About robot applications and robotic research in cooperative projects between industrial companies and research organisations

Christoph Hellmann[a], Thilo Zimmermann[a], and Werner Kraus[a]
[a]Fraunhofer IPA, Stuttgart, Germany

Abstract

An approach for studying relations between robot applications, robot technologies and market domains topics is introduced in this contribution. Questionnaires for gathering data in bilateral research projects with a research institutes and an industrial company as partners are proposed. A circular cosmograph chart is suggested for visualising the data intuitively. The approach is demonstrated in a small scale study with 46 projects. The relations between robot applications and robotic technology clusters and market domains are made visible by the resulting chart. The described approach is a completely new way of analysing and representing developments in the field of robotic research and robot applications.

Keywords: robot applications, robotic research, technology transfer

1 Introduction

The relation between research organisation and companies is an important driver knowledge transfer and innovation. The EARTO association recently funded a study about the economic footprint of nine European research and technology organisations (RTO) examining this relation [5]. The results of the study showed that the nine RTOs had collaborative research contracts of almost 2.5 billion euro per year. According to the study contract research is a highly effective method of knowledge transfer from research organisations to industry.

In the traditional linear innovation model RTOs take the role of linking basic research in universities and experimental development in companies by working in the field of applied science [11]. The study mentioned above implies that RTOs are still a major link between research and industry and an important driver of innovation. However, the understanding of the process of innovation has changed considerably since the development of the linear innovation model which only describes the one-way knowledge transfer from universities to companies. Today, innovation is understood as a more complex process which is currently described by different approaches such as the triple, quadruple or quintuple helix [9][12][13]. In contrast to the traditional approach of pushing new knowledge and technologies created at universities into industry, these new models see innovation as a two-way knowledge transfer [14].

Gathering data about research topics and new developments in robotics has been part of publicly funded projects for some time. Reports about new technologies have been presented for example by the FP6 project SMErobot [15] or the FP7 project ECHORD [6]. These reports contain qulitative information about challenges met and research conducted during the projects. These rather outdated reports are a valuable source of information about current trends and new research in robotics. Another source of information about research topics and markets in robotics are the multi-annual roadmap (MAR) and the strategic research agenda for robotics (SRA) [1] [2]. These documents provide a structured overview over research domains and applications in robotics. However, they contain little information about companies' research needs and mainly focus on research at universities and research organisations or research labs. Garcia et al. [4] describe the evolution of robotics in the last half century as a response to societal needs. The article is based on research results and focuses on robotic history. It gives a good overview over robotic research. However, it does not exactly show which research topics are currently driving innovation. A study published under the title "A Helping Hand for Europe: The Competitive Outlook for the EU Robotics Industry" [3] in 2010 examines innovation activities in robotics. It is mainly based on specialist interviews and market research. It shows that there is little quantative data available about innovation activities.

Other sources of information about the current state of the art in robotics from an industrial point of view are reports about service robotics and industrial robotics which are anually prepared by the International Federation of Robotics [7][8]. These reports contain a myriad of information about robot markets. They also discuss new technologies which are developed and forecast when they will be ready for the market.

The EU funded Robott-Net project [10] examines how knowledge transfer from research organisations into viable products works in industry-research cooperation. The project aims at creating a sustainable innovation network between four leading European research and technology organisations (RTO), namely the Danish Technological Institute (DTI), Fraunhofer IPA (IPA), the Manufacturing Technology Center (MTC) and Tecnalia (TEC) and regional industry. In its first phase the Robott-Net project offered 64 vouchers for three month of free of charge technology consultancy. Companies with a business idea in robotics could apply for these vouchers. The methods and data presented in this paper are based on this phase of the project.

Knowledge about new business ideas in robotics and thus innovation activities is important for many parties such as governments, research organisations and industrial companies. Governments are interested in knowing the status of innovation in order to provide an optimum of support. Research organisation need to know which robot technologies are currently needed by industry and also what robot applications and markets are currently targeted by new business ideas. The information is also interesting for companies as it gives an outlook to the future market structure as well as into the innovation process in general.

