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Industry-Academia Collaborations in Robotics: Comparing Asia, Europe and North-America*

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Abstract— **In this contribution, we look at technology transfer in robotics. Generally, there is a delay between a science-push and a market-pull. In order of finding means to decrease this lag, we are going to look at the causes of this effect and at the means for improving technology transfer. For this purpose, we use a variety of data sources which shed light on the current situation in Asia, Europe and North-America. First, we will examine the technology-readiness level (TRL) scale which can be used as a means of measuring market readiness of innovative technology. After this we will look at what means experts find useful for technology transfer. Finally, we investigate academia-industry collaboration as one tool to increase technology transfer. We demonstrate a strong collaboration between industry and academia in North America which we see as a response to the lower numbers of robots deployed in the industry in North America compared to Asia and Europe. This is an on-going trend which occurs in parallel to a global trend in growing numbers of robots in use.**

I. INTRODUCTION

Robotics is an applied field to a large extent. Great societal changes are expected from technological innovations in this field [1] as well as a change in manufacturing and many other economic areas [2].

In innovation in robotics one can perceive a lag between science-push and market-pull. This is also called a double-boom cycle [3] in which one finds such technology innovation peaks ahead of a peak in the market for that technology. One example of a double boom on a large scale is the history of artificial intelligence where a first boom in research efforts could be noticed in the late 1950s and early 1960 but the first interest by larger industries began in the 1970s [4]. In order of decreasing the time between the peaks one has to find means of effective technology transfer.

We look at this by comparing different data sources which shed light on the situation of robotics innovation in Asia, Europe and North America. Our particular focus is industry-academia collaboration. As we will argue, this can be seen as one of the most promising tools for technology transfer. However, the history of such efforts has not always been easy due to the problem of finding common ground [5]. Often the industry is interested in profit which needs to be shown in the short term whereas research institutions take a long term view.

The question which we address here is how technology transfer is handled on different continents. For this purpose we will first look at the technology readiness level (TRL) scale [6] which is a means of measuring the market-readiness of a technological innovation. The TRL serves as one means of measuring progress in contrast to the academic measures of progress, such as number of publications or number of citation, and the industrial measure of success which would be monetary profit mainly. We are particularly interested in how well it is known and how wide spread the adoption of this scale is.

Further, we will look at what experts suggest is to be done to increase technology transfer. For this purpose we used a questionnaire which was handed out to experts on various occasions. We try to elucidate what the experts regard as successful means of driving robotics innovation.

In the light of these results, we draw a comparison between Asia, Europe and North America. First, we are going to look at where most technology transfer happens. For this purpose, we have examine the pertinent publications in robotics and try to assess what quantity of these arise academia-industry collaborations. Further, we will then look at the actual numbers of robots in use worldwide to see whether these efforts actually have already resulted in measurable results.

II. TECHNOLOGY TRANSFER IN ASIA, EUROPE AND NORTH AMERICA

A. *Knowledge transfer between Industry and Academia*

In a first step, we tried to assess whether technology transfer is generally considered to be in a good state. For this purpose, questionnaires were distributed among practitioners in the field of robotics on different continents.

Robotic experts from Asia, Europe and North America[1], from both academia and industry, were asked to rate the quality of know how transfer between academia and industry ([7] [8], Fig. 1.). Their rating suggests that there is room for improvement. Only 29% judge technology transfer to be good whereas only 4% went as far as to call it excellent. This is only a third of all responses which indicate a clear positive picture of transfer. Only 3% judge it to be bad but the vast majority – 64% of the responses – judge technology transfer to be mediocre. This result does not indicate a devastating sense of non-communication among industry and academia.

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[1]31 respondents, all at least senior scientists: 15 experts from Asia and 7 from North America who were visited during two lab tours in 2011 and 2012 as part of the ECHORD project ([9] and [10]), and 9 experts from Europe who applied for an ECHORD experiment by submitting a proposal that was above quality threshold but who were not successful because of the budgetary cut-off.

