European Commission

Business Innovation Observatory

Service Innovation for Smart Industry

Human-robot collaboration

Case study 39

Internal Market, Industry, Entrepreneurship and SMEs

Service Innovation for Smart Industry

Human-robot collaboration

Business Innovation Observatory
Contract No 190/PP/ENT/CIP/12/C/N03C01

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European Union, February 2015.

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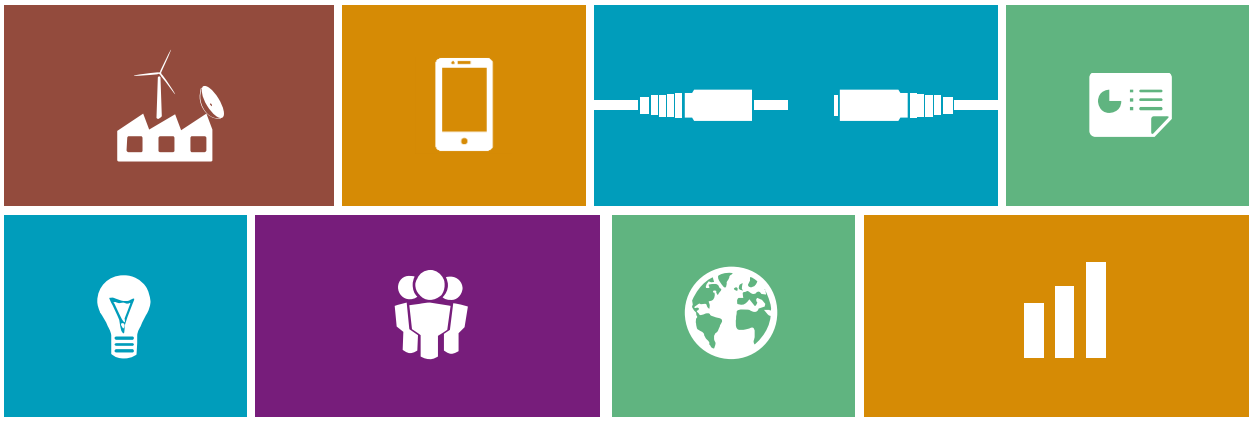

1. Executive summary

The advances in sensors, hydraulics, mobility, machine vision and big data are making human-robot collaboration on the factory floor a technical reality. The new generation of collaborative robots (or 'co-bots') entering manufacturing may overhaul the 'division of labour' between man and machine.

By definition, collaborative robots are designed for direct interaction with a human within a defined collaborative workspace. Co-bots often display human-like features such as dual-arms and facial expressions; they are designed to be safe, adaptable, and user-friendly. Advances in robots' artificial intelligence and common sense are transforming collaborative robots into smart and autonomous co-workers. Thus, machine efficiency and human creativity no longer need to be separated, but can be combined effectively thanks to this new breed of robots.

The increased consumers' demand for customised, new and innovative or continuously improved products is paving the way for collaborative robotics. This kind of production requires flexibility in order to cope with rapidly changing consumer preferences. Collaborative robots are inherently flexible and thus predestined for such small-scale, adaptable production. Importantly, they are most useful when human attributes such as judgement, creativity and cognition add value to the process.

Furthermore, collaborative robotics is tapping into a new, largely unexplored market, which includes SMEs and first-time robot users. In addition to generating growth, collaborative robotics is likely to have a significant impact on manufacturing at large. Human-robot collaboration will strengthen Europe's SME manufacturing base beyond productivity gains resulting from automation, and may thus contribute to maintaining manufacturing capabilities on the continent. Not least, collaborative robots could enhance the quality of workplace, as they free workers from 'dull & dirty' jobs, thus allowing them to dedicate themselves to more interesting and creative tasks.

Human-robot collaboration still represents a frontier both for producers and adopters of this technology. Advances in robotics technology, demand for flexible means of production, and strong R&D capabilities are driving the uptake of co-bots. On the other hand, a series of major challenges need to be overcome. Guaranteeing safety is one of the greatest challenges for human-robot collaboration. Financing robotics SMEs and the commercialisation of R&D are other essential aspects of success in collaborative robotics.

There are important domains in which policy can make a difference in supporting this trend. Standardisation of safety rules and mitigation of safety risks are certainly a crucial area for policymaking. As financing robotics projects is a stumbling block for many SMEs in the sector, policy instruments can intervene in this domain. Moreover, R&D the lack of commercialisation and exploitation of research results need to be tackled by policy. Robotics companies need significant support in accompanying their innovative ideas to the market in order for collaborative robotics to succeed.

