ISSN 2599-8293

European Commission

CORDIS Results Pack on artificial intelligence and industry

A thematic collection of innovative EU-funded research results

May 2020

Turbocharging European industry

Research and Innovation

Contents

Editorial

Turbocharging European industry

AI and advanced robotics are opening new horizons in all sectors of industry, in terms of both developing novel manufacturing techniques, as well as overhauling the interaction between human workers and automated tools. This CORDIS Results Pack presents the first innovative results of 13 ongoing (or recently finished) Horizon 2020 projects that are leading the way in embedding AI applications into industry.

'Industry 5.0' is a term that has been gathering pace over the past few years, with its broad definition being a major shift within industrial production towards a much closer and intertwining state of cooperation between humans and machines. It promises the creation of a new symbiotic environment between a workforce comprising both human operators and increasingly autonomous and intelligent mechanical colleagues. This transition is being heavily influenced by the phenomenal growth in advanced robotics and Artificial Intelligence (AI), and consequently offers many golden opportunities for Europe.

Harnessing the benefits of AI

Manufacturing and industrial production have remained a constant backbone to Europe's economic prosperity and growth for more than two centuries. And it's here on the factory floor where some of the first major AI-based innovations are being pioneered and rolled out.

The infusion of AI processes into manufacturing offers many positive benefits, such as the development of novel industrial processes for both existing as well as newly-emerging industries, enhancing production efficiencies and redefining the role of human workers as they take on new roles and responsibilities to collaborate with and supervise the (often repetitive) tasks of their AI-powered machine co-workers. Importantly, the use of AI/Augmented Reality techniques in factories promise to make human roles less hazardous, less monotonous and less physically exhausting.

Supporting the spread of AI in European manufacturing

However, there is still much work to be done to completely overhaul and adapt European industry to these new technologies and, by extension, these new opportunities. This is regardless of the fact that Europe is already one of the world's major leaders in the development of AI.

Therefore, the European Commission is dedicated to enhancing Europe's leadership in the field of AI, viewing it as an area of strategic importance and a crucial source of future economic growth. The European Commission has been working hard with Member States to foster a genuinely collaborative AI strategy, embodied in the 2018 Communication 'Artificial Intelligence for Europe', which also emphasises the importance of AI in European manufacturing. The Commission has also massively increased its funding of AI research through the Horizon 2020 programme, with EUR 1.5 billion having been pledged for the period 2018-2020, and will keep funding AI research and applications through Horizon Europe and Digital Europe programmes.

13 pioneering projects

This CORDIS Results Pack showcases 13 projects that have been pioneering the way forward with AI technologies geared towards industry and manufacturing.

AI-powered drones for difficult maintenance tasks

Picture a drone equipped with arms and an artificial intelligence system making it smart enough to attend to the most remote, complex and delicate maintenance tasks. Now, compare this drone with alternatives and realise how it enables cheaper, faster and more effective maintenance than alternatives. You've just met a new generation of drones developed under the AEROARMS project.

© AEROARMS

AEROARMS are not your typical drones. To large refineries operating tens of thousands of kilometres of pipes, they offer a unique solution to prevent corrosion and accidents. The drones can fly to the most elevated structures, map them, calculate pipe wall thickness thanks to their ultrasonic sensors, deploy non-destructive test (NDT) sensors, and even perform important maintenance tasks. All this, with the promise of up to EUR 700 000 of savings in inspection costs per refinery per year.

The main innovation under the project AEROARMS (AErial RObotic system integrating multiple ARMS and advanced manipulation capabilities for inspection and maintenance) lies in the world's

first intelligent aerial robotic manipulators, including arms and multi-thrust platforms (tilted rotors) that can exert forces in any direction. Thanks to its advanced AI, the drones can hold on to an inspected object with one arm while inspecting it with another. Their talents were successfully demonstrated in real-life situations, including wall thickness measurements of pipes and tanks.

"We demonstrated the aerial manipulators in a cement factory in southern Spain and in a refinery in northern Germany. Demonstrations included the installation of permanent sensors in inaccessible sites along with wall thickness measurements, which are very important to evaluate the effect of the corrosion and avoid accidents due to leakages of explosive gases," says Anibal Ollero, project coordinator, professor and Head of the Robotics, Vision and Control Laboratory at the University of Seville in Spain.

We are already targeting new applications in agriculture, search and rescue, and even in logistics and transportation where our intelligent aerial manipulators could deliver supplies directly to people.

This is, of course, just an illustration of the drones' capabilities. They can be used to install surveillance sensors and communication equipment such as antennas in inaccessible sites or – as demonstrated by the University of Seville and the CATEC Aerospace Technology Center in the AEROBI project – for the detection and evaluation of cracks in bridge pillars or piers, using ultrasonic sensors in the end-effector of their arm. "This is highly relevant when considering the EU's large number of road and rail bridges that are more than 50 years old, and the need for inspection and assessment of these bridges," says Ollero.

The drones can fly autonomously for most operations, and a backup pilot can always take control in case of emergency situations.

Countless opportunities

Seven months after its end, AEROARMS has been widely acknowledged for its contribution to consolidating aerial manipulation as a new technology field in which AI can be applied. It has led to several industrial applications and the creation of a start-up – Vertical Engineering Solutions (VES) – which is currently developing a new version of the AEROX system – one of the project's drones developed at CATEC – and has been invited to demonstrate it in the United States within the coming months.

In December 2019, the follow-up AERIAL-CORE project was kicked off to push the limits of aerial robotics. "The new project applies Artificial Intelligence to increase the operation range and safety of aerial robots. It aims to implement AI in long-range (kilometres) aerial inspection, aerial manipulation, as well as co-working between aerial robots and people working at height," explains Ollero. "Meanwhile, my European Research Council (ERC) Advanced Grant GRIFFIN is using the results of AEROARMS to develop a new generation of bioinspired aerial robotic manipulators."