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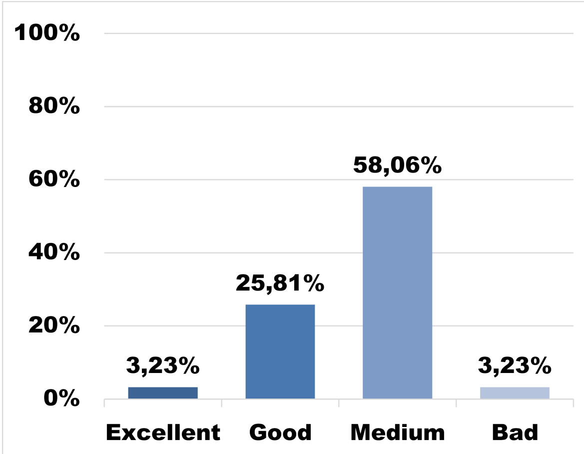

Fig. 1. The quality of know how transfer between academia and industry, as rated by robotic experts from Asia, North America and Europe, from both academia and industry.

However, the low amount of excellent judgments and the high amount of medium quality ratings does engender a discussion on how one can increase the perceived quality of transfer. Moreover, one may ask how one actually defines quality of transfer.

B. Measures of Quality of Transfer

The problem which the section above raises is how the quality of technology transfer can actually be judged. The problem is that industry and academia have different currencies for the purpose, metaphorically speaking. The necessarily different standards in the industry and academia lead to different reward systems for the practioners engaged in technology development on both sides. The industry values monetary gains whereas research in academia is evaluated according to the knowledge gain, which can be quantified in the number of publications in which such new knowledge is codified and which arises from technology development [11], [12]. It is clear that by these standards the industry must seek robustness of technology whereas academics must strive for novelty which is often orthogonal at best to robustness.

The ratings do suggest that some kind of common tool for quality assessment is needed which is independent of the standards which are discussed above. One such measure is a scale called the Technology Readiness Level (TRL, [13]). The TRL scale goes from level 1 basic technology research to level 9 system test, launch and operations in 9 discrete but not necessarily equidistant steps. One can use this scale as a tool for deciding how far a technology is in its development but also as a measure of the progress made within a technology-oriented research project. The steps which are lower on the scale and therefore describe an earlier stage of development will traditionally fall within the domain of academia whereas the later stages of development which are assigned a higher numerical value on the scale will traditionally be of interest to the industry. However, for a technological innovation to move from a laboratory to the market, this technology will have to go through all nine stages. The TRL can serve as a roadmap as well as a means of monitoring the successful transfer in the process.

We suspected that one possible reason for the mediocre ratings by the experts (above) could be that concepts like TRL are not well known. These concepts allow a translation of the value of results between academia and industry.

TRL is a means of assessing progress independent of the measures of successful innovation which the two parties involved – academia and industry – generally adopt to rate successful work.

The adoption of this scale within the robotics community still appears thin. For the purpose of finding out more about how research efforts are measured on a scale which is neither specific to the goals of the industry nor the academic world, we will now look at how well-known this scale is among practitioners in the field of robotics.

We asked 97 members of the robotics community[2] whether they were familiar with or even using TRL (Fig. 2). 61% of the respondents from academia and 76% of those from industry had not even heard of TRL before.

Whereas TRL is much better known in academia (36%)

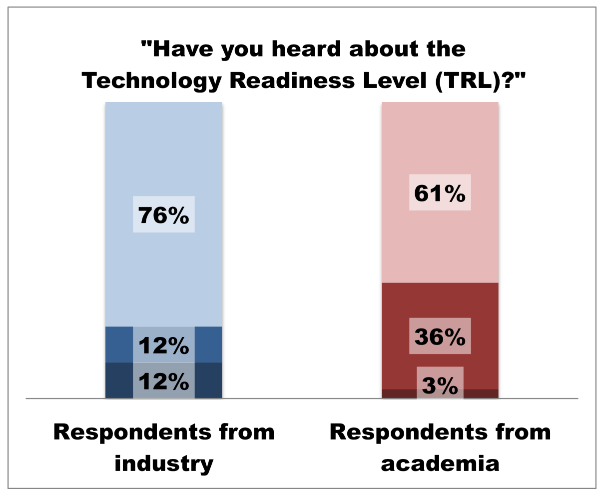

Fig. 2. Responses of 97 members of the robotics community, asked whether they had heard of the Technology Readiness level (TRL).