2. Human-robot collaboration

2.1. Presentation of the trend

Today, **collaboration between workers and machines** on the factory shop is becoming the new frontier in industrial robotics. A new generation of collaborative robots (or 'co-bots') is entering the market with the potential to transform the way industrial automation operates.

By definition, collaborative robots are designed for direct interaction with a human within a defined collaborative workspace. This characteristic distinguishes them from previous industrial robots that work in safety cages far away from human workers. Additionally, collaborative robots often display human-like features such as dual-arms and facial expressions; they are designed to be safe, adaptable, and user-friendly.

Thus, the 'division of labour' between men and machines, which is still today prevalent on factory floors, will likely be rethought in the next generation manufacturing. Machine efficiency and human creativity no longer need to be separated, but can be combined effectively thanks to this new breed of robots.

At the heart of this new trend lie a series of recent developments, which are having considerable impact on manufacturing. Mass customisation, shrinking electronics as well as the cheaper robotics technology are cases in point. With the growth of advanced manufacturing techniques, manufacturing is becoming increasingly a technology driven industry. Going forward, even low-tech is more and more produced in a sophisticated way.

Collaborative robots are particularly apt at performing low-value added tasks such as packing, placing and storing. This allows them to fill a growing market need precisely for enhancing low-value production. Additionally, their flexibility and adaptability makes them suitable for small batches of production, which are characteristics of SME manufacturing. Combining the advantages of automation while maintaining the flexibility of human workers allows for the much wider application of automation, accessible not only to large manufacturers but also to SMEs.

Declining prices of robotics technology is also an important factor for the uptake of co-bots in SMEs. Lowering costs in robotics, such as computing and sensor technology, allowed pioneer firms such as Rethink Robotics and Universal Robots to slash the price of their collaborative robots at approximately one fourth[1] of the price of traditional automation systems.

The robot Baxter developed by *Rethink Robotics* (see Figure 1), is often considered as the first of its kind and has paved the way for a wave of followers. While each firm is adding its own technology and innovativeness to the final product, a few characteristics are shared among collaborative robots such as safety features, user-friendliness or flexible use as mentioned above.

Figure 1: Baxter, pioneer collaborative robot

Source: Rethink Robotics

Most importantly, co-bots need to be safe for humans to be around. Unlike traditional industrial robots that operate fenced off from workers, the collaborative robot has various safety mechanisms in place in order to avoid harming humans around it. Typically these robots are lightweight and move more slowly compared to their industrial counterparts. Additionally, enhanced sensor technology allows them to detect and avoid collision.

Furthermore, co-bots are meant to be as user-friendly as possible. In fact, they 'learn' new tasks through physical demonstration or only need few hours of re-programming without specialised knowledge.

Lastly, collaborative robots are appealing thanks to their versatility and their ease of repurpose. They can be installed quickly and re- trained for other jobs. Co-bots are 'flexible workforce multipliers', as they can run 24/7 or act as additional workforce if needed.

The success of collaborative robots rests on growing industry needs for automation in all realms as well as on the effective combination of human and machine skills. Going forward, human-robot collaboration will be an integral part of the factories of the future.

Table 1: Overview of the company cases referred to in this case study

Company	Location	Business innovation	Signals of success
F&P Personal Robotics	Switzerland	P-Rob robot family: flexible, safe and collaborative robot arm	- Pioneers in the field of human-robot collaboration - Swiss CTI label - Extensive coverage in national press
Bionic Robotics	Germany	Safe and lightweight collaborative robot arm	- Awarded with EUROP/EURON Robotics Technology Transfer Award for "outstanding innovations in robot technology and automation" in April 2009 - Participation of Land Hessen as investor
FerRobotics	Austria	Robot application that provides tactile sensitivity	- Awarded the State Prize for Innovation: ECONOVIUS 2012 - Awarded the Upper Austrian Prize for Innovation 2011 - Nominated for the Hermes Award 2011 - Awarded with the Innovation Award 2010 and the Manufacturer Award 2010 in the context of the Strategic Manufacturing Award 2010 - Technology successfully introduced in numerous applications, notably in BMW's Spartanburg - Extensive media coverage both in national and international press and national TV
Robotnik	Spain	Customised mobile robot platforms	- Reference company in the field of service robotics - Certified in ISO 9001:08 - Design, manufacturing and commercialization of products and systems based on robotic technology - Certified in UNE 166002:06 - R&D management in the development of projects in the field of robotics - Growth of 40% per year
Scape Technologies	Denmark	Bin-picking technology	- Winner of 2008 KUKA Application Award for spectacular application ideas and exceptional robotic solutions - Winner of Produktprisen 2009, the annual product price of Denmark's most prestigious engineers magazine - Extensive press coverage
Blue Ocean Robotics	Denmark/ Lithuania	Innovative business model based on direct validation of innovations by customers	- Global operations with both offices/partners and customers/clients mainly in Europe, USA, Middle East, China, Korea, Japan and Singapore - Portfolio of more than 40+ early-stage robotic solutions - Extensive media coverage in Danish, Lithuanian and other outlets

2.2. Companies offering solutions related to human-robot collaboration

Problem 1 – Conventional industrial robots work with high precision and speed, but only on a large scale. This makes them relatively expensive, inflexible and dangerous for humans.

Innovative solution 1 – F&P Personal Robotics is a leading provider of light–weight robots arms and adaptive grippers which work directly together with humans. It has pioneered the field of collaborative robotics since the 1990s. The development of the robot arm was spurred by SME demand for a flexible robot. F&P's current generation of co-bots, the *P-Rob*, is a robot arm with 6 degrees of freedom.

The *P-Rob* is intrinsically safe for human interaction, can be programmed easily and intuitively, and has a variety of flexible applications, where collaboration with humans is needed. *F&P Personal Robotics'* co-bots are applied in sectors such as industry, but also service robotics, lab automation, research/education.

Source: F&P Personal Robotics

Problem 2 – Safety is key for collaborative robotics. It is often achieved through complex control systems, but robots are rarely designed to be inherently safe.

Innovative solution 2 – Bionic Robotics offers a lightweight, easy-to-handle, flexible automation solution in the form of a collaborative robot arm that is inherently safe for humans. It has developed a unique approach for making its collaborative robot arm safe, namely a passive safety concept. Instead of relying on controls, the robot is designed in such a way that it cannot exert enough power to be harmful.

This safety concept has been certified by the German trade association (German *Berufsgenossenschaft*) for its use together with humans without requiring further safety measures such as any type of sensors.

Also, it is designed for easy implementation with a 'plug and play' system. The programming of the robot arm works through an intuitive teaching system making it easy for first-time users.

Source: Bionic Robotics

Problem 3 – Robots lack the sensitivity that humans have. The tactile sense is a human ability that comes in handy in a variety of production processes.

Innovative solution 3 – FerRobotics offers a patented technology that provides robots with tactile sense. *FerRobotics*' tactile sense is sold as a robot application that is compatible with all established robots on the market. The company is the only provider worldwide of these self-operating, active device solutions.

This tactile technology allows the robots to bridging problematic gaps in automation and can be applied in many industries, such as manufacturing, medical technology, as well as fitness and simulation.

Source: FerRobotics

Problem 4 – Service robotics needs to perfectly fit customer's need, but solutions are often too standardised.

Innovative solution 4 – Robotnik is a leading company in the field of service robotics. It is specialised in the development of mobile robot platforms that it customises for its clients. These mobile platforms have a variety of applications from industry to R&D.

Robotnik has customised a number of mobile platforms that serve industrial processes. For instance, it has developed a robot for metal spraying and a robot for cleaning pools of nuclear power plants. A significant amount of *Robotnik*'s business is the development of robot platforms for research.

Source: Robotnik

Problem 5 – Many companies have developed bin-picking solutions but these are often not reliable and standardised enough for production purposes

Innovative solution 5 – Scape Technology has developed a unique solution for cost effective and flexible automatic picking of components in an industrial context. Its software and hardware solution enable robot arms to see, find and grip components randomly placed in pallet-bins and boxes.

The innovative element of this solution lies in the standardisation of software and hardware of bin-picking that can be applied to any robot, notably collaborative robots. Thanks to the standardisation the implementation times of bin-picking are reduced and the solution is reliable and effective.

Source: Scape Technologies

Problem 6 – Very often R&D in robotics remains at the research stage and does not reach the market. Customers find it difficult to become familiar with cutting-edge robotics technology.

Innovative solution 5 - Blue Ocean Robotics's mission is to create a bridge between academia/research and the world of business. To do so, it relies on the lean start-up concept, i.e. having innovative solutions validated by the customers directly instead of relying on market research for market entry. To this purpose, *Blue Ocean Robotics* seeks out customers that are interested in being early adopters of technology and works with them to determine if the solution adds value.

Blue Ocean Robotics produces its own robots as well as distributes cutting-edge technology from other manufacturers. In addition, it offers comprehensive service packages to its clients. The company is specialised in the topic of human-robot collaboration and delivers a variety of co-bot solutions in manufacturing, education, health and other domains.

Source: Blue Ocean Robotics

3. Socio-Economic Relevance

3.1. The market potential of the trend

According to the World Robotics 2014 report, industrial robotics grew at a compound annual growth rate of approximately 9.5% between 2008 and 2013.[2] Overall demand for robotics is forecast to remain sustained and reach double-digit figures. These growth rates are accompanied by a surge in investment activity in robotics from both venture capital firms and firms outside traditional manufacturing activities, such as Google and Amazon.[3]

Wider adoption of robots comes at a time when manufacturers are under pressure to increase productivity and low-wage off-shoring is no longer as profitable. In fact, traditional low-wage countries such as China are starting to automate heavily too.

Yet, traditional industrial robots are very costly. It is estimated that the capital costs alone account for 25 to 30% of the total system costs, to which the costs for programming, setup, and dedicated work shells need to be added. This makes such machines prohibitively expensive for SMEs.[4] Moreover, automation offers most productivity gains when robots take over low-skilled jobs in high-wage countries. So far this applies mostly to the automotive industry, which has a 10 times higher "robot density" (robots per 10,000 employees) than general industry.[5]

Thanks to human-robot collaboration, automation is no longer limited to the 'dull, dirty, and dangerous' work, but can enter a variety of industries and sectors that require versatility and dexterity. Plastics, medical devices, food & beverage, high-tech industries are increasingly expressing interest in collaborative robotics.[6]

In addition to their flexible application, the competitive price makes co-bots appealing. Most manufacturers of collaborative robots have adopted a distinct pricing strategy in order to appeal to SMEs. For instance, *Universal Robots* sells its collaborative robot arm at EUR 20,000-30,000 compared to six digit figures for an industrial robot.[7]

Furthermore, major robotics companies (*KUKA, Fanuc, ABB, Yaskawa*) have recently announced that SMEs represent an untapped market and predicted growth in general applications among smaller factories.

Thus, an entirely new market is opening up for collaborative robots, which includes SMEs and first-time robot users. This is supported by the fact that the companies interviewed have a positive outlook for their respective markets.

For instance, *F&P* is counting on selling over one hundred of its co-bot this year but will be expanding in the thousands by the end of the decade. *Bionic Robotics* is expecting the market for collaborative robots to grow stronger than the overall robotics market. *Scape Technologies*, too, foresees an expansion of its market thanks to collaborative robotics.

3.2. The social impact of human-robot collaboration

Direct interaction between humans and robots has long inspired science fiction. With the human-robot collaboration becoming a reality science fiction is about to turn into a science fact. Moreover, the trend of human-robot collaboration has concrete implications for our society, notably in the workspace but also in other domains.

Collaborative robots are likely to improve the quality of workplace, as they liberate humans from 'dull & dirty' work and allow them to dedicate themselves to more interesting and creative tasks. This comes at a time in which fewer people consider manufacturing appealing as a career and companies have difficulties finding the right skills on the market.[8]

Furthermore, co-bots may contribute to the empowerment of workers. The application of collaborative robots demonstrated that putting humans in charge of the machines has a positive impact on job satisfaction. As co-bots are managed and taught through intuitive systems, the control of the robots is no longer limited to specialised engineers.

Lastly, human-robot collaboration is not limited to manufacturing. In fact, some of the technologies used in production have applications for other societal challenges, too. *FerRobotics*'s tactile robot is a clear example of such a transferable technology. For instance, the tactile sense of the robot can be successfully applied in the clinical field as well as for elderly care.

3.3. The impact on the value chain

As with all automation, human-robot collaboration has a significant effect on the value chain of its adopters. Beyond the traditional benefits of automation, collaborative robots are having an impact on the entire value chain of Europe's manufacturing industry.

"Conventional thinking is that companies are buying robots to replace people. It's not that simple. In many cases companies are using robots so they can expand and improve product quality and increase production" comments a senior executive interviewed by PwC in a report on the next generation robots in manufacturing.[9] Accordingly, adding robots may lead to subsequent growth through automation, which in turn creates greater employment.

According to the aforementioned PwC report, 35% of manufacturing companies consider that new development in robotics have the most impact on the creation of new jobs and opportunities, while 28% see the replacement of workers as the main impact.

For starters, co-bots such as Baxter add value to typical low-value tasks such as loading/unloading, testing and sorting, as well as picking and placing. This allows companies, in particular SMEs, to speed up typical non-skilled manual tasks.[10] Also, robots can run non-stop and thus act as "flexible workforce multipliers".

Furthermore, co-bots optimise the production process thanks to greater precision and speed. The quality of production is enhanced, while station times and redundancies are reduced. In addition to these productivity gains, employees are freed up for other tasks that can generate greater value to the company.

But beyond the productivity gains of single firms, human-robot collaboration strengthens the overall competitiveness of the whole manufacturing industry. Increased competitiveness allows maintaining manufacturing capabilities in Europe and contributes to the 're-shoring' of industrial jobs.

The relatively cheap price of co-bots changes may change the cost calculations for manufacturing firms entirely: if the co-bot costs less than 4 EUR/hour in rental fee, the incentive to look for cheap labour abroad is significantly reduced.[11]

While the final impact on competiveness and job creation is debated and may not be answered conclusively, it remains clear that collaborative robotics will significantly shape the manufacturing value chain.

4. Drivers and obstacles

Despite strong market potential and positive societal impact, human-robot collaboration still represents a new frontier for both producers and adopters of this technology. Advances in robotics technology, demand for flexible means of production, and strong R&D capabilities are paving the way for the uptake of co-bots. On the other hand, a series of challenges need to be overcome, notably: safety and risk aspects, financing of high-tech, market entry, commercialisation of R&D, as well as talent attraction.

4.1. Factories of the future and advanced manufacturing

Since the economic crisis in 2009, manufacturing has re-claimed its standing in the policy arena. Policymakers have recognised the role of manufacturing as a means of tackling the major societal challenges in Europe and globally. Manufacturing, in particular its 'smart' version, is backed by the political agenda at EU and national level.

But beyond flagship projects such as the "Factories of the Future", technological advances are actually driving the next generation manufacturing. And if production is going to be anything but 'smart', it will certainly include robotics, and more specifically its sophisticated version, i.e. human-robot collaboration.

Today's advances in sensors, hydraulics, mobility, machine vision and big data[12] are making human-robot collaboration a technical reality. Furthermore, all aspects related to the robots' artificial intelligence and common sense are transforming robots into smart and autonomous co-workers. These include advances in semantics, reasoning, self-learning, social awareness and decision-making capabilities.

In addition to funds flowing to robotics research from the manufacturing side, key robotics actors are taking action on their own. To further strengthen R&D in the robotics domain, they have formed the *euRobotics* interest group, comprising key stakeholders such as the European Commission and 180 among companies and research institutes. This platform is streamlining research priorities and has launched a EUR 700 million robotics research programme called SPARC. Human-robot collaboration is recognised as a priority area with wide-ranging implications for the robotics industry as a whole.

4.2. Demand for flexible production

Consumers' appetite for customised, new and innovative or continuously improved products requires flexible production that is able to cope with rapidly changing consumer preferences. Given their limited size, SMEs produce in small quantities and need flexibility in their manufacturing processes.

However, SMEs are not the only producers that are interested in enhanced flexibility in production. Even large manufacturers need to be responsive to demand and are therefore restructuring their production processes.

Collaborative robots are inherently flexible and thus predestined for such small-scale, adaptable production. Importantly, they are most useful when human attributes such as judgement, creativity and cognition add value to the process.

4.3. Europe's head-start in research

Europe is leading in robotics research, as it is demonstrated by a dedicated 200 million research budget from the Horizon 2020 envelope.[13] Indeed, the topic of human-robot collaboration originated as a research topic in Europe more than a decade ago.

In addition to having a head-start in the research domain, Europe is overall advanced in automation compared to other industrialised countries, notably the U.S. As a result, it is well-placed to reap the benefits of human-robot collaboration.

Beyond strong capabilities in research, universities and research institutes play a vital role in supporting and sustaining innovative companies in the field. In fact, most interviewed companies benefit from close collaboration with a research/university institute. Such bilateral cooperation has been recognised as critical success factor by the majority of interviewed companies. Close ties to a specific research institute may serve a number of purposes, such as development and testing of ideas, mentoring, as well as recruitment of talents.

While research overall can be considered one of Europe's strong points and collaboration with selected institutions is a crucial step for success, the feedback on European research projects is mixed. For instance, *Blue Ocean Robotics* considers these research projects a strategic priority and invests time and resources in them. Yet, it has learned how to navigate these projects skilfully in order to reap benefits from them. This entails coming into an agreement with researchers on how to best accommodate the interests of both academia and industry.

"Participating in research projects is a strategic focus and long-term investment for us. But we have to fight our battles" – ***Blue Ocean Robotics***

This key problem relates to a skewed incentive system, as *Robotnik* points out: since researchers in Europe are mainly rewarded by the number of publications they bring out, and not by the number of products that they successfully bring to the market, they tend to focus on subjects that are highly theoretical and not of interest to the industry.

Companies dedicate significant time and resources to such projects, but too often they cannot extract value from them at the end. Small companies simply cannot afford this.

Not least, administrative burden and the overall lack of strategic focus further deter SMEs from participating in European research projects.

4.4. Commitment to collaborative robotics

Even though the benefits of direct interaction between humans and robots have already been successfully tested, collaborative robotics is still demanding full commitment in order to deliver to its full potential.

The first difficulty lies in convincing clients of the benefits of collaborative solutions. Compared to industrial automation, the benefits are much more complex to calculate and to sell: the return on investment of co-bots is not easily quantifiable as it includes 'soft' elements such as a more interesting work environment.

A second challenge is related to the acceptance of co-bots by their fellow co-workers. Workerbots such as Baxter and pi4 have been marketed as "complements to industrial automation" that do not replace the human workforce.[14] Yet, this may not always suffice to dispel fears of workers, if not accompanied by clear communication.

*"The benefits of a collaborative robot are much more complex to calculate and to sell" – **F&P Personal Robotics***

Interestingly, the physical aspect of the robot plays a significant role for its acceptance. The collaborative robot needs to appear as non-threatening as possible. Human-like features or 'warm' materials such as plastic are important steps for making the robot factory-friendly.

4.5. Safety and risks: robot governance

The first Asimov law of robotics states that "a robot may not injure a human being or, through inaction, allow a human being to come to harm." While taken from a work of fiction, this principle can provide a serious basis for robot governance.[15]

Guaranteeing safety to workers represents one of the biggest challenges in human-robot collaboration. In fact, guaranteeing 100% safety as stipulated by the Asimov law may be entirely unachievable or come at a prohibitive cost. The industry and the market need to be willing to accept a degree of residual risk for collaborative robotics to succeed.

The technology today is moving at a faster pace than the most reputable institution for voluntary international standards, the International Organisation for Standardisation in Geneva, can keep up with. The existing standard for collaborative robotics mandates that power and force limits need to be enacted in order to have a cage-free robot. Yet, there is no consensus on what is allowable power and allowable force.

As long as no standard has emerged, the industry will continue to develop its own approaches to safety. The most commonly adopted mechanisms to ensure safety are related either to limiting the force that is exerted on the human body ('power & force' limiting') or to reducing the speed of the robot when a human is in proximity ('speed & separation monitoring'). In contrast, producers such as *Bionic Robotics* focus on developing a robot that does not exert enough force to cause any harm.

4.6. The winding road from R&D to the market…

Managing the transition from research & development to a marketable product is a minefield full of hurdles that entrepreneurs need to overcome. In the following section, the main critical steps mentioned by our showcased companies are presented.

The lack of a strong entrepreneurial culture is the starting point. Compared to the U.S., European investors are less willing to take risks, in particular at the early stages of a start-up, the interviewed companies note. Also, failing with a business idea does not have the same stigma overseas as in the old continent.

Beyond entrepreneurial spirit, public support for accompanying new ideas on the market is considered inadequate. Instead, substantial resources are spent on R&D programmes, with little consideration for the impact of these public funds in terms of commercially viable results. "If only a fraction of the R&D money would go into the subsequent step of the innovation chain, it would already do a lot of good", adds *FerRobotics*. From this company's perspective, the formation of start-ups and spin-offs from research is plainly underfunded.

Further to this, in case SMEs receive public support for launching their innovative product, they are tied to a business plan. However, this limits their ability to apply their commercial sense for fine-tuning the technology to the market. Often, the original business plan does not lead to commercial success, but still adjustments are difficult to make.

Once a company is set up and running, it is faced with administrative burdens starting from day one. Moreover, each company's process needs to be set up for the first time; this, however, takes time and turns the entrepreneur away from his core business.

The next critical step for the start-up's survival is related to market entry. This is even tougher if the company introduces a new and disruptive technology, for which the market has to be created. The challenge is convincing potential customers of the value of one's product with few or no references to show for it.

"I don't know any entrepreneur who was sucessful with his original business plan" – ***FerRobotics***

For *FerRobotics* this meant insisting on getting customers to try out its technology. *Blue Ocean Robotics,* on the other hand, focuses on the 'early adopters', i.e. consumers that enjoy being the first ones testing new technologies. *Bionic Robotics,* too, has heavily invested in outreach through industry fairs, road work, direct calls and similar activities.

4.7. ...and to a global player

The ambition of all enterprises interviewed is to be present on the global market, as competition in the robotics field is on international scale. In this regard, the US and China are among the most attractive markets for international expansion. For companies originating from a small country internationalisation is not even a choice, but a necessity, as the local market cannot sustain their growth. Take *Blue Ocean Robotics*: with Denmark and Lithuania as home markets, international expansion is crucial.

Most companies interviewed are already successfully competing in the global market place and have established sales and distribution networks in Europe or beyond. Yet, they maintain that being competitive as a European company is more challenging. *Robotnik* underlines that the level of taxation is a heavy burden for a SME.

Similarly *Blue Ocean Robotics* highlights that due to high wages it will not be able to employ as many people as the company needs. Finally, language and cultural barriers play a role, too. For instance, simply conducting business in English may not work everywhere in Europe; in order to tap the European market enterprises need to invest in local distribution with all the associated limits and costs.

4.8. Financing robotics

Access to finance is one of the most common challenges for start-ups and SMEs. In addition to the general difficulty to acquiring funds, there are some specificities of the robotics sector that the interviewed companies pointed out.

First, few venture capitalists are acquainted with robotics and what it entails. In fact, for this type of business you need to be prepared to invest in technologies that may not yield profits for up to 10 years. As pointed out by *FerRobotics*, a robotics start-up needs to re-invest its profits in the early years in order to reach a critical size and expand globally. Many private equity and venture capital firms expect returns much earlier and are not ready to front such an investment.

"If I don't re-invest my profits in the early years, I gamble my future as a company. But investors don't see this" – ***FerRobotics***

A second issue encountered is related to raising the second round of investment capital needed for the expansion of the sales and distribution network as well as for additional product development. This is case of *Bionic Robotics*, which notes that the majority of investors show little interest for companies that have proven technological concept but still need to expand their market share.

Even if venture capital/private equity is available, it may not prove as attractive as a financing option given the strings attached to the investment money. In most cases, *Robotnik* explains, investors demand significant controlling rights over the company or the right to sell the company entirely.

For entrepreneurs that are passionate about their innovation and their company, this is often too difficult a compromise. Similar issues have prompted *Scape Technologies* to a management buyout, too. Yet, relying exclusively on their internal resources may involve missing important business opportunities.

4.9. Skills and talents

Finding the right skills and recruiting talents is a typical challenge for young companies. Two main aspects stand out from the interviews with the showcased companies.

First, due to an unparalleled increase in knowledge in the field of robotics over the decade, universities are not always able to keep up with their curricula. As a result, recent graduates are lacking basic knowledge needed for jobs in service robotics. Yet, another difficulty lies in the attraction of talents. Evidently, small companies and start-ups have a hard time in competing with the engineering giants that can offer more in terms of salary, job security, and prestige. They thus tend to be snubbed by potential talents and face hardships to attract skilled workforce.

5. Policy recommendations

Collaborative robots are making their way into the today's and tomorrow's factories. Even though technology advances for the most part autonomously, there are important areas in which policy can make a difference in supporting this trend.

5.1. Regulation of safety standards and mitigation of risks

Standardisation of safety rules is certainly a crucial area for policymaking, as an equal-level playing field needs to be defined in order to allow human-robot collaboration to further develop. The needs of the workers and industry have to be taken into account with a view of ensuring maximum safety on the one hand, and technology advances on the other.

F&P Personal Robotics considers the current developments as "fair" and moving in the right direction, while other companies such as *Scape Technologies* see safety rules as potentially burdensome. As with all regulations, standards should avoid overregulation but guarantee maximum safety.

Some concern was issued by *FerRobotics* that the industry as a whole may not yet be willing to accept residual safety risks deriving from human-robot collaboration. This could slow down the uptake of collaborative robotics, especially if dealing with SMEs and first-time adopters of robots. Policy action could prove instrumental to supporting the trend.

For instance, schemes for mitigation of risks could be envisioned from the policy side, such as mandatory insurance or similar arrangements. On the other hand, the industry must be committed to heavily invest in safety as well as in the education of consumers on how to behave safely around a co-bot.

5.2. Incentivising high-tech finance

The specificities of the robotics sector make it relatively capital intensive. Significant investment is needed in R&D and infrastructure alone for the creation of a prototype and for establishing the proof of concept. In most cases, all of this happens before the companies are anywhere near to making any profits.

Moreover, return on investment in high-tech takes generally more time to achieve than in other sectors, as profits need to be re-invested. This means that investors have their capital locked for potentially a relatively long time — which bears significant opportunity costs. As a result, most investors are not attracted by the sector and choose other opportunities.

On top of this, European investors tend to jump in only at a later stage, when the company has already reached a sizeable market share.

One possibility to support long-term capital investments needed by robotics and high-tech start-ups would be to act through tax incentives. Making long-term investment more advantageous from a tax perspective would reduce its overall cost and increase the attractiveness of financing such an undertaking.

5.3. The SME Instrument and beyond

The commercialisation and exploitation of research results as highlighted by the companies interviewed has been recognised as an important policy objective. In fact, the new SME Instrument set up within the Horizon 2020 programme already addresses many of the issues that came to the fore in our interviews.

The objective of the SME Instrument is defined as 'helping high-potential SMEs to develop ground-breaking innovative ideas for products, services or processes that are ready to face global market competition.' Specifically, the SME Instrument offers support in the following three areas:

- Business innovation grants for feasibility assessment purposes
- Business innovation grants for innovation development & demonstration purposes
- Free-of-charge business coaching
- Access to a wide range of innovation support services and facilitated access to risk finance, to ease the commercial exploitation of the innovation.

These elements are certainly important steps in the right direction, as they cover many points raised by the enterprises showcased in this case study. But more could be done.

First, many companies are not aware of opportunities at EU level. In fact, only one company cited the SME Instrument as an interesting development. Worse, some SMEs may be discouraged from applying to EU programmes after unsatisfactory participation in research projects.

Thus, clear communication about available instruments would benefit interested stakeholders. The work of euRobotics as a platform for sharing information has been praised and could be a way to move forward.

Furthermore, the funding of the SME Instrument could be expanded and be more in proportion to the overall budget of Horizon 2020. For the time being, the Instrument is endowed with EUR 3 billion, while Horizon 2020 disposes of nearly EUR 80 billion.

5.4. Getting the most out of R&D grants

As outlined above, the SME Instrument provides significant support in accompanying innovative ideas to the market. But some areas of improvement remain to be tackled in order to fully reap the socio-economic benefits of R&D. This entails streamlining the R&D process, particularly in the following areas:

- Incentive structure of R&D grants,
- Flexibility in business plan development
- Facilitating market entry through reference portfolio

In human-robot collaboration all of these elements are particularly important, as the field is relatively new and R&D is needed to boost it.

The R&D incentive structure puts entrepreneurs at odds with the scientists. Policy could ensure that both categories have broadly the same objectives through a different reward mechanism. Both academia and industry stand to gain from cooperating instead of trying to reach their own separate agendas.

As indicated by the FerRobotics, the initial business plan rarely guarantees success on the market. It is up to entrepreneurs to use their intuition and adapt to the market. However, SMEs need to be allowed this flexibility and not be locked into a business plan that hinders their growth.

Public procurement and public-private-partnerships (PPP) can be used as instruments for facilitating market entry, in that they can help building a solid portfolio of references. For instance, the "Factories of the Future" PPP offers opportunities in this regard. Other similar activities targeted specifically at SMEs that are launching their innovation for the first time could be envisioned.

5.5. Developing skills

The robotics sector is developing fast, and universities are finding it hard to keep up with the pace of change. This leads to companies taking the role of teaching institutions in order to fill the skills gap. Yet, this system demonstrates great inefficiencies and should be improved. Students spend years being taught material that is not relevant, whereas companies have to take a teaching/training role in order to make up for this lack.

*"There has been an explosion of knowledge in robotics over the last 10 years" – **Robotnik***

In order to overcome such skills gap, universities and industry need to aligning curricula to the industry's need on the one hand, and to the latest developments in research on the other. Given that academia-industry cooperation has proven a critical success factor for most companies interviewed, this could be extended to the skills domain, too. Robotics companies and research institutions could form partnerships with a focus on skills. Alternatively, traineeship programmes could be subsidised, if they involve teaching from the robotics company.

6. Appendix

6.1. Interviews

Company	Interviewee	Position
F&P Personal Robotics	Dr. Hansruedi Früh	CEO
Bionic Robotics	Ralf Teichmann	CEO
Robotnik	Roberto Guzman	CEO
FerRobotics	Dr. Ronald Naderer	CEO
Scape Technologies	Søren Bøving	CEO
Blue Ocean Robotics	Dr. Claus Risager	Partner & Director

6.2. Websites

F&P Personal Robotics	www.fp-robotics.com
Bionic Robotics	www.bionic-robotics.de
Robotnik	www.robotnik.eu
FerRobotics	www.ferrobotics.at
Scape Technologies	www.scapetechnologies.com
Blue Ocean Robotics	www.blue-ocean-robotics.com

6.3. References

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