, so as to minimize the mean squared distance from each data point to its nearest center. The grouping is done around these centers. The software used to perform this clustering was the Waikato Environment for Knowledge Analysis WEKA (Hall et al., 2009).

In Section 5 we employ social network analysis methods to analyze co-authorship networks (Newman, 2001a) and topic co-occurrence network (Newman, 2001b). Co-authorship networks reflect collaboration between scientists (Newman, 2004), quantifying the level of networking that corresponds to the node degree, the average paths for knowledge diffusion that corresponds to the average shortest path lengths and finally indentifying clusters of nodes that tend to work together. These clusters are identified using the widely known Girvan–Newman algorithm (Girvan & Newman, 2002), that exhibits very good performance (Newman, 2004). This algorithm has been widely used over databases of scientific papers to characterize a certain discipline, like Mane and Borner with *Proceeding of the National Academy of Science* (Mane & Börner, 2004) or Li et al with *IEEE Intelligent Transportation Systems* (Li et al., 2010). We applied the same concept to the co-authorship of ECHORD proposals building networks of institutions, countries and topics. To visualize analyze the networks we

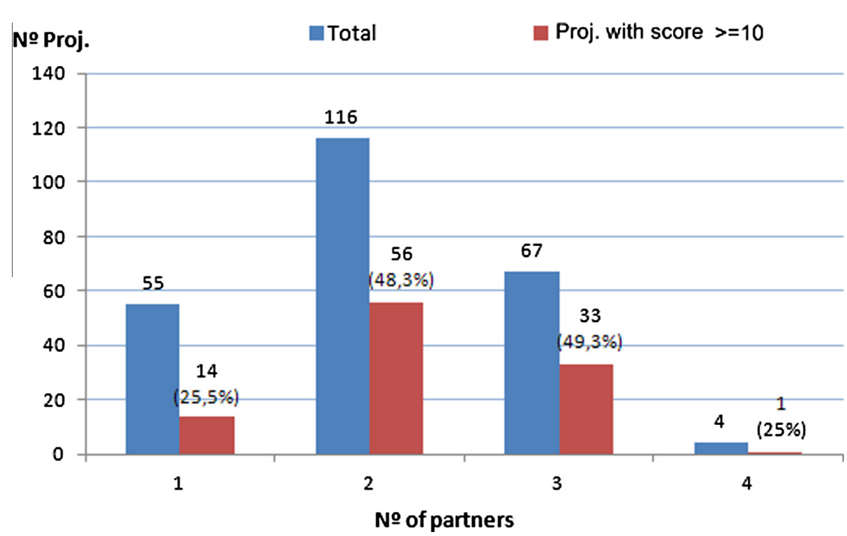

Fig. 1. Distribution of projects per number of partners.

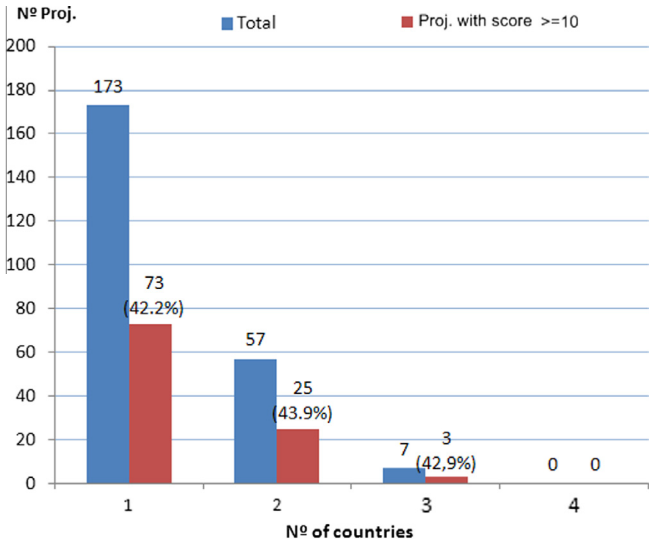

Fig. 2. Distribution of projects per number of countries.