as compared to the industry (12%), the adoption rate of this tool is higher in the industry (12%) as compared to academia (3%). This suggests that if industrial practitioners know about TRL they are more likely to use it in comparison to academia, where the scale is better known but adopted less among the researchers who are aware of the concept.

As half of the experts from the industry who actually are aware of TRL have used it, we feel that this may be a useful tool for measuring success. The problem is that academic researchers seem much more reluctant to rate their technology in this way according to our survey.

A wider use of such measures of success may help improve the transfer of technology between academia and industry.

[2] 41 visitors of the ECHORD booth at Automatica 2012 and IROS 2012, and 56 authors of publications in major robotics journals that resulted from academia-industry collaboration.

The results of collaboration would become more transparent through such a tool. However, making the success measurable is only one issue. There are other means of improving collaborations. We address these in the next section.

C. How can knowledge transfer be improved?

We further asked the same robotic experts[3]: "Which routes of knowledge transfer do you consider most efficient?" and "What should be done to improve knowledge transfer?". The respondents were given a set of options which they rated using a Likert scale [9], [10]. The same set of options was provided for both questions.

The rating results are plotted in Fig. 3 with answers for

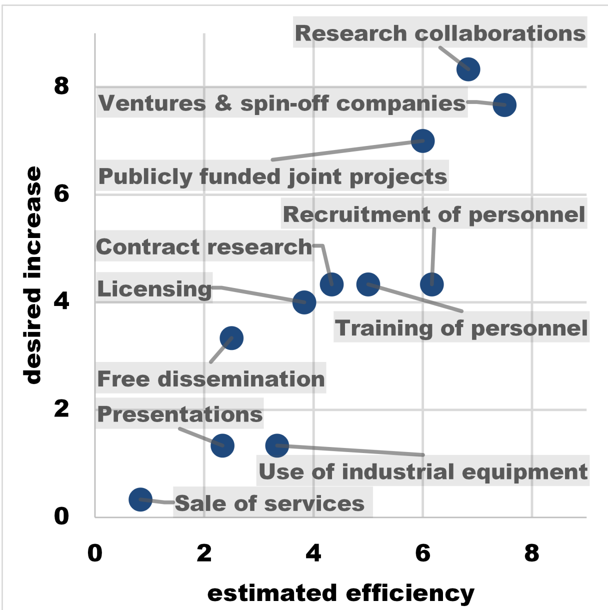

Fig. 3. Robotics experts' responses to Which routes of knowledge transfer do you consider most efficient? on the abscissa and responses to What should be done to improve technology transfer on the ordinate.

the 1^{st} question on the abscissa and results from the 2^{nd} question on the ordinate.

It is apparent that there is a positive relationship between the two sets of answers. This is clear in most items but there are also noteworthy deviations: "Free dissemination" was rated rather low with respect to efficiency and it received only moderate values for desired increase. Roughly the same value for increase was given to "Recruitment of personnel" which received a much higher rating in the estimated efficiency. From this we can conclude that the measure of recruitment should not be employed more than it already is – not because it is not efficient, but because there is already enough activity in the current situation.

A strong emphasis lies on measures aiming for a collaborative effort, be it research collaborations, publicly funded joint projects or even spin-off companies and ventures. Looking at "research collaborations", we observe about the same high value for efficiency, but also a high rating regarding desired increase. This means there is a large agreement that this measure is both very important and not enough employed. Therefore, here one can see an actual opportunity for increasing a technology-push contingent with a market-pull.