We focus on cooperative projects between research organisations and companies. These project bring together companies' robot applications and research and new technologies from research organisations and are an important part of the innovation process [14].

2 Methodology

Our goal was to gather data about new business ideas in robotics. Our simplistic model, depicted in **Figure 1**, describes a cooperation between a research organisation and an industrial company for realising a business idea. Thus, in a research-industry cooperation the industrial company and the research organisation share a business idea. Both partners bring in specific knowledge about robot applications and robotic technologies. In general the industrial company has a broader knowledge about the applications whereas research organisations bring in knowledge about technologies. The two partners join in a cooperation for realising a business idea for a specific market domain. To characterize a business idea the following three properties of the modell can be used: robot applicaiton, required technologies and the target market.

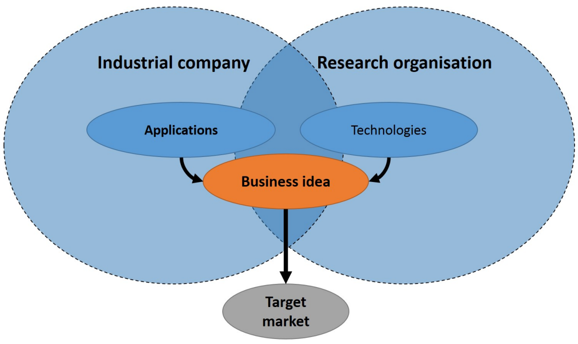


Figure 1 A simpistic model of technology transfer in a cooperation between research organisations and industrial companies

The strategic research agenda for robotics [1] defines seven market domains for robotics. These market domains are manufacturing, healthcare, agricultural, civil, commercial, consumer, military as well as logistics and transport. Military applications were not considered in this paper. Consequently, our study uses a set of six market domains. The manufacturing market covers robots which are used in manufacturing processes such as welding, surface treatment and others. Healthcare is a growing market for robotics and all business ideas in robotics which could be used in public or private health fall into this category. Business ideas for robots which are used in agriculture such as autonomous farming robots or milking robots target the agricultural market domain. Robots used for public interest purposes such as search and rescue, civil infrastructure or law enforcement fall into the civil market domain. The commercial market domain contains all robots which are not directly used in manufacturing processes but are used by companies to improve other processes for example in the service sector or construction and demolition. Business ideas for robots which are sold to private customers such as vacuum cleaner robots fall into the consumer market domain. The domain logistics and transport covers business ideas about robots for use in transportation of people and goods or other logistic applications.

To classify research and technology domains we based the categories on the strategic research agenda for robotics [1]. A set of six different technology domains are defined in the strategic research agenda. These are human robot interaction, perception, navigation, mechatronics, cognition and systems development. Each technology domain has multiple subdomains. This simplifies the process of classification for the technology domains.

The third property in the model is robot applications. To find categories we have systematically classified the voucher applications in Robott-Net and defined a set of eight categories which are handling, logistics, intralogistics, assembly, inspection and quality control, bonding (welding, soldering and gluing), machining, surface treatment.

In order to gather data about the business ideas we have devised a simple questionnaire. For each category in the set of categories described above the participant questioned indicates wether the business idea falls into the category. The questionnaire consists of three sections, one for each property. In each section the categories of the corresponding property are listed as multiple choice questions.