It seems like there is no stopping the innovation wave inspired by AEROARMS, and the future could hold even more surprises. Asked whether he expects applications for other markets to be developed, Ollero answers positively. "I am sure there will be. We are already targeting new applications in agriculture, search and rescue, and even in logistics and transportation where our intelligent aerial manipulators could deliver supplies directly to people while they are working, or at home when they cannot leave." A very topical idea indeed, when most Europeans are confined to their homes waiting for the Coronavirus crisis to ease.

PROJECT
AEROARMS – AErial RObotic system integrating multiple ARMS and advanced manipulation capabilities for inspection and maintenance

COORDINATED BY
University of Seville in Spain

FUNDED UNDER
H2020-LEIT-ICT

CORDIS FACTSHEET
cordis.europa.eu/project/id/644271

PROJECT WEBSITE
aeroarms-project.eu

Robotic extraction of asbestos fibres from buildings

Europe has paid a high price for asbestos, with over 100 000 related deaths. First in line in the fight to free buildings from asbestos contamination, workers in the construction sector could soon find a helping hand in the form of an AI-piloted robotic system.

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The constant and multifaceted evolution of society has left very few industries unchanged. For most sectors, this has meant moving towards increased automation. Most, but not all. One unyielding sector has largely stayed true to its old ways: the construction sector.

For the past 200 years, the same repetitive, standardised and physically challenging construction tasks have been performed by workers with their own two hands. But this could change soon, as emerging voices – some of which decided to stand together under the Bots2ReC (Robots to Re-Construction) project – have been calling for the sector to embrace automation.

The reasoning behind Bots2ReC is simple: some tasks are simply too hazardous for humans to perform, and machines could easily replace them. “Besides the exposure, some processes or the

materials handled in those processes generate health hazards in the form of dust, vibration, noise or toxic substances. It is precisely for these tasks that we could expect great benefits from – and also show the massive potential of – automation to achieve sustainable socio-ecological improvements," says Tobias Haschke, coordinator of the project on behalf of RWTH Aachen University.

Tailored to construction sector needs

To enable such automation, the project consortium first had to overcome barriers related to the nature of the construction sector. Whereas most industries manufacture in a defined environment, the construction industry has historically had to cope with a continuously changing environment with varying rules and procedures. As Haschke explains: "The key to success lies in the technical control of this constant change."

Recent developments in computer science, storage systems and sensors were key enablers that set Bots2ReC in motion. They enabled the introduction of semi-autonomous solutions through mobile handling of environment complexity.

Over a span of 3 years, the project team developed a robotic system capable of handling asbestos removal on construction sites. "The robot operates asbestos removal comprehensively and not just piece by piece. Thanks to its AI capabilities, it is also tailor-made to be used under real conditions," Haschke explains. "The AI combines a tailored lightweight data format for environmental representation with a complex planning module. As a result, it can provide a scalable system in terms of fleet size and it automatically adapts to the floor plans at hand."

The AI combines a tailored lightweight data format for environmental representation with a complex planning module. As a result, it can provide a scalable system in terms of fleet size and it automatically adapts to the floor plans at hand.

Most tests of the Bots2ReC were carried out with a grinding disk to reflect the actual process of asbestos removal. This helped the team understand and subsequently control the complex mechanisms of such interaction. Furthermore, the system was examined for its suitability for use in normal residential buildings, and tested in various room and floor plan constellations. The results are promising, with basic accessibility reaching almost 90 % of the wall surfaces of a general dwelling. A direct comparison to manual work is still pending and will be implemented in the follow-up of the project.

The greatest achievement

"To me, our greatest achievement is the robot itself. Its design and mode of operation are tailored to the requirements of the construction industry, and its design method is unique. This is reflected in the processable ceiling height of 3 m, which is simultaneously paired with an arm payload of 20 kg and continuous power supply via the mobile, omni-directional tandem system," Haschke explains.

The project has already generated attention in the construction industry, both for its complete robotic system and for its components. Although Bots2ReC was completed in November 2019, the team has been investigating further developments of grinding processes, planning logic and radar technology since then. These are already in demand and should be commercialised within the next 2 years. "We are especially proud of the products that have been decoupled during the project and are already available on the market in the form of two mobile robots at Robotnik Automation SLL and various improved radar sensors from indurad GmbH," Haschke notes.

With its focus on asbestos, Bots2ReC is well placed to reduce the future health burden on workers. There is little doubt that the cost of the technology will easily be counterbalanced by its high social benefit and economic efficiency. The project could be adapted for the removal of other hazardous products, such as lead paint.