D. Academia-industry collaborations worldwide

As, according to the robotic experts questioned in our surveys, an increase of research collaborations would have the potential to improve knowledge transfer between academia and industry, we looked at where in the world industry-academia joint projects are based. Assuming that a successful collaboration will likely result in a scientific publication we analyzed successful submissions to major robotics conferences and journals and identified those which had resulted from academia-industry collaboration.

We scanned all publications presented at the IROS and the ICRA conferences, which are the most pertinent venues for presenting results to the robotics community [12][4]. The results are illustrated in Fig. 4. Of all conference publications that were result of academia-industry collaboration, most (42.3%) had at least one author affiliated with an institution or company in North America, followed by Asia/Australia (38.6%) and Europe (35.7%)[5]. In the majority of the cases (84.3%), all authors of a specific paper were from the same continent.

Three instances of each of the two annual conferences between 2010 and 2013 were taken into account. In this time frame, each conference was held once on each of the three continents (see Fig. 4). No relationship of the country the conferences took place in and the country of the authors' affiliation could be observed. For example, a conference taking place in Europe did not mean that most authors of academia-industry collaborative publications were affiliated with a European institution or company.

The analysis was further enhanced by including five top journals in robotics and extending the years analyzed back to 2009[6]. The results are illustrated in Fig. 5. They confirm the findings of the conference analysis: A large majority (70.4%) of the authors of publications which resulted from industry-academia collaborations was affiliated with an institution or company based in North America. Europe (27.6%) and Asia/Australia (24.5%) supply not even half as many authors proportionally.

[3] 31 respondents, all at least senior scientists: 15 experts from Asia and 7 from North America who were visited during two lab tours in 2011 and 2012 as part of the ECHORD project ([9] and [10]), and 9 experts from Europe who applied for an ECHORD experiment by submitting a proposal that was above quality threshold but who were not successful because of the budgetary cut-off.

[4] See for example: http://www.ias.tu-darmstadt.de/Miscellaneous/ConferenceQuality (accessed 15 March 2013).

[5] As each publication could have authors from several continents the percentages do not add up to 100%.

[6] Journals analyzed (all issues from 2009-2011): International Journal of Robotics Research, IEEE Transactions on Robotics, Robotics and Autonomous Systems, Autonomous Robots, and Robotica. In total 1362 publications, of which 98 (7.2%) were industry-academia cooperations.

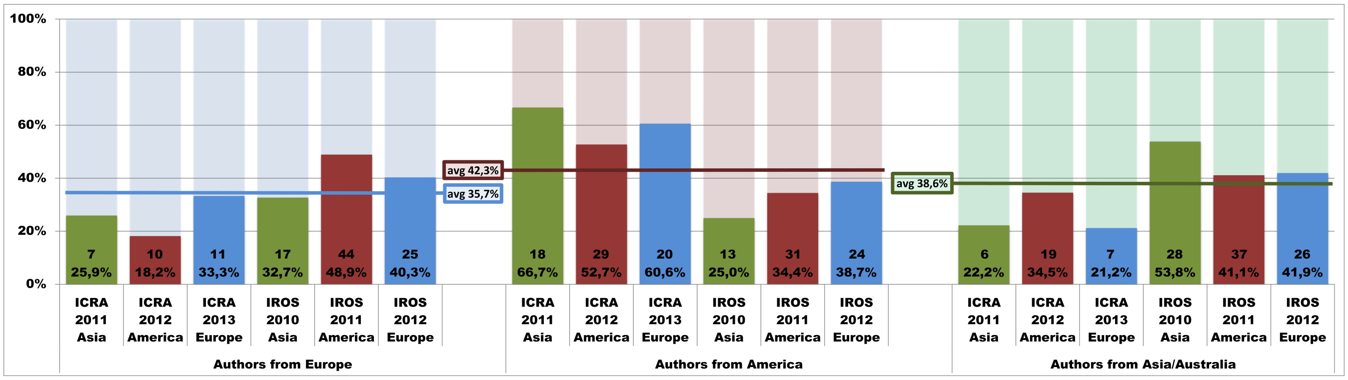

Fig. 4. Percentage of authors from specific continents in conference publications that resulted from an academia-industry collaboration at two major robotics conferences (IROS 2010-2012 and ICRA 2011-2013). The color of the bar stands for the continent where the conference was held, the background color stands for the continent where the authors' affiliation is located (green: Asia, red: North America, blue: Europe).