In a cooperative project knowledge is distributed between all parties and the complete knowledge in the project is a inclusive disjunction of the knowledge of the participating parties (equation 1). Likewise, the complete answer to a question about a business idea on which multiple parties are working cooperatively can only be given by asking all parties. Therefore, in industry-research-cooperation both parties need to fill out the questionnaire. We asked the responsible person in the industrial company and the responsible person in the research organisation to fill out the questionnaires. Their answers were combined by inclusive disjunction to create the complete results (equation 2).

$$K_{company} \vee K_{rto} \equiv K_{cooperation} \tag{1}$$

$$A_{company} \vee A_{rto} \equiv A_{cooperation} \tag{2}$$

The data we gathered about markets, robot applications and robot technologies is extremly interesting as it provides information about current innovation activities. However, we have also developed a method to look at the relations between robot applications, robot technologies and robot markets. To visualise these relations we use a circular cosmograph flow chart which is generated using the software tool circos [16]. To find out about the relations between robot applications, robot technologies and robot markets we analyse them in pairs. We use circos to draw three flow charts depicting the relations between robot applications and market domains, robot technologies and market domains as well as robot applications and robot technologies. The analysis of the relation between to properties of business ideas is carried out using a matrix in which each row belongs to a category of one property and each column to a category of the other property. Consequently, each element of this matrix shows how many business ideas touched a category of one property as well as a category from the other property. This matrix is generated using the set of cooperative answers of the questionnaires. An answer vector $a_{category}^{property}$ is created for each classification category of the properties of a business idea and thus corresponds to a single question in the questionnaire. The answer vector has an element for each business idea examined by the questionnaires. Each element of the vector indicates wether the corresponding business idea is a member of the category. The vectors of all categories are used to generate a matrix using the formula shown in (equation 3) for analysis of relations between robot applications and robot market domains.

$$\begin{pmatrix} a_{Handling}^{application} \cdot a_{Manuf.}^{market} & \dots & a_{Surf.Treat.}^{application} \cdot a_{Manuf.}^{market} \\ \dots & \dots & \dots \\ a_{Handling}^{application} \cdot a_{Agricul.}^{market} & \dots & a_{Surf.Treat.}^{application} \cdot a_{Agricul.}^{market} \end{pmatrix} \quad (3)$$

A matrix entry indicates the number of business ideas that fall into a category of one property as well as into a category of another property. This illustrates how closely one category of a specific property is related to a category from another property. Circos can then be used to visualise the matrix in a circular cosmograph flow chart.

3 Results

The method we described for data collection was used in Robott-Net. The following section details the results we obtained by using this approach on 46 cooperative projects between research organisations and industrial companies. The 46 projects considered in this study were projects between Robott-Net research organisations and industrial companies. The business ideas worked on in the ROBOTT-NET voucher projects are at TRL4 [17] or higher.
The industrial companies are homogeneously spread over different company sizes and company types. In terms of company sizes we classify companies as large companies if they have more than 250 employees, smaller companies are SMEs and young companies are start-ups [18]. 43% of the companies considered in this project are large companies, 36% are SMEs and 21% are start-ups. In terms of company types we classify companies as robot developers or end-users. 48% of the companies looked at were robot developers and 52% were robot developers.

3.1 Robot applications

The basic data we gathered indicates that a major part of business ideas for robotics are driven by handling applications. In Robot-Net 29 of 46 business ideas were related to handling applications as illustrated in **Figure 2**. Intralogistics applications (16) are the second most important driver of robotic business ideas in Robot-Net, closely followed by assembly (13), logistics (13) and inspection and quality control (12) applications. Machining, bonding and surface treatment applications are less important.