PROJECT
Bots2ReC – Robots to Re-Construction

COORDINATED BY
RWTH Aachen University in Germany

FUNDED UNDER
H2020-LEIT-ICT

CORDIS FACTSHEET
cordis.europa.eu/project/id/687593

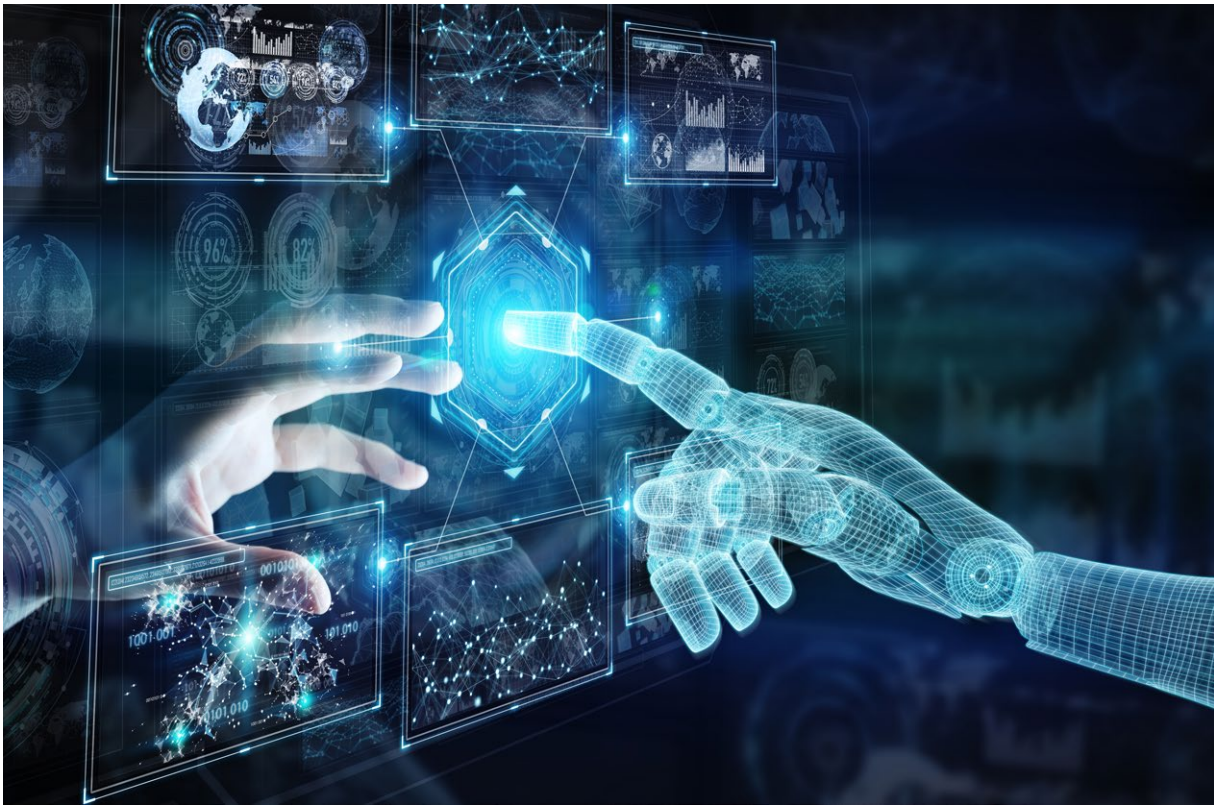
PROJECT WEBSITE
bots2rec.eu

AI-powered robots to speed up metal and composite part production

Cognitively enhanced robots have recently been tested in metal and composite parts production scenarios, and their performance could have a defining influence on the sector. The AI-powered, autonomous and collaborative robots speed up production time and even learn from experience.

The wide gap between current robots and their future, science fiction-inspired lineage can mostly be summarised in two words: cognitive computing. It's the same barrier that today prevents most robots on production lines from performing anything other than repetitive operations. Breaking it could result in faster production time and reduced cost.

The COROMA (Cognitively enhanced robot for flexible manufacturing of metal and composite parts) project has taken this challenge head on by developing a 'cognitively enhanced' robot specifically for metal and composite parts production. Capable of understanding its surrounding environment and learning from it, this robot makes use of its embedded reasoning



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and sensing capabilities to perform better than its counterparts – autonomously.

"Our robot builds upon vision-based scene understanding techniques to navigate a cluttered workshop and find the parts that must be manufactured," explains Asier Barrios, researcher at IDEKO and coordinator of COROMA. "It can work in cooperation with humans, tap into the same know-how of the manufacturing process and mimic how we learn by means of sensors and machine learning algorithms."

Our robot builds upon vision-based scene understanding techniques to navigate a cluttered workshop and find the parts that must be manufactured.

Let's take the example of grinding – an essential step in many industrial processes by which materials are mechanically broken into fine granules. The COROMA robot completely understands how a grinding tool gets worn. It predicts when unwanted vibrations may occur based on previous experience, learns how some areas of certain part types are more prone to have defects, and inspects these first to save time.

Combining AI-based autonomy combinations

Asked about what he considers as the most innovative aspect of the project, Barrios points out the combination of different autonomy-increasing solutions based on artificial intelligence. "This is true both from the point of view of the manufacturing process and from that of the human-robot interaction. Our solution allows robots to deliver improved performance, increased productivity and better part quality, while at the same time providing more adaptability to changing environments and production needs. It also results in increased safety, mobility and scene understanding features," he says.

To test its robots in action, the project team carried out prototype demonstrations in operational environments and workshops replicating factory floors. They used real parts from the aerospace, naval and energy-generation sectors, and had the robots perform a variety tasks. "The robots ground parts of aircraft engines, deburred and ground tubes and racks for the storage of nuclear fuel and inspected steam generator nozzles using ultrasonic technology. They also sanded moulds to manufacture the hull of large glass-fibre boats and machined composite parts for boats and aircraft profiles," Barrios explains.

The benefits were outstanding. Thanks to its embedded AI and mechatronics, robot programming time was reduced by between 38 % and 98 %. In some scenarios, the total manufacturing time was reduced by up to 60 %, while the time required to set up the manufacturing of new parts was reduced by up to 85 %.

Wide market interest

COROMA was successfully completed in September 2019, but work has continued ever since. Some of the project results are already commercialised by project partners as stand-alone solutions, such as robotic hand grasping software and laser-based object localisation hardware.

"Several project partners are working on the exploitation of the complete COROMA solution for the grinding of metal parts and sanding of large moulds for composites. Some third parties indeed would like to take these to the market as turnkey solutions. We also have some technologies still in their certification phase such as the safety module, as well as others being refined to be commercialised by third parties. These include the prediction of stable robotic machining, grinding tool wear learning, and lifelong learning about the most probable defect-generating features of metal and composite parts for non-destructive testing," Barrios concludes.