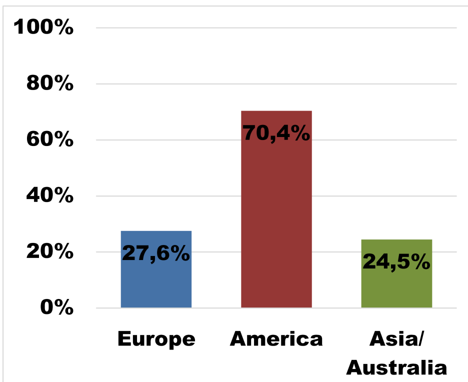

Fig. 5. Percentage of authors from specific continents in journal publications that resulted from an academia-industry collaboration in five major robotics journals between 2009 and 2011.

Methodological note.: The criterion we used to classify a publication as an academia-industry collaboration was based solely on the affiliations of the contributing authors. A publication was classified as collaboration, if and only if at least one of the authors' affiliations was a company and at least one an academic institution. In order to check the validity of this approach in general, the following cross-check was carried out: An email was sent to the corresponding authors of all papers that were accepted for the IROS conference in 2012, asking them to indicate if their paper was the result of academia-industry collaboration. The 210 answers received (approx. a quarter of all 858 papers) were compared with the list of affiliations stated on the respondents' IROS papers. The comparison revealed that our method leads to the same result in 84% of all cases. There is a substantial share of 13% of papers which resulted from academia-industry collaboration but is not visible in the author list, and there are 6 papers (3%) which do not result from collaboration, although for some reason the paper is authored by people from both industry and academia. In summary, our method is valid for most of the IROS-2012 contributions and there is no reason to assume that this is different for the other conferences and journals we have selected.

E. Size of robotics industry worldwide

The question which needs to be answered against the background of these results is whether a high degree of collaborating is reflected in the commercial application of the results. With North America being so dominant in terms of authorship of publications that resulted from academia-industry collaboration, it seems plausible to assume that North America is also the part of the world with the most (successful) academia-industry collaborations in robotics, while Asia and Europe are much less strongly represented. This raises the question whether there is a relationship between the number of successful academia-industry collaborations and the size of a continent's robotics industry.

Looking at the number of robotics units in use worldwide (see Fig. 7), one can observe a growth in the estimated operational stock of robots at the respective year-end from 1999 to 2011 on a global level.

Asia/Australia is clearly the strongest continent, followed by Europe and North America [14]. This relationship between the continents has been roughly the same since 1999. A forecast made by the IFR Statistical Department in 2012 suggests that by 2015 the current dominance of Asia will only increase [14]. Robot sales are predicted to rise by about 6% in Asia/Australia, about 5% in the Americas, and about 2% in Europe. In term of shipments, a similar picture is painted: In Asia most countries are predicted to have a considerable increase of industrial robots operating, while the robot stocks of most of the European and North American countries are predicted to stagnate or even slightly decrease. As the size of the manufacturing industries in different countries can vary substantially, the total number of robotic units can be a misleading measure [14]. Thus it can be useful to take the country's robot density into account, the number of multipurpose industrial robots per 10,000 persons employed in manufacturing industry.

In terms of robot density, Noth America is ahead of Europe and Asia in the automotive industry, while in all other industrial areas, Asia is leading (see Fig. 6; see also [15]).

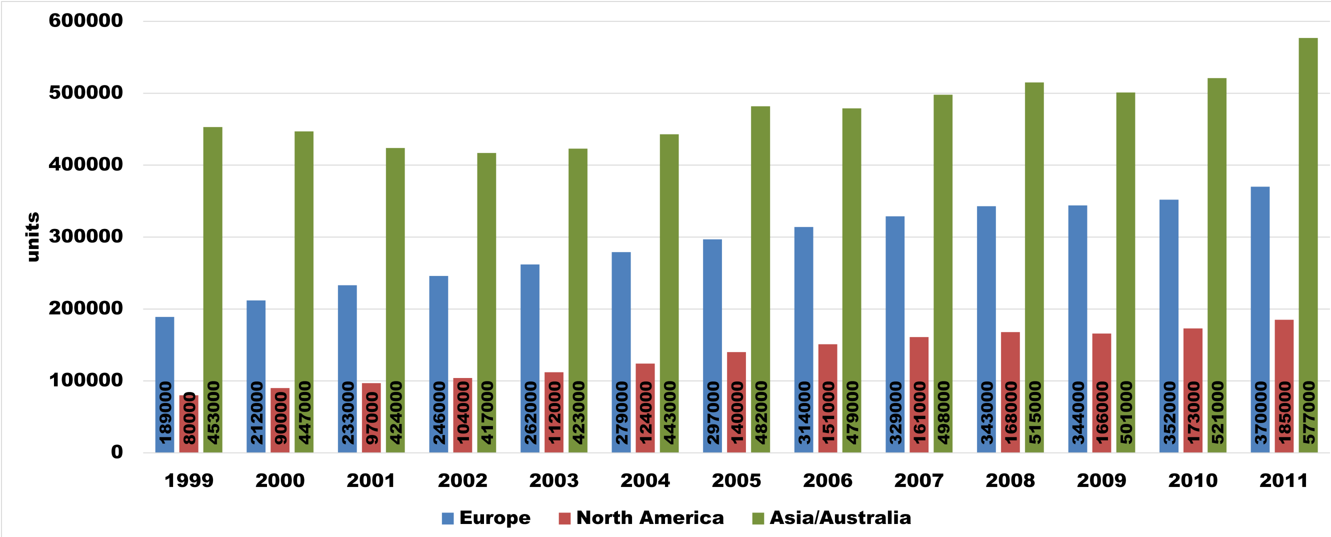

Fig. 7. Estimated operational stock of robots at year-end 1999-2011 (adapted from [14] pp. 117, 140, 213). The green bars represent Asia/Australia. The blue bars represent Europe. The red bars represent North America.

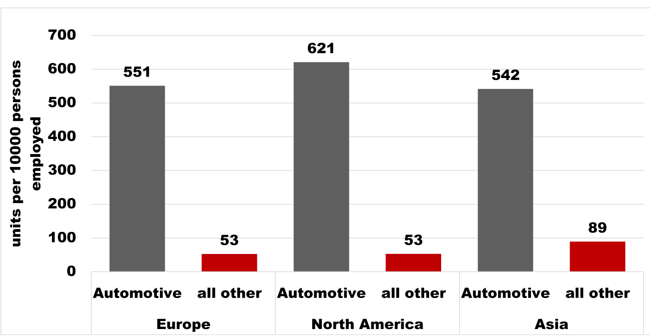

Fig. 6. Estimated number of multipurpose industrial robots per 10,000 persons employed in automotive industry and in all other industries in 2011 (adapted from [5], p. 56).

The results show that in the current situation North America shows less robotic technology in use in industrial settings than in both Asia and Europe. This is surprising considering the fact that the USA (as one part of North America) was the first to adopt robotic technology in manufacturing as early as the 1960s [16]. In comparison between Japan and the USA, development in the USA has been slower with regard to robotics for several decades [17]. The reasons for this are mainly economic and have to do with fear of loosing too many jobs in the USA through automation as well as different views on the returns that robotic technology brings. However, in line with our argumentation above regarding effective means of technology transfer and double boom cycles, we hold it likely that North America may show a drive towards more operational stock of robotic technology in the industry in the foreseeable future. What the data on North America shows could be the first peak in such a double boom cycle. If industry-academia collaborations are effective in advancing technology transfer then the growing numbers of recent collaborations, shown in our analysis of conference contributions and journals, are going to be the basis on which a market-pull follows. This is, however, only a prediction based on the data available. One will have to monitor the situation to see whether this will actually happen.