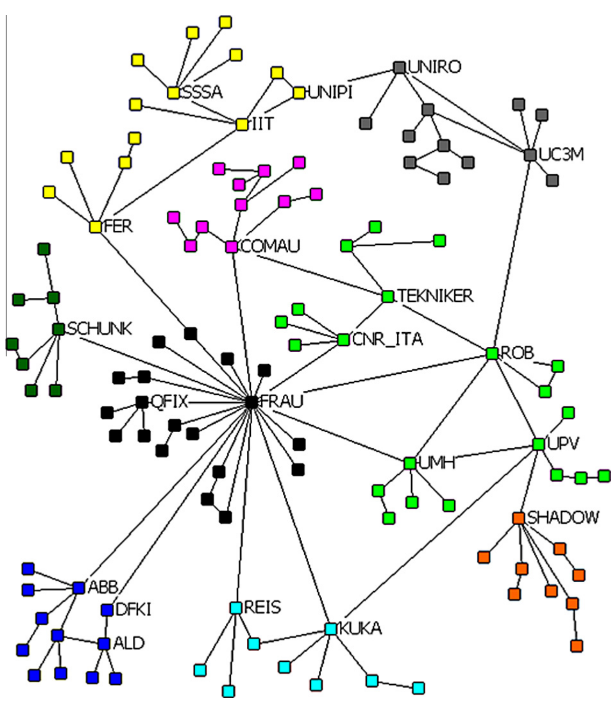

Fig. 3. Largest component of the institution-level co-authorship and clustering.

used the UCINET and Netdraw software (Borgatti, Everett, & Freeman, 2002).

The classification of the experiments according to the SRA, presented in Section 5, was made in two steps. First the members of the ECHORD core consortium manually classified the experiments and then the classifications were presented via a web-questionnaire to the respective experiment coordinator that ratified the option. Then, the use of pre-answers, resulting from previous analysis from core partners, promoted higher levels of participation (45%). The aimed results of this classification is the most relevant technology that is being developed in the experiment, and the most significant product vision that can be foreseen in the scope of the ECHORD experiment.

Table 1
Most productive institutions.

Rank	Institution	N° prop.
1	Fraunhofer Institute	23
2	Shadow Robotics	10
2	Robotnik	10
4	Fer Robotics	8
5	ABB	7
5	Scuola Sup. Sant'Anna	7
5	Univ. Poli. Valencia	7

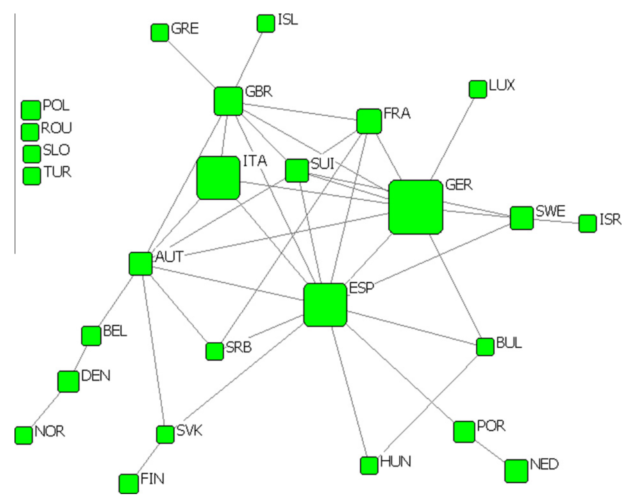

Fig. 4. Country level co-authorship (Country acronyms according to the ones used by the Olympic Committee).

3. Collaboration patterns

The data resulting from the set of 242 ECHORD proposals involves a total of 509 proponents, 264 institutions and 26 countries.

The total number of proposals that scored above 10 –the minimum score to be considered for funding according to the *European Commission* usual criteria- was 104, which represents approximately 46% of the total number of proposals.

In general terms, proposals involving partnerships between institutions obtained significantly higher scores than single partner proposals (48.1% vs. 25.5%). Particularly, submitted proposals with 2 or 3 partners were the ones showing the best ratio between approved and submitted experiments (Fig. 1).

Another interesting conclusion from the data analyzed is that the quality of the proposals is not affected by the number of countries involved (see Fig. 2).

Notice that, in contrast with the rest of the paper, Figs. 1 and 2 show data based on projects instead of based on participants (please see the methodology in Section 2.3).

3.1. Institution proposal co-authorship

The obtained institution-level co-authorship network includes 263 institutions, 200 ties, 48 components and an average number of collaborators per proposal (degree) of 2.08. The network is dominated by a big component with 114 nodes in which 9 clusters (clustering coefficient = 0.406) were identified using the Girvan–Newman algorithm (see Fig. 3). This cluster includes all the most productive institutions (Table 1.