PROJECT
COROMA – Cognitively enhanced robot for flexible manufacturing of metal and composite parts

COORDINATED BY
IDEKO in Spain

FUNDED UNDER
H2020-LEIT-ADVMANU

CORDIS FACTSHEET
cordis.europa.eu/project/id/723853

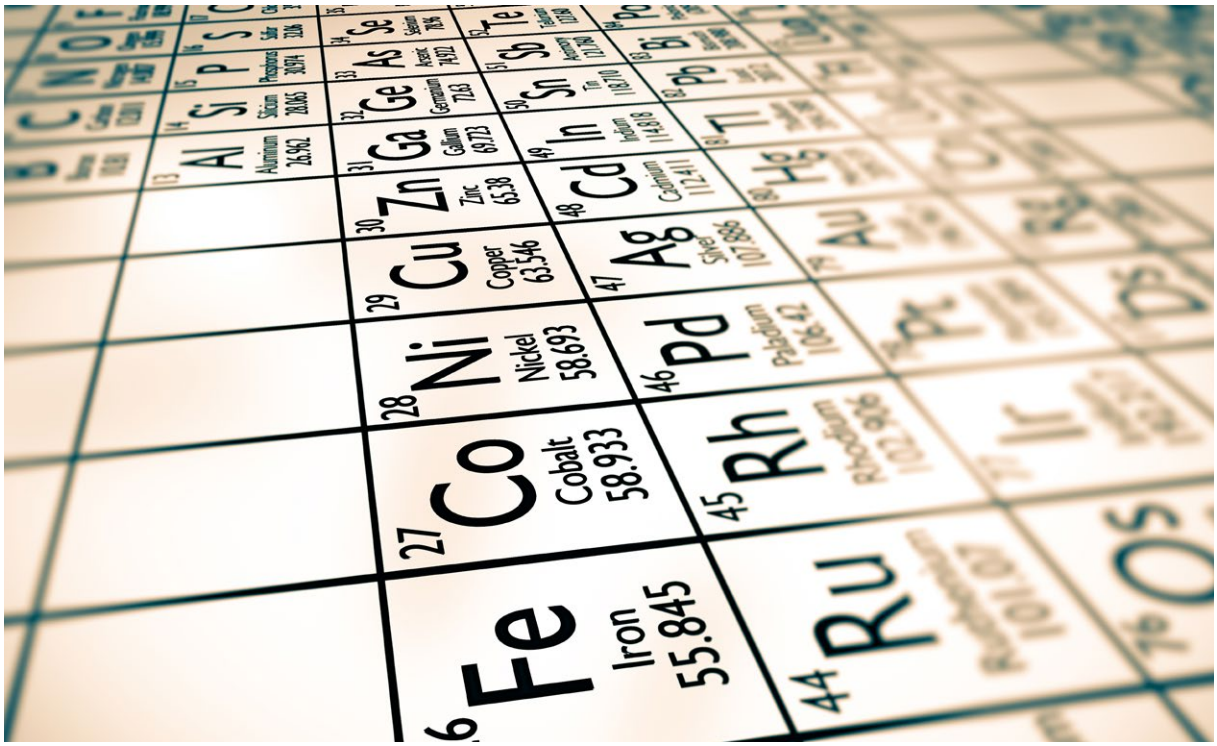
PROJECT WEBSITE
coroma-project.eu

Earth-abundant materials to catalyse green energy production?

The CritCat project may have killed two birds with one stone. By replacing rare metals with earth-abundant materials in catalytic reactions, its team proposes a path towards a reduced carbon footprint and cheaper production cost for the chemical industry, while at the same time increasing the viability of new energy conversion technologies.

It is one of society's greatest paradoxes: the political will to save resources and the climate when the most popular technologies are energy-greedy and dependent on rare resources and materials. A common case in point is obviously smartphones and their reliance on rare earth metals. But the same goes for catalysts – substances increasing the rate of chemical reactions that happen to hold the keys to green energy conversion technologies.

The catalyst problem was at the heart of the project CritCat (Towards Replacement of Critical Catalyst Materials by Improved Nanoparticle Control and Rational Design). Its objective: substituting rare critical metals used in heterogeneous and electrochemical catalysis (usually platinum group metals (PGMs)) with earth-abundant materials. Over 3 years, the project consortium explored the properties of ultra-small transition metal



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(TM) nanoparticles to enable emerging energy conversion technologies.

To do so, the team consecutively split water into hydrogen and oxygen to identify TM alternatives to catalytic PGMs, synthetised samples, characterised them and used them in chemical benchmark reactions to measure their catalytic activity. Eventually, they developed prototype electrolysers from the most promising candidates to investigate their performance.

No more trial and error?

The project's innovation, however, doesn't lie solely in the identification of new, cheaper materials. Instead of using the traditional lab-based trial-and-error process, the team opted for artificial intelligence and computer simulations, in the form of a materials modelling platform for catalyst design.

"We provide a full ecosystem from electronic structure simulations (density functional theory (DFT)) to real reactions, and we incorporate machine learning algorithms to streamline and handle complex potential energy surfaces (PES) for reaction energetics," explains Jaakko Akola, coordinator of CritCat on behalf of Tampere University.

The platform first requires input data from density functional theory (DFT), so that the algorithms can be trained to predict PES. The next step is to introduce other machine learning algorithms to identify the characteristic properties (descriptors) that are intimately linked with catalytic activity.

He continues: "The platform first requires input data from DFT, so that the algorithms can be trained to predict PES. The next step is to introduce other machine learning algorithms to identify the characteristic properties (descriptors) that are intimately linked with catalytic activity. As the DFT database increases, the capacity of the platform to predict the properties of new materials also increases."

Towards hydrogen-based energy solutions

The project's electrolyser prototype is an important step towards green energy production based on earth-abundant materials. It could eventually solve, for instance, the problem of the intermittent supply of solar/wind energy by converting electricity to hydrogen.

Equally, the project's modelling platform has yet to reveal its full potential. First – although the modelling platform has yet to become more effective than trial and error – the fact that its predictive power increases as the database of studied materials grows and the machine learning tools keep being developed, is very promising. The acquired chemical insight can also be reused later, unlike trial and error.

Secondly, the team has only scratched the surface of potential applications, as Akola points out: "The platform has first and foremost been designed for hydrogen evolution reaction (HER), which is relevant for the production of hydrogen energy by splitting water. However, our goal has been to produce a modelling infrastructure that can be applied for other chemical reactions – both gas phase and electrochemistry – easily."

This is precisely what the project team has been working on since CritCat's completion in June 2019. They are currently working on catalysts and prototype devices for fuel cells, as well as the conversion of CO_2 to synthetic fuels.