III. Discussion

A. Technology Readiness Levels

As a starting point for our investigation of technology transfer, we looked at the overall situation and how experts judge transfer currently. The result is a rather mediocre view of the current state. However, this rating is based on experts' judgments. The experts' subjective judgments will be colored by their respective background. The reward systems in academia and industry differ leading to different evaluations of the situation. Whereas an academic researcher might judge a project a success using dissemination activities as a means of measure, an industrial partner will evaluate transfer from the perspective of immediate profit.

However, a scale such as TRL would show that there are many discrete steps along the way which both parties concerned need to be involved in with differing degrees of engagement. The steps lower on the scale and earlier in the development of technology often fall into the domain of academia whereas the industry will show an increased interest in the steps which are higher on the scale and later in the development process.

Adopting such tools as TRL for the monitoring of successful transfer might lead to an improved transfer process. However, our data suggests that a vast majority of experts in the field of robotics who were asked about the topic was not familiar with the concept. Especially, academic researchers seem reluctant to adopt such a tool in their work. Though, it is rarely used overall. What needs to be noted here is that TRL alone does not guarantee success in the market. There are related concepts which try to market readiness [6] which supplement the TRL which by itself only measures technology development stages.

B. The State of Technology Transfer

After finding that technology transfer is widely seen to be mediocre by experts in the field of robotics, we looked at their suggestions of how technology transfer can be improved. Our results indicate that overall both profits and dissemination activities do not serve as a means of good transfer on their own.
Industry-academia collaborations are judged to be an effective means of improving transfer, though. The extent to which this is practiced and its effects were then examined. It appears that North America is particularly strong in industry-academia collaborations in the field of robotics judging by joint publications at the most pertinent conferences and in the relevant journals. However, the industry does not reflect this with Asia having a far larger share of robotic technology in use than both Europe and North America. In contrast, though, a density measure reveals that Europe has the highest density of robots in use. This is a measure which normalizes the number of robots over the population.

C. Markets and Research in Asia, Europe and North-America

One can see that despite the fact that America has a good amount of industry-academia collaborations, both Asia and Europe show a higher market penetration. The reason for this is often attributed to a fear that robotics will eliminate jobs in USA [1].
Our study of research publications, however, shows a very active research scene in North America which may lead to changes in the current situation. We assume that this rise in collaboration is a reply to the lower numbers of robots deployed in the industry in North America in comparison to Asia and Europe. The consequence of this increased and joint technology-push in the robotics research scene in North America will lead to a boom in the market. Thus, higher numbers of robots used in industrial settings are to be expected. Additionally, the delay which usually exists between science-push and market-pull is going to be much smaller if the experts we questions are correct in their assessment of academia-industry collaborations being a very effective means of driving innovation in robotics.

IV. Conclusion

We investigated the process of technology transfer in robotics. Experts in the field of robotics, who we asked for their opinion, judged the quality of current technology transfer as mediocre rather than good or excellent. To improve this, we have suggested using tools such as the TRL scale for a better evaluation of quality in transfer and for practioners in the field to assess their progress.
In the next step, we asked experts to rate which measures they see as promissing in technology transfer. Industry-academia collaborations received strong ratings. Thus, we looked at recent publications in the pertinent literature for evidence of such collaborative research.
Geographically, North America is very strong in this comparison. Paradoxically, though, they are behind both Asia and Europe in industrial deployment of robotic technology.
We suggested that the research activity in North America may be the peak in a science-push which is eventually going to lead to a market pull. Therefore, we believe that industry-academia collaborations should be encouraged for more successful and faster technology transfer.

Acknowledgment

We thank the experts who filled-out our questionnaires during the North American Lab Tour 2011 and the Lab Tour of Asia in 2012. Similarly, we are grateful for the questionnaire data provided by colleagues who participated in our surveys at the Automatica trade fair in 2012 and the IROS conference in 2012. We would also like to express our thanks to those researchers who responded to our emails regarding industry-academia collaborations.

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