As expected the clusters are usually built around key institutions either companies or research institutions, which are labeled in Fig. 3 together with the nodes that constitute bridges between

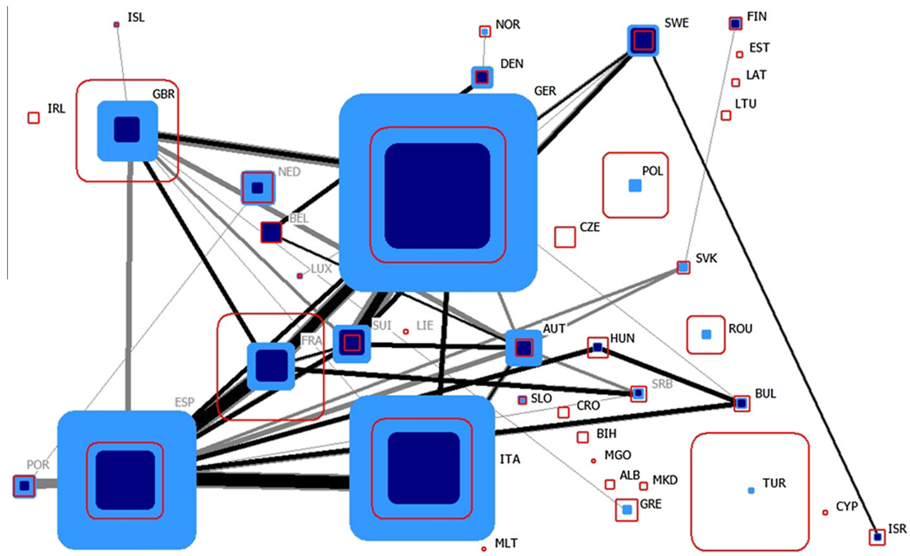

Fig. 5. Geographic distribution of ECHORD experiment proponents.

Table 2
Clusters of countries by performance and international cooperation.

Cluster 1	BEL, SWE
Cluster 2	GER, ITA
Cluster 3	DEN, ESP, AUT, SUI
Cluster 4	NED; GBR, FIN, POR
Cluster 5	FRA, HUN, SRB, BUL, ISR

clusters. The *Fraunhofer Institute* node shows the higher centrality and has connections to 7 other clusters (out of 9). On the industrial side most of the major/traditional industrial robot suppliers has its own cluster (*ABB*, *KUKA*, *Schunk*, *Comau*), but also smaller companies play important clustering roles like *Shadow Robot Company*, *Qfix Robotics*, *FeR Robotics*, *Aldebaran Robotics* and *Robotnik*. It should be noticed that the last are mostly from non-traditional countries in terms of robot hardware suppliers (e.g. *UK*, *Spain*, *Austria*, *France*) and are supplying differentiating products like *Robot Hands*, *Humanoids*, *Compliant Manipulators or Mobile platforms*. The analysis of the cluster also shows that despite the global high level of international collaborations in the ECHORD project, the key players within each cluster are commonly from a single country: the light blue cluster includes both German robot manufacturers, the light green cluster is dominated by Spanish research institutions (*Univ. Miguel Hernandez*, *Univ. Politécnica de Valencia and Tekniker*) and companies (*Robotnik*), and the yellow cluster includes three Italian research institutes: *Scuola Superiore Sant'Anna*, *Italian Institute of Technology* and the *University of Pisa*.

3.2. Country coauthorship

The obtained country level co-authorship (Fig. 4) network includes 26 nodes and 48 ties with an average degree of 1.846. *Spain* and *Germany* are the countries with more cooperations (degree 12 and 9, respectively).

Despite the central role of key institutions and countries, shown in the institution and country co-authorship networks, these networks do not clearly follow power law distributions that would indicate *scale-free* characteristics (Albert & Barabási, 2002; Boccaletti, Latora, Moreno, Chavez, & Hwang, 2006).

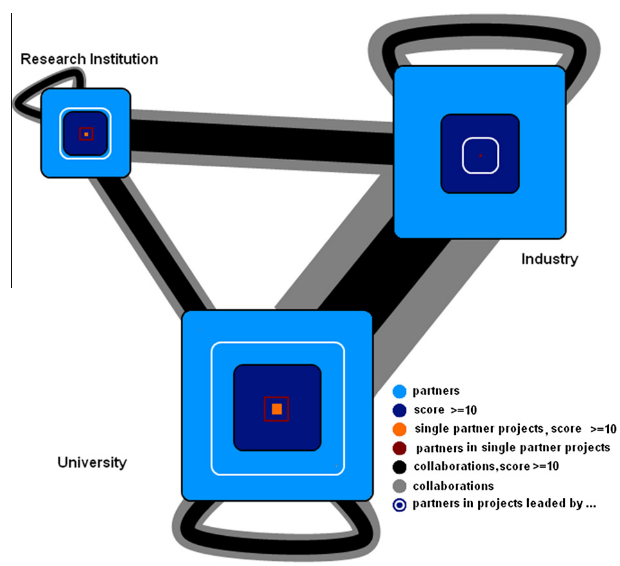

Fig. 6. Partner type distribution in ECHORD.