PROJECT
CritCat – Towards Replacement of Critical Catalyst Materials by Improved Nanoparticle Control and Rational Design

COORDINATED BY
Tampere University in Finland

FUNDED UNDER
H2020-LEIT-ADVMAT

CORDIS FACTSHEET
cordis.europa.eu/project/id/686053

PROJECT WEBSITE
critcat.eu

AI empowers the smart workers of the future

Artificial intelligence can be harnessed to empower workers in smart factories of the future. EU researchers have developed tools, including evolutionary algorithms, to optimise task allocations and ensure that staff can achieve their full professional potential.

AI solutions developed through the Factory2Fit (Empowering and participatory adaptation of factory automation to fit for workers) project have been designed to enable workers to have more influence over their work, and to take greater responsibility for their own learning and skills development. Final solutions were piloted in industrial environments, and demonstrated the positive impact that AI can have on both productivity and worker well-being.

Since project completion, some of these tools, such as a knowledge sharing system, have been integrated by industry project partners, while research partners are currently looking for further application opportunities.

"An important lesson has been that when increasing automation in factories, technologies should be integrated smoothly with human expertise," says project coordinator Eija Kaasinen from VTT in Finland. "For user acceptance and wide adoption, new solutions must take into account individual worker characteristics, skills and preferences."

Human-centred solutions

Smart factories use ICT technologies to plan, monitor and control production. This has the potential to achieve operational efficiencies, support individual customer requirements and provide

workers with more highly skilled jobs. Given rising concerns over the impact of automation on jobs however, it is critical that human-centred factory solutions are prioritised.

In this respect, there is growing recognition that technology should not be seen as a threat, but rather as an opportunity to redesign work environments that take into account workers as skilled individuals. This was the overall concept of the Factory2Fit project.

New solutions must take into account individual worker characteristics, skills and preferences.

"Our aim was to pilot human-centred factory solutions, improve work flows and engage workers," explains Kaasinen. "Any smart factory solution should keep in mind that the technology itself is not smart; it is the combination of advanced technology and human practical knowledge that is smart."

The Factory2Fit project began by observing and interviewing workers and other industrial experts to get a thorough understanding of their needs and expectations. Workers from pilot companies participated in numerous co-design and evaluation activities. Project partners then developed tools, designed to help workers fulfil their potential in the workplace.

Intelligent tools for skilled workers

Successful tools include an intelligent task distribution solution, developed as part of a wider Decision Support System to help factory supervisors allocate tasks. The tool uses an evolutionary algorithm that takes into account multiple criteria such as worker skills, capabilities and personal preferences. A Worker Feedback Dashboard was also developed to provide personal feedback on achievements and well-being.

A number of solutions were designed to help workers influence their own work. A virtual factory for example was built to test and further develop ideas in co-design sessions with workers and other work community members. Novel gamification techniques were also used to encourage knowledge sharing. The tools have the potential to be applied in numerous industrial settings and work environments.

"These solutions to engage the work community, including knowledge sharing, training and participatory design solutions, were piloted with industrial partners Continental (later CPT Group GmbH), Prima Power and UTRC," says Kaasinen. "The pilots proved to be very successful, with 93 % of industrial users supporting the adoption of solutions. This indicates that workers are willing to take more active roles in designing their own work. An engaged work community is flexible and prepared for changes, because workers feel responsible, not only for their daily performance, but also for the future of the company. When people can influence their work, they experience their work as more meaningful."

PROJECT
Factory2Fit – Empowering and participatory adaptation of factory automation to fit for workers