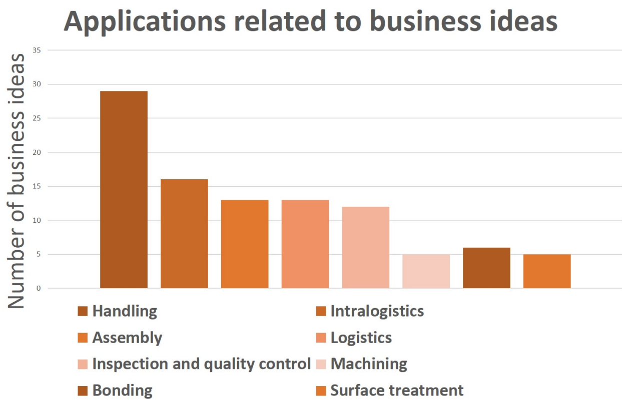


Figure 2 Relations observed between business ideas and robot technologies

The importance of handling applications matches the market demand for handling robots. The world robotics report for industrial robotics [7] shows that 48% of the robots shipped in 2015 were intended for handling applications. It is interesting to note that assembly applications are targeted by thirteen business ideas whereas bonding (welding, gluing, soldering) applications where only part of six business ideas. In 2015 welding robots accounted for 24% of industrial robot sales whereas only 10% were intended for assembly applications. Logistics applications are a typical service robot applications and responsible for 46% of the service robotics sales in 2015 [8]. The number robots for logistics sold in 2015 is comparable to that of robots for assembly applications.
It seems that the number of new business ideas in Robott-Net is corresponding to the market share of the robot applications with some exceptions (e.g. welding).

3.2 Robot technologies

In Robott-Net perception was the most important technology for new business ideas. 36 of the business ideas further developed in Robott-Net were related to perception research **Figure 3**. Mechatronics (34) and systems development (31) were also important technologies the business ideas where related to. Navigation technologies were used in 22 business ideas and human robot interaction was a topic in 17 business ideas. Cognition was a topic in only 11 business ideas.

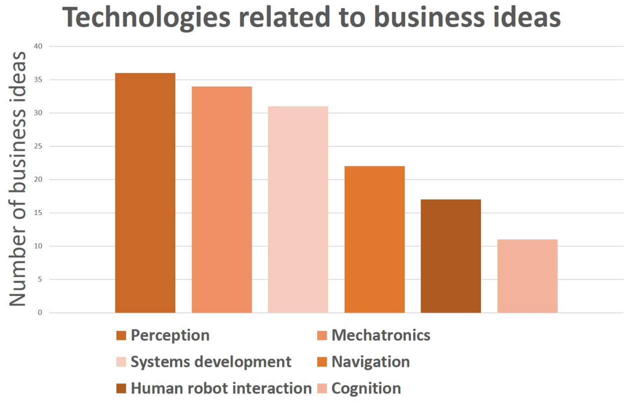


Figure 3 Relations observed between business ideas and technologies

The importance of perception technology is due to the fact that many applications depend on perception [2]. Mechatronics is the basis of all technologies for robotics and consequently is a topic in most business ideas. Systems development has an impact all other technology clusters and therefore is a technology which is contained in most business ideas looked at in this study. Navigation, human robot interaction and cognition play are not part of as many business ideas as they are only needed for some robot applications.

3.3 Market domains

In terms of markets targeted by business ideas in Robott-Net, the manufacturing market was the most targeted domain with 25 business ideas targeting it **Figure 4**. The commercial market was targeted by 12 business ideas and the logistics market by 6. The consumer (3), healthcare (2) and agricultural market played a subordinate role in Robott-Net.

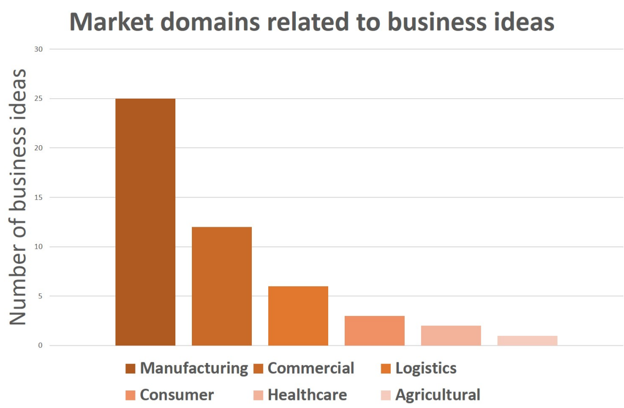
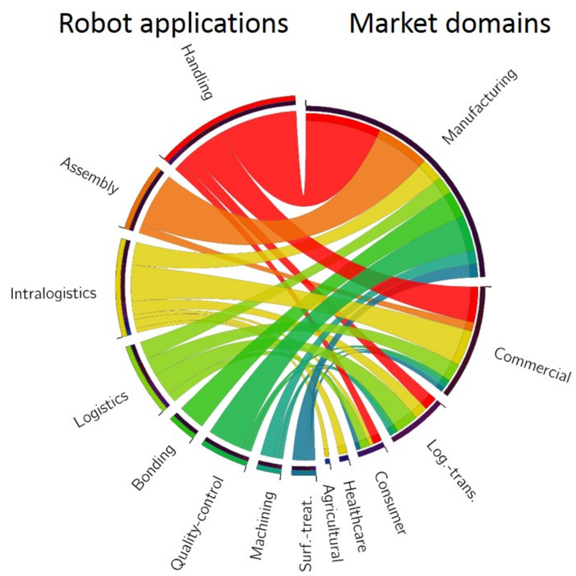