3.3. Country cluster in research profile

In order to characterize the research profile of different European countries in the field of robotics, the above network analysis was complemented with a cluster analysis using specific information from the proposals, namely, the origin of the main proponent (including country characteristics), the success rate and the international partnership ratio.

Fig. 5 illustrates the geographical distribution of the proposals submitted to ECHORD. For each country, the light blue square represents the number of proponents, the [1]dark blue square represents the number of proponents with experiment review scores above 10 points (>10) and finally the red frame represents the population of the country (the scale is 1 proponent per million inhabitants).

The analysis of these data shows that 7 countries (*Iceland*, *Swit-*

[1] For interpretation of color in Figs. 5,7, and 8, the reader is referred to the web version of this article.

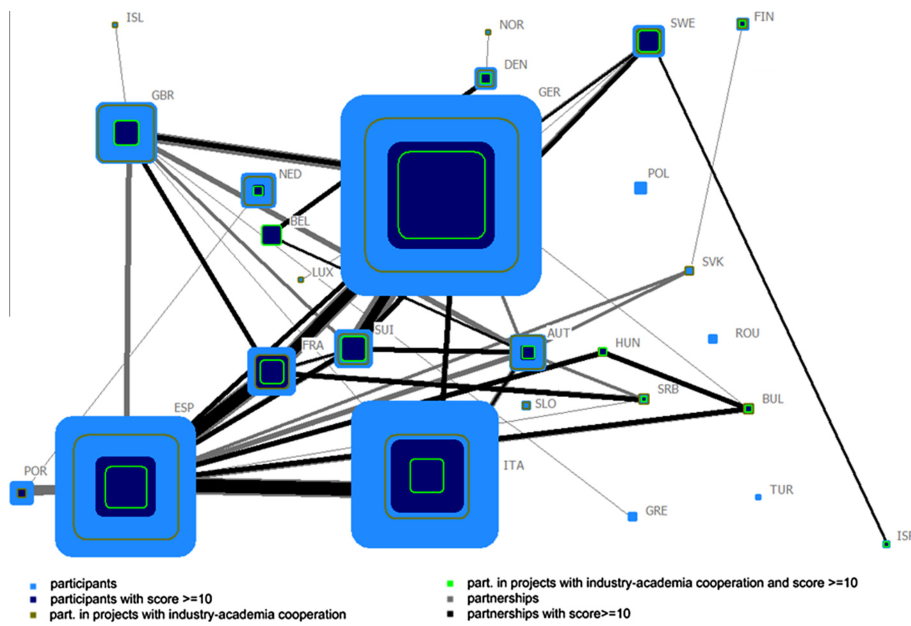

Fig. 7. Industry academia cooperation in ECHORD experiment proponents.

Table 3
Clusters of countries in ECHORD project: industry–academia collaboration.

Cluster 1	BEL
Cluster 2	POR
Cluster 3	DEN, GER, ESP, NED, AUT
Cluster 4	FRA, ITA, ISR, FIN
Cluster 5	HUN, GBR, SRB, SWE, BUL, SUI

zerland, *Austria*, *Luxembourg Denmark*, *Sweden and Spain*) have at least 1.5 experiment proponents per million inhabitants and represent the most productive countries in terms ECHORD proposals. On the other hand 14 countries (*Cyprus*, *Czech Republic*, *Estonia*, *Ireland*, *Latvia*, *Lithuania*, *Malta*, *Ireland*, *Liechtenstein*, *Croatia*, *Macedonia*, *Albania*, *Montenegro and Belarus*) have not made any proposal to ECHORD and 4 countries (*Turkey*, *Poland*, *Romania*, *and Norway*) have less than 0.25 proposals per million inhabitants. This is the group of the less productive countries in proposals production in the context of ECHORD.

In terms of proposal quality, the top five countries ranked by the ratio of their proponent's participations with review scores above 10 are *Belgium* (100%), *Sweden* (76%), *Hungary* (67%), *France* (63%) and *Switzerland* (62%). On the other hand, it was observed that ECHORD received proposals from 9 countries (*Norway*, *Poland*, *Slovenia*, *Slovakia*, *Iceland*, *Luxembourg*, *Romania*, *Greece and Turkey*) without any positive classification. In terms of international collaboration 8 countries endorsed 100% of their proposals in cooperation with foreign countries: *Hungary*, *Bulgaria*, *Serbia*, *Norway*, *Israel*, *Iceland*, *Luxembourg and Greece.*

Inspection of Fig. 5 reveals several important differences on country profiles in terms of robotics research. To quantify these differences we performed a K-means clustering analysis on the countries with at least one approved proposal, considering the following attributes: number of proponents per million inhabitants, percentage of proponents with scores above 10, percentage of international collaboration and successful international collaboration. The weight of the attributes was normalized, and the weight of the last two was reduced to half due to their similar nature (related to international cooperation). If we consider 5 clusters the results obtained are presented in Table 2.

Table 2 results match the data graphically shown in Fig. 5 and indicate 5 different country profiles for robotic research. The first cluster is composed by small/medium countries, with very high-quality proposals (88% of proposals above 10 in the cluster average) and very successful international collaborations. The second cluster is composed by big countries, with medium/high rate of proposals production and medium quality of proposals (based on score levels). The third cluster is composed by countries with extremely high proposal production (more than 2 proposals per million inhabitants in the cluster average) and medium quality in terms of score. The forth cluster includes countries without successful international collaboration, average proposal production and low quality of proposals. The last cluster is characterized by the low level of proposals per million inhabitants, extensive international collaboration and medium/high approval ratio of the proposals.

4. Industry academia collaboration

One of the main purposes of the ECHORD project is to promote industry–academia collaborations. The collaboration patterns and the respective success are depicted in Fig. 6 which reveals several facts:

- The number of proponents from either industry or academia approximately doubles the number of proposals from research institutions.
- Research institutions collaborations with industry double their collaborations with academia.
- Proposals partnerships between research institutions have the highest quality (based on the proposal obtained score): 62% of proposals above 10 points, against 52% between universities and 36% between industrial partners.
- Despite the good amount of industry proponents to the ECHORD initiative, it is clear from the available data that usually industry plays a secondary role in the submission process: they usually do it together with universities or research institutes, and do not take the lead of the consortium. In fact,

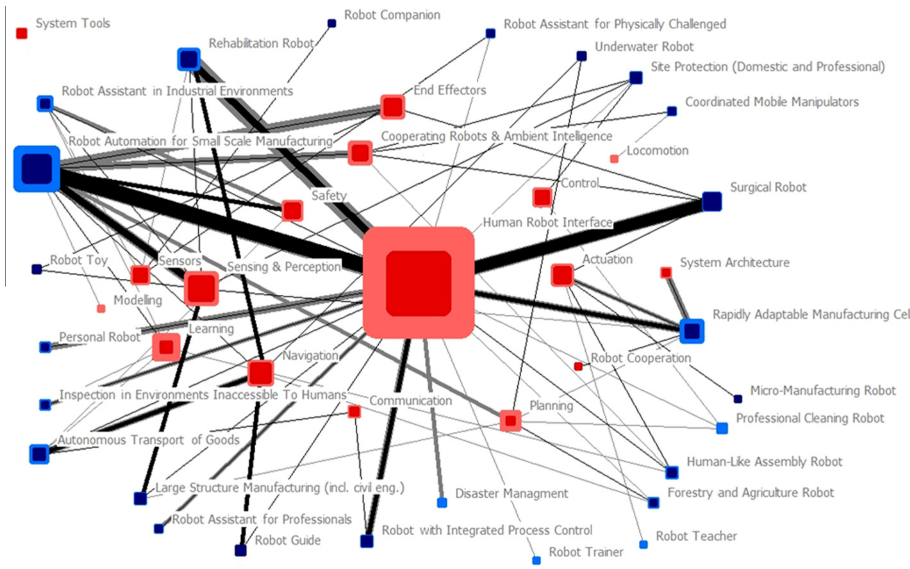

Fig. 8. Network of SRA technologies and application topics.

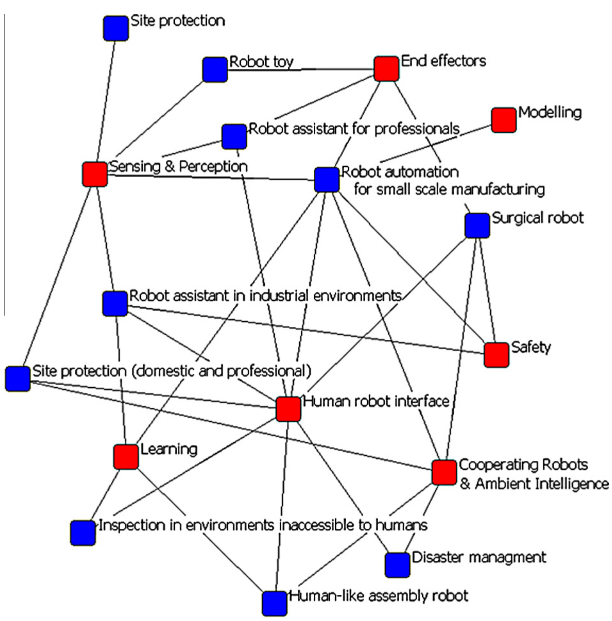

Fig. 9. The human–robot interface cluster.

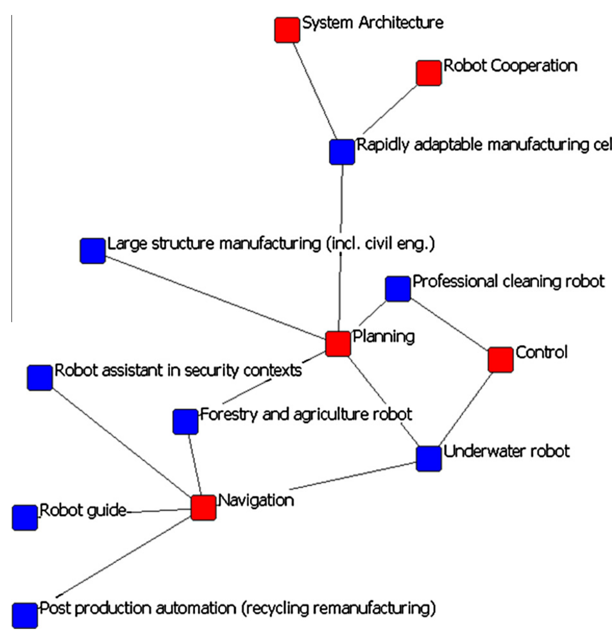

Fig. 10. The Navigation/Planning cluster.

there were significantly fewer proposals led by industry than led by universities or research institutions, and ECHORD did not register a single successful proposal (score above 10) having only one proponent from industry.

4.1. Geographical distribution

Considering the geographical distribution, Fig. 7 shows in green the number of proponents with score above 10 points that were part of a consortium with industry–academia collaboration. A detailed look into the approved proposals shows again different profiles in terms of industry–academia collaboration patterns. For this analysis we considered only the countries with approved proposals and we performed a simple K-means clustering analysis considering the number of industry–academia cooperations and

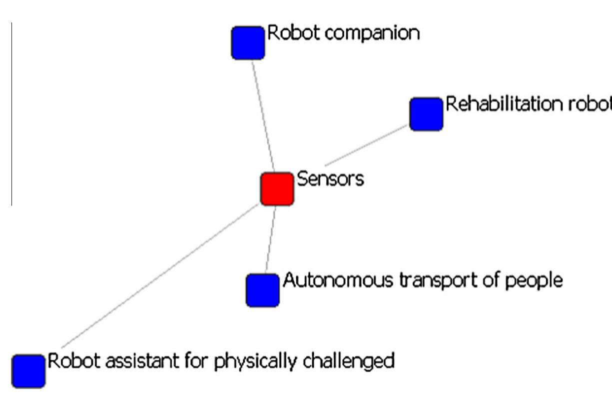

Fig. 11. The "sensors" cluster.

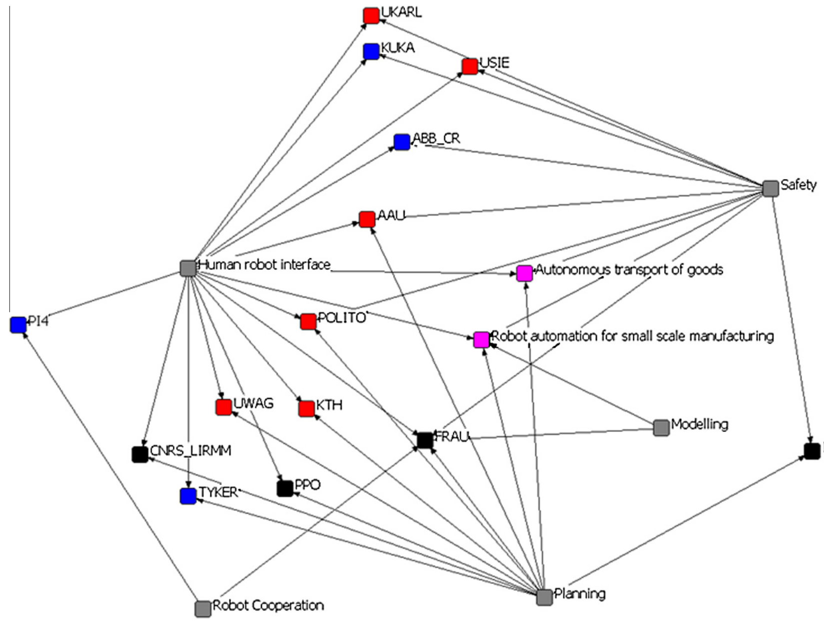

Fig. 12. Human–robot interface cluster.

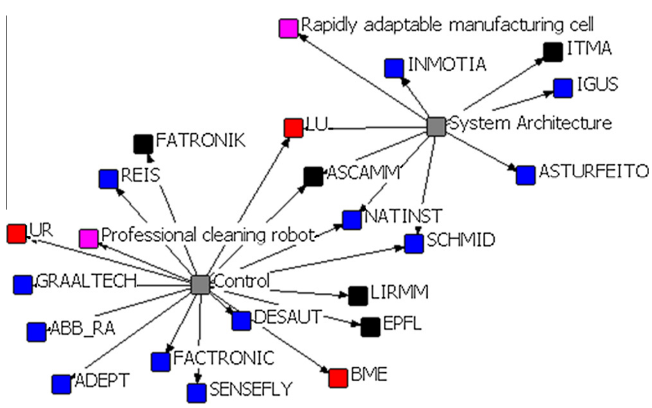

Fig. 13. Control and System architecture cluster (nowadays, FACTRONIC-Tecnalia France, FATRONIK - Tecnalia Spain).

the success of such cooperations. The results are presented in Table 3.

The first cluster includes *Belgium* that is the only country with 100% of proposals including industry–academia collaboration and all of them with score above 10 points. The second cluster includes only *Portugal* and is characterized by the low level of proposals with industry–academia cooperation and no approved proposals of such type. The third cluster includes countries with high number of industrial participation which quality is medium/low. The forth cluster is characterized by countries with low industrial participation and medium scores and finally the last cluster includes countries with high levels of participation and medium/high scores for industrial participations.

5. The ECHORD project in the strategic research agenda (SRA) framework

According to the methodology described in Section 2 each ECHORD experiment was classified in terms of the most relevant Technology and the most relevant Product Vision. Fig. 8 shows the network of technologies and product visions addressed by the ECHORD experiment proposals. The dimension of the rounded squares is determined by the number of proposals that addressed a certain topic, with dark colors for the proponents which proposals reached a score with at least 10 points: dark red for technologies and dark blue for product visions. Similarly black partnerships belong to projects with score above 10 points and the grey connections represent the rest of the proposals.

The analysis of this data shows that the SRA technology that by far gathered most proponents was *Human Robot interface* with 34% of the total, followed by *Sensing and Perception* (9.2%), *Learning* (7.1%), *Navigation* (6.5%), *Cooperating Robots & Ambient Intelligence* (6%) and *End Effectors* (6%). The SRA *Product Visions* with the highest coverage with ECHORD experiment proposals were *Robot Automation for small scale manufacturing* (21.1%), *Rapidly adaptable manufacturing cell* (9.6%) *and Rehabilitation robot* (8.8%).

These results are in line with the ECHORD research foci (see Section I) although biased towards the focus *human–robot interaction and safety* and weak in the focus *Networked robots* (*Communication* – 2%).

Concerning the ECHORD scenarios, the results present in Fig. 3 show that the scenarios are well represented. The *human–robot co-worker* scenario is covered by the most chosen SRA technology, *Human–Machine Interface*, and several product visions (*Robot Assistant for professionals, Robot Assistant in Industrial environments, Robot assistant for physically challenged*). The *hyper-flexible manufacturing cells* scenario is very well represented with *Robot automation for small scale manufacturing* and the Rapidly adaptable manufacturing cell. Finally the scenario *cognitive factory* is the less represented but nevertheless *Learning* is the third technologies with more proposals.

Quality wise the technologies that granted higher scores were the *Robot Cooperation* (100%, 1 out of 1), *Navigation* (75%, 9 out of 12), *Sensing and Perception* (71%, 12 out of 17) *and Actuation* (70%, 7 out of 10). On the other hand, the SRA technologies with the lower ratio were: *Locomotion* (0%, 0 out of 1), *Modeling* (0%, 0 out of 1) and *Planning* (22%, 2 out of 9).

Concerning the pairs *Technologies–Product Visions* there is a large diversity of interconnections that show the interdisciplinary of the robotics subject. The pairs with most proposals all included the SRA technology *Human–Robot interface* and the following product visions: *Robot Automation for small scale manufacturing, Rehabilitation Robot and Surgical Robot.*

Considering the *Robot Automation for small-scale manufacturing*, which is the Product Vision with more proposals, it is interesting to note that the technologies that paired with higher success ratios were *Sensing and perception safety* and *human robot interface*. On the other hand the *End-Effectors* technology paired with *Robot Automation for small-scale manufacturing* with significantly low quality.

5.1. SRA technologies and product vision clustering analysis

Connecting SRA technologies and product visions that occur in the same proposal leads to a network of SRA topic co-occurrence with 42 nodes and 114 ties. To identify research clusters present in Europe, the co-occurrence network presented in Fig. 8 was analyzed using Girvan–Newman algorithm. The results show (Fig. 9) that the largest cluster is very diverse and is dominated by the SRA technologies *human robot interface* and *Sensing and Perception* and the product visions *Robot Automation for small scale manufacturing*, *Robot assistant in industrial environments* and the *Surgical robot*.

The second largest cluster is presented in Fig. 10 and its key SRA technologies are *Planning*, *Navigation* and *Control*. In terms of product visions the ones that show higher centrality measures are the *Forestry and agriculture robot*, *Underwater robot* and *Professional Cleaning Robot*.

Nevertheless being one of the smallest clusters, the cluster built around the technology Sensors (Fig. 11) groups 4 product visions related with human interaction: *Robot companion*, *Robot assistant for physically challenged*, *Autonomous transport of people and rehabilitation robot*.

This cluster reinforces the high focus given in the ECHORD proposals to the human robot interaction not only on the technology human robot interaction but also on support hardware development.

5.2. Mixing SRA and institutions

The network of SRA technologies and Product Vision was extended with the institutions that are involved in the project and a major network of 306 nodes was created. Clusters were identified using the Girvan–Newman algorithm. The most significant cluster is presented in Fig. 12 and includes both the SRA technology *Human–machine interface* and the SRA Product vision *Robot automation for small scale manufacturing*, which are the most common in the ECHORD proposals, but also includes the product vision *Autonomous transport of goods* and the technologies *Planning*, *Robot Cooperation*, *Safety* and *Modeling*. In terms of key institutions in this cluster the *Fraunhofer Institute*, the *Politecnico di Torino* and the *Aalborg University* constitute the academic core and the *ABB*, *KUKA*, *Tyker and PI4* are the most relevant companies.

The cluster presented in Fig. 13 is dominated by the SRA technologies *Control* and *System architecture*. The key institutions for this cluster are Lund University, ASCAMM research institute, National Instruments Germany and the company SCHMID. Although playing a minor role of pending nodes the SRA products present in this cluster are the *Rapidly adaptable manufacturing cell* and the *Professional cleaning robot*.

6. Conclusion

Being the ECHORD experiments small technical projects the core consortium lowered the entrance barrier by allowing single partner and single country proposals. The score of the reviewing process show that, even in small projects (typically 18 months and 300 k€), single partner projects have worse quality than multi-partner proposals: 48.1% vs. 25.5%. In terms of international cooperation the ratio of proponents that participated in 10+ proposals (evaluation score above 10) with international cooperation is similar to the ratio for single country proposals. These values might indicate that the common mandatory requirement for EU financing of multi-country proposals (with at least three countries), may indeed promote the participation from peripheral countries but does not have a direct influence on the quality of the proposals.

Despite the high participation of industrial participants in ECHORD proposals, it is clear they play a secondary role in collaborations.

The human robot interaction was highly addressed by the ECHORD proposals and is by far the most relevant topic in the point of view of the European robotics community. This is clear not only on the number of proposals that addresses this topic explicitly but also on the amount of proposals that address satellite technologies that will enable product visions with extensive human machine interaction, like *Sensors*.

Unlike the relevance of the cognitive scenario in the recent European research strategy for robotics and the specific scenario defined in the ECHORD context, the *Learning* research topic attracted a medium number of proposals with particularly low and an overall disappointing quality: only 22% of proposals above 10 points.

The technology *End effectors* was particularly addressed by one of the ECHORD scenarios: *Robot Hands and complex manipulation*, and achieved a good score ratio (64%). However a detailed look into the data shows that the approval ratio of this technology when paired with the product vision *Robot Automation for small scale manufacturing* is significantly smaller than with other product visions. This result shows that the quality research made in the *End-effectors* is largely biased outward the industrial scene.

Analyzing the network of institution-level co-authorship an interesting facts should be deducted: (1) the key players (with a relevant number of connections or playing inter-cluster connections) are organized geographically; (2) there is a new group of key players that are robot hardware suppliers with highly differentiating products coming from countries without significant tradition in this area.

Acknowledgments

We would like to express our gratitude to Rui Ligeiro from the Mechanical Engineering Department, University of Coimbra for his help with data gathering.

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