COORDINATED BY
VTT in Finland

FUNDED UNDER
H2020-LEIT-ADVMANU

CORDIS FACTSHEET
cordis.europa.eu/project/id/723277

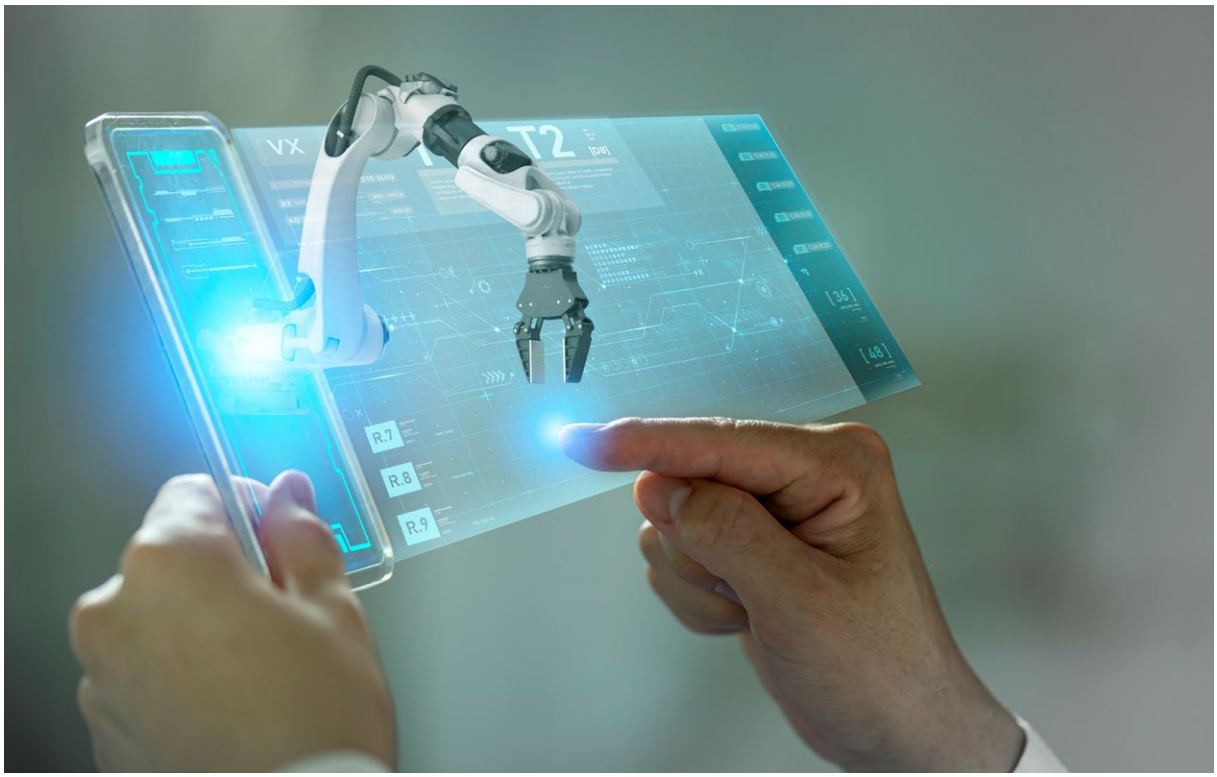
PROJECT WEBSITE
factory2fit.eu

AI delivers smart skills and zero-defect manufacturing

Researchers in the EU have demonstrated that zero-defect manufacturing architecture incorporating artificial intelligence can bring real benefits across a range of different sectors. Feedback from the industrial partners involved has been very positive, and two patent applications for smart inspection tools have been filed.

"A major advantage is that the proposed architecture we designed is general enough to be applied to very different manufacturing processes, ranging from mass production to batch production," explains GOOD MAN (aGent Oriented Zero Defect Multi-stage mANufacturing) project coordinator Cristina Cristalli from Loccioni – AEA in Italy. "Robust algorithms, sensors and Multi Agent Systems were built to operate on non-ideal data sets and with different machines, to reflect what life in a real factory is like."

The GOOD MAN architecture and its components were successfully deployed in three industrial case studies: at Volkswagen Autoeuropa, Zannini and Electrolux. Each case study required a degree of customisation and configuration according to their specific processes and objectives. "At Volkswagen Autoeuropa, the systems were running continuously for more than 1 year, collecting and analysing real-time data on the production of more than 140 000 cars," says Cristalli.



AI in industrial processes

Multi-stage manufacturing is the most common modern production system structure. This involves numerous processes that are run in series, sometimes in parallel, to perform a sequence of operations necessary to produce or assemble a product. This is typical of many sectors, from automotive to appliance manufacturing and from aerospace to consumer electronics.

The overall quality of any final product depends on the performance of each of these individual processes. Moreover, the performance of downstream processes can be affected by deviations upstream. Modern manufacturing plants therefore need to be understood not just in terms of individual processes, but also in terms of how these processes relate to each other.

"The good news is that modern digitalised factories create a huge amount of real-time data," says Cristalli. "We can observe process correlations and build up data models to implement innovative control strategies based on artificial intelligence, to prevent defects and maintain overall system performance. However, even if these concepts are being widely discussed at the academic level, there is still a lack of evidence that such an approach can be effectively implemented."

The aim of the EU-funded GOOD MAN project was therefore to move this academic discussion into industrial applications. "From the beginning, we were very clear about end user requirements," adds Cristalli. "We invested a lot of effort and time in developing technologies that are ready to be generalised and easy to be deployed in the manufacturing environment."

Smart tools for skilled manufacturing

Another key aspect was the integration of different developed technologies, to deliver the GOOD MAN architecture and methodology as a new approach to quality control. Real-time data collection and defect diagnosis were carried out at every single process level, as well as between processes to gain a better picture of inter-stage correlations. This was achieved through combining process and quality control in a distributed system architecture thanks to Multi-Agent Systems (MAS), which allows for distributing intelligence and data analysis algorithms by a network of distributed intelligent nodes.

We invested a lot of effort and time in developing technologies that are ready to be generalised and easy to be deployed in the manufacturing environment.

Several smart inspection tools were also developed during the 3-year project. "Two have led to two patent applications by the Università Politecnica delle Marche," notes Cristalli. One relates to a smartphone-based portable laser scanner to support operators during the assembly of car bodies. This enhances their measuring capacity and fully integrates them into the production line.

"This realises the concept of the man-in-the-loop, which is important to prevent automation negatively impacting on the workforce," explains Cristalli. The second innovation is about a telecentric vision system for burr detection in turned metal parts. Both systems have met the requirements for industrial implementation.

PROJECT
GOOD MAN – aGent Oriented Zero Defect Multi-stage mANufacturing

COORDINATED BY
AEA in Italy

FUNDED UNDER
H2020-LEIT-ADVMANU

CORDIS FACTSHEET
cordis.europa.eu/project/id/723764

Middleware system utilises AI to coordinate building energy management

What if a building isn't as energy efficient as it should be? A novel open-source building energy management platform that utilises Artificial Intelligence diagnoses and fixes problems.

These days, buildings are carefully designed to be energy efficient. Yet, sometimes, they do not perform as intended. This discrepancy is called the energy performance gap.

Construction can be inexact, introducing unintended gaps and other defects. Furthermore, once built, temperature control and ventilation systems may not perform exactly as expected. Building occupants may also behave unpredictably.

It's a builders' platform, not unlike the iPhone operating system, whereby developers can create software for the platform to suit their own needs.

Getting energy-efficient buildings to operate as intended is not simple. The EU-funded HIT2GAP (Highly Innovative building control Tools Tackling the energy performance GAP) project developed a new building energy management platform that takes the complicating factors into account to reduce the performance gap. The system, which includes modules that are based on Artificial Intelligence (AI) algorithms and techniques such as data mining and Knowledge Discovery, focuses on the operational phase of a building's life, meaning the long period after construction and before decommissioning where tenants occupy the building. The project developed a new paradigm for building energy management platforms and marketed the resulting product.

Middleware platform and its modules store

The system is an open-source middleware platform called BEMServer. It receives information measured by building management systems and other sensor infrastructure. After centralised processing, various specialised modules access the information and provide actionable information to building managers and occupants. For example, the modules might identify faults or inappropriate settings concerning building equipment or alert to energy-inefficient user behaviours.

All modules connect to the BEMServer. They can exchange information with other modules, making possible new data sets and combined analytics and therefore new advanced services.