Figure 4 Relations observed between business ideas and technologies

The manufacturing domain is traditionally the biggest market for robotics [2]. Consequently, it is obvious that many business ideas target this domain as the data shows. Transport and logistics as well as the commercial domain are also traditional markets for robotics [2] with high sales volumes. Our data shows, that this makes these market domains interesting for new business ideas. The consumer, healthcare and agricultural domain are newer domains and have high barriers to market in form of normative and legal requirements. The collected data shows that less business ideas target these markets.



	Manufacturing	Commercial	Log.-trans.	Consumer	Healthcare	Agricultural
Handling	17	8	3	2	0	0
Assembly	12	2	0	0	0	0
Intralogistics	5	8	3	1	2	1
Logistics	4	4	5	2	0	0
Quality control	8	1	1	0	0	0
Machining	3	1	1	0	0	0
Bonding	6	0	0	0	0	0
Surf.-treat.	3	1	0	1	0	0

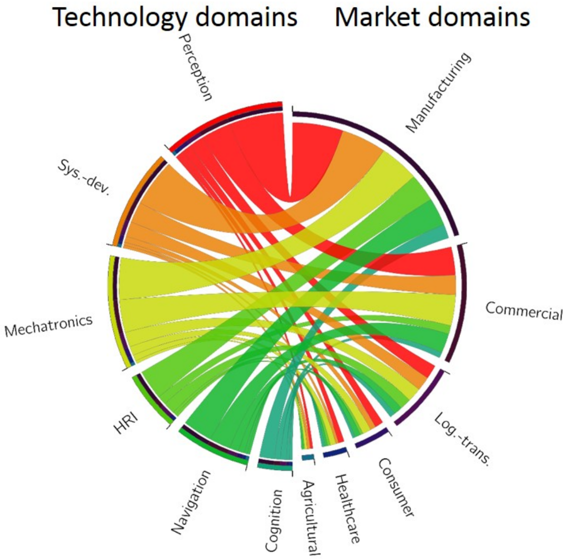
Figure 5 Cosmograph flow chart visualising relationships between robot applications and robot market and a matrix containing the visualised data

3.4 Robot applications and market domains

The relations between robot applications and market domains in Robott-Net are illustrated as a flow chart in **Figure 5**.The flow chart shows that every market domain is linked to many different robot applications. However, some robot applications are only related to a small number of market domains. Assembly, bonding, machining, quality control and surface treatment are primarily contributing to the manufacturing domain. This no suprise because they are all parts of the manufacturing process. Handling, intralogistics and logistics applications contribute to a wide array of market domains. These applications are more versatile and often used in service robotics. The data presented shows that typical service robotic applications such as logistics and intralogistics are finding their way into traditionally industrial market domains such as manufacturing.

3.5 Robot technologies and market domains

Figure 6 shows the relations between robot technologies and thus research topics and robot market domains. It is easy to see, that market domains and robot technologies are closely related. In Robott-Net business ideas targeting all market domains have been worked on. The business ideas have tried to bring robot technologies from every category to the market domains. This demonstrates that in Robott-Net there is strong technology transfer between robot market domains. Technologies which are used in one market domain are transferred to other market domains. This is one benefit of a cooperation between research organisations and industrial companies. Whereas research and developments in industrial companies are often limited to a specific market domain and the technologies present in the market domain, research at research organisations is not limited to a market domain. Therefore, the cooperation between industry and research could improve cross-fertilisation.

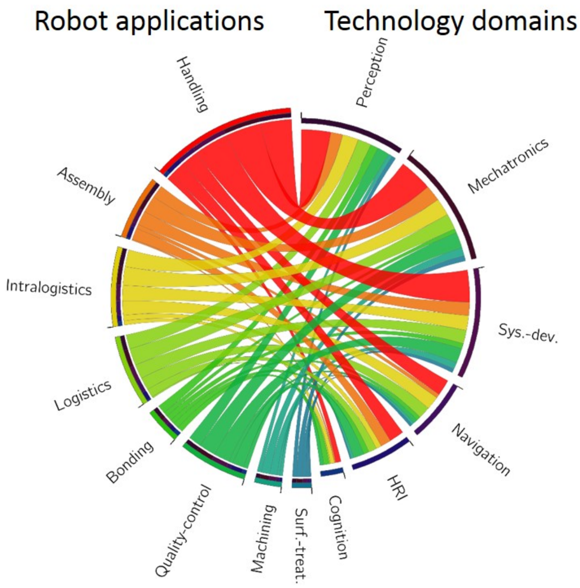


	Manufacturing	Commercial	Log.-trans.	Consumer	Healthcare	Agricultural
HRI	10	3	4	1	1	0
Perception	18	10	5	3	2	1
Navigation	10	7	3	2	1	1
Mechatronics	14	11	5	3	2	1
Cognition	5	2	2	1	1	0
Sys.-dev.	16	7	5	2	1	1

Figure 6 Cosmograph flow chart visualising relationships between robot technologies and robot market and a matrix containing the visualised data

3.6 Robot technologies and robot applications

Robot applications and robot technologies are strongly interconnected as can be seen in the flow chart in **Figure 7**. New business ideas try to improve existing applications using new technologies. It appears that for improving robot applications one needs knowledge about a wide range of robotic technologies. Almost all robot applications in Robott-Net are connected with all six technology and research clusters.



	HRI	Perception	Navigation	Mechatronics	Cognition	Sys.-dev.
Handling	11	22	12	25	4	24
Assembly	8	9	3	12	1	10
Intralogistics	4	12	10	13	3	11
Logistics	6	10	9	12	1	10
Quality control	8	9	3	12	3	11
Machining	2	3	2	6	0	5
Bonding	4	6	3	3	4	4
Surf.-treat.	1	3	2	4	0	3

Figure 7 Cosmograph flow chart visualising relationships between robot applications and robot technology domains and a matrix containing the visualised data.

This indicates that a cooperation between research organisations and industrial companies can be advantegeous for developing completely new robotic technologies. It appears that to improve robot applications knowledge about most robotic technology clusters is involved. Research institutes can provide this knowledge.

4 Conclusion

A simplistic model for technology transfer in cooperative projects between research institutes and industrial companies has been proposed. Using the model we identified properties which describe the business ideas that are object of such cooperative projects. The properties are the robot application on which the business idea is based, the robotic technologies that are needed to realise the business idea and the target market domain of the business idea.

Using these properties we have created a simple questionnaire that allows the classification of a business idea. A method of collecting and combining data when using the questionnaire in projects with multiple partners has been proposed. A method of analysing and visualising the relations between robot applications, robot technologies and target markets has been developed.

The methods developed for analysing business ideas in cooperative projects have been used in Robott-Net for analysing 46 cooperative projects between research organisations and industrial companies. The resulting data gives an overview over the robot applications, technologies and robot market domains which were involved in Robott-Net. It shows which domains of robotics current innovation activities are focussed on.

The analysis of relations between the properties of a robotic business idea shows that all robotic technology clusters and consequently all research domains are used to improve robot applications and bring new solutions to all market domains. This indicates that cooperation between research organisations and industrial companies can be beneficial.

We believe that using the approach in a larger scale study would provide important and reliable information about the innovation actvities in European robotics.

5 Acknowledgement

The research leading to these results has received funding from the European Union Horizon 2020 Programme under grant agreement no. 688217 (TT-NET).

6 Literature

[1] SPARC: "Strategic research agenda for robotics in Europe", 2013

[2] SPARC: "Multi-annual roadmap for robotics in Europe", 2016

[3] S. Forge and C. Blackman: "A Helping Hand for Europe: The Competitive Outlook for the EU Robotics Industry", Publications Office of the European Union, JRC 61539, Luxembourg, 2010, doi:10.2791/48951

[4] E. Garcia, M. A. Jimenez, P. G. De Santos and M. Armada: "The evolution of robotics research", IEEE Robotics and Automation Magazine, vol. 14, no. 1, pp. 90-103, March 2007, doi: 10.1109/MRA.2007.339608

[5] V. Bilsen, I. De Voldere, M. Van Hoed and K. Zeqo: "Economic Footprint of 9 European RTOs in 2015-2016", EARTO – European Association of Research and Technology Organisations, Brussels, 2018

[6] ECHORD: "Gearing up and accelerating cross-fertilization between academic and industrial robotics research in Europe: Technology transfer experiments from the ECHORD project", Switzerland, 2014, doi: 10.1007/978-3-319-02934-4

[7] International Federation of Robotics: "World robotics report 2016 industrial robotics", VDMA, Frankfurt, 2016

[8] International federation of robotics: "World robotics report 2016 service robotics", VDMA, Frankfurt, 2016

[9] Etzkowitz, H.: "The Triple Helix - University-Industry-Government Innovation in Action", Taylor&Francis, 2008, ISBN 978-0-415-96451-7

[10] Robott-Net Consortium: Robott-Net Website, https://robott-net.eu/

[11] Bush, V. "Science: The Endless Frontier", United States Government Printing Office, Washington DC, 1945, https://www.nsf.gov/od/lpa/nsf50/vbush1945.htm

[12] E.G. Carayannis and D.F.J. Campbell: "‘Mode 3’ and ‘Quadruple Helix’: toward a 21st century fractal innovation ecosystem", Int. J. Technology Management, Vol. 46, Nos. 3/4, 2009, DOI: 10.1504/IJTM.2009.023374

[13] Carayannis, E.G., Barth, T.D. and Campbell, D.F.J.: "The Quintuple Helix innovation model: global warming as a challenge and driver for innovation", Journal of Innovation and Entrepreneurship, Vol 1, 2, 2012, DOI: 10.1186/2192-5372-1-2

[14] Carayannis, E.G. and Campbell, D.F.J.: "Triple Helix, Quadruple Helix and Quintuple Helix and How Do Knowledge, Innovation and the Environment Relate To Each Other?", International Journal of Social Ecology and Sustainable Development, Vol 1. 41-69, DOI: 10.4018/jsesd.2010010105

[15] SMERobot: "The European Robot Initiative for Strengthening the Competitiveness of SMEs in Manufacturing", Fraunhofer IPA, Martin Haegele, 2009, https://cordis.europa.eu/docs/publications/1201/120142241-6_en.pdf

[16] Krzywinski, M. et al.: "Circos: an Information Aesthetic for Comparative Genomics.", Genome Research, 2009, doi:10.1101/gr.092759.109

[17] European Commission: "Technology readiness levels", Horizon 2020 - Work programme, Commission Decision C(2014)4995, 2014-2015, https://ec.europa.eu/research/participants/data/ref/h2020/wp/2014_2015/annexes/h2020-wp1415-annex-g-trl_en.pdf

[18] European commision: "Evaluation of the SME Definition", Ref. Ares(2015)1824978, 2015, https://ec.europa.eu/docsroom/documents/10035/attachments/1/translations/en/renditions/pdf