User-created modules

Uniquely to HIT2GAP, modules can be created by third-party developers. BEMServer being deliberately open-source, developers do not have to recreate core functionalities of the middleware. "It's a builders' platform," says project coordinator Pascale Brassier, "not unlike the iPhone operating system, whereby developers can create software for the platform to suit their own needs."

The system can therefore be modified and improved, and will remain up to date with emerging technologies. Fully commercial systems do not have this flexibility.

Under the HIT2GAP concept, users only pay for the modules and not for the middleware BEMServer.

Enforcing Building Information Modelling with AI

Some of the modules utilise AI algorithms, including the Fault Detection and Diagnosis – Principal Component Analysis (FDD-PCA) module that utilises the HIT2GAP integrated data access to offer enhanced monitoring capabilities that evaluate building behaviour with respect to normal operation. If the module detects a fault, it allows for its isolation and for pinpointing the variables causing it, ensuring that maintenance crews can more easily identify causes or explain why the fault has occurred. Meanwhile, the Fault Detection and Diagnosis (FDD) uses machine learning based methods that continuously analyse time-series data from the BEMServer and provides a message to building operators if anomalies are detected.

Finally, another module that utilises AI, ENIXO, is an application that produces recommendations about the energy waste situations in the whole system and sends messages to facility managers and other targeted users through the use of semantic reasoning.

"So far, 12 modules have been delivered," says Brassier. "BEMServer has been deployed at four pilot sites: in France, Ireland, Poland and Spain." Each pilot selected the modules most relevant for their needs and for the different problems encountered in their building.

BEMServer has been shown to work as intended, connecting buildings to information management modules. In testing, the system appropriately provided numerous warnings and alerts and helped building managers in decision making. Documentation for the system, and for most of the modules, has been made available to developers.

Next steps for BEMServer

Next, the team plans to develop further demonstration cases, and to extend the BEMServer through new or improved functions, including additional core functionalities based on AI. Future developments will focus on advanced preprocessing functions able to detect and correct data errors ensuring a minimum level of data quality.

The team also plans to improve the user experience, including updated administrative and other functions. Soon, a second, more commercial version will be released to the marketplace.

PROJECT
HIT2GAP – Highly Innovative building control Tools Tackling the energy performance GAP

COORDINATED BY
NOBATEK/INEF4 in France

FUNDED UNDER
H2020-LEIT-ADVMANU

CORDIS FACTSHEET
cordis.europa.eu/project/id/680708

PROJECT WEBSITE
hit2gap.eu

Fostering human-machine collaboration in the factories of the future

Analysis and augmented reality will smooth cooperation between man and machine in the manufacturing workplaces of the 21st century. One EU-funded project has been at the forefront of this industrial metamorphosis.

The future of manufacturing will depend on the evolving relationship between humans and machines, such as robots, particularly in the design and creation of highly specialised and customisable products.

The MANUWORK (Balancing Human and Automation Levels for the Manufacturing Workplaces of the Future) project sits at the core of this cooperative mission, developing technologies and systems to support the design and operation of manufacturing

workplaces that support human collaboration with other operators and machines.

The project designed: a computational method to optimise human-automation levels for work load balancing; a framework for the evaluation of worker satisfaction, safety and health; a solution for Industrial Social Networking in manufacturing; and another solution created to facilitate the use of Augmented Reality (AR) in the manufacturing workplace.

Workers should not only be able to collaborate physically with a machine; they should also be able to deal with the digital counterpart of a machine, its so-called 'digital twin'.

"At the dawn of Industry 4.0, which asks for more complex machines and automation technology in the manufacturing workplaces, it is essential that all the necessary technology and processes are in place so that humans and automation are taking advantage of each other's strengths," says Kosmas Alexopoulos, MANUWORK coordinator and a Research Engineer in the Laboratory for Manufacturing Systems at the University of Patras.

A new reality

MANUWORK pilots experimented with wearable technologies and AR technology for human-robot interaction. The main goal is to assist operators in their daily activities, by adding text, holograms or virtual objects into the visual image of the real world thereby creating an AR image.

A virtual object can show the human worker the place in which a new part best fits inside a bending metal tool. In such a case, the AR application adapts its functionality to the profile and skill level of the operator and offers training and guidance throughout this process. AR is also used for interactive visual analysis of operations between humans and robots – showing humans the no-go areas in a robot's path to avoid accidents.

Another project use case focuses on workers with cognitive disabilities. "In this case, a collaborative robot and AR were used to guide them step by step in performing electrical wiring tasks, so they don't need to interpret electrical schematics themselves and don't even need to be able to read properly or have good spatial awareness," says Johan Kildal, a researcher at Tekniker (member of the Basque Research & Technology Alliance).

Testing the tech

Following trials last year, four further industrial test cases are underway. One involves the car manufacturer Volvo, in the creation of a key engine component, and another Lantegi Batuak, an organisation that provides sheltered employment for workers with disabilities.

"The overall feedback is that the operators from the plant feel comfortable working close to the robots and see potential obvious uses for this type of automation in their daily work," Alexopoulos says.

The MANUWORK team considers the collaboration with Lantegi Batuak as an excellent example of how factories-of-the-future technologies are able to assist workers with disabilities to carry out jobs that were previously out of reach for them. "In this way, future factories can be more inclusive and socially sustainable," says Alexopoulos.

As new technologies, and AI innovations in particular, continue to revolutionise the way humans work, systems such as MANUWORK will be integral for ensuring a successful partnership between man and machine. "Workers should not only be able to collaborate physically with a machine; they should also be able to deal with the digital counterpart of a machine, its so-called 'digital twin'," concludes Alexopoulos.

PROJECT
MANUWORK – Balancing Human and Automation Levels for the Manufacturing Workplaces of the Future

COORDINATED BY
University of Patras in Greece

FUNDED UNDER
H2020-LEIT-ADVMANU

CORDIS FACTSHEET
cordis.europa.eu/project/id/723711

PROJECT WEBSITE
manuwork.eu

An innovative AI platform to boost resource and energy efficiency

A data-driven lab enables experts to collaborate, model, develop and evaluate novel predictive control functions in a rapid and cost-effective way.

Process industries, which manufacture and process large batches of material, draw on the intensive use of raw materials and energy. As such, even small efficiency improvements can lead to large savings, in terms of both economic and environmental costs. This is particularly the case for specific industrial processes such as the smelting of primary aluminium, in which the production is organised in different areas including the anode production plant, potlines and casthouse, characterised overall by significant consumption of energy and raw material.

Thanks to the MONSOON solution, data scientists involved in collaboration with process experts can develop, evaluate and deploy novel predictive control solutions in a rapid and cost-effective way, create predictive functions with the help of machine learning algorithms and make simulations, possibly using online data from the connected production environment.

One way to drastically improve performance is using predictive modelling, exploiting widespread sensors and data acquisition, and using AI techniques. Yet, the monitoring of production processes remains challenging since it requires the collection and evaluation of large amounts of data; and the adoption of model-based predictive functions is not always feasible at a sustainable cost or with sufficient reliability.

The EU-funded MONSOON (MOdel based coNtrol framework for Site-wide OptmizatiON of data-intensive processes) project aimed to rectify this problem, by establishing a data-driven framework and suite of tools to allow experts from across multiple disciplines to work together effectively and enhance the production efficiency of the European process industry. MONSOON uses AI-based predictive approaches to perform plant- and site-wide optimisation of production processes.

Data and development

The MONSOON framework is split into two major components: the 'Real Time Plant Operation Platform' and the 'Cross Sectorial Data Lab'.

The Real Time Plant Operation Platform is designed to be deployed onsite, and helps with various functions including: data collection and monitoring of plant-wide resources; dealing with interoperability issues and the management of data flows; detection of problems and faults that could compromise MONSOON platform operations; and carrying out the designed predictive functions – predicting, for example, abnormal behaviours in specific processes.

The Data Lab is a collaborative environment, where data flows in from multiple sources to be analysed at scale. This allows: collaboration among data scientists and process experts; advanced modelling; simplified access to data collected from the field; and the design, development and testing of new predictive functions.

"Thanks to the MONSOON solution, data scientists involved in collaboration with process experts can develop, evaluate and deploy novel predictive control solutions in a rapid and cost-effective way, create predictive functions with the help of machine learning algorithms and make simulations, possibly using online data from the connected production environment," says Claudio Pastrone, Head of IoT and the Pervasive Technologies Research Area at the LINKS Foundation.

Bringing the MONSOON

The MONSOON solution was deployed and tested in two pilot sites, proving near-real-time prediction for improving product quality and machine maintenance. At a GLN manufacturing plant in Portugal, MONSOON was used to improve injection moulding. The other pilot site was focused on carbon and electrolysis areas of primary aluminium production and involved Aluminium Pechiney and a plant from Liberty House in France. Overall, the project addressed aspects related to the digitisation of the plants, data collection, and the creation of specific predictive functions, and fostered teamwork between data scientists and process experts.

Under the ongoing digital revolution of Industry 4.0, the MONSOON project could contribute to a wider adoption in European process industries of plant-wide and site-wide monitoring and control. Due to the decrease in process time and resource and energy consumption, the project could also help boost European industry in the worldwide race for competitiveness and sustainability.

"I would like to highlight and thank all the MONSOON partners for the great collaboration within the project and also beyond," Pastrone adds. "I've had the opportunity to work with great professionals from all around Europe," he says.

PROJECT
MONSOON – MOdel based coNtrol framework for Site-wide OptmizatiON of data-intensive processes

COORDINATED BY
LINKS Foundation in Italy

FUNDED UNDER
H2020-LEIT-ADVMANU

CORDIS FACTSHEET
cordis.europa.eu/project/id/723650

PROJECT WEBSITE
spire2030.eu/monsoon

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Swarming sensors open the world up for exploration

A project funded under Horizon 2020's Future Emerging Technologies programme is letting us explore, map and understand even the most difficult- and dangerous-to-reach environments.

Humans are creatures of exploration. Each new environment we understand gives us new knowledge that can benefit society. Yet there is still much to explore, including the structures we are creating every day.

Mapping pipelines could help us to find structural faults or leaks that are affecting the delivery of safe drinking water and check its quality. Exploring underground channels could make the extraction of natural gas more efficient, and help us to find new locations to store CO_2 from carbon capture technologies. Peering deep into volcanoes and inside glaciers could help scientists model climate change better. Yet even the most advanced sensors cannot reach these locations safely and effectively.

That's where the Phoenix (Exploring the Unknown through Reincarnation and Co-evolution) project comes in. Phoenix has

integrated elements of software, hardware and Artificial Intelligence to create swarming motes – tiny robotic spheres that can travel to unknown locations, exploring, sensing and mapping as they go.

I'm certain that we would not have been able to find any other funding source that would be willing to invest in such a risky idea – and therefore we would not have been able to explore and evolve this technology at all without Horizon 2020!

"We keep running into people who are interested in trying our Phoenix SMARBLE technology for new applications, such as inspection of industrial mixing tanks, inspection of sewer systems and water cleaning, home monitoring, and (but this would be rather further into the future) medical applications," says Peter Baltus, Professor and Chair of the Integrated Circuits group from the Department of Electrical Engineering at Eindhoven University of Technology and Phoenix project coordinator.

Advanced simplicity

The tiny bots are just 6 cm in diameter, but, with advanced components, can be feasibly reduced to a cm-sized ball or smaller. At this size and with enhanced battery technology, the motes can also function for far longer.

The motes use miniaturised, highly efficient ultrasound electronics and transducers, which use less space and also less energy. Testing showed communication can work between the motes up to several metres while underwater.

Yet much of the hardware is adapted from off-the-shelf components, to be made more efficient and smaller. In the future, these can and will be seamlessly swapped out as technology advances.

Crowd intelligence

Some key underpinnings of the technology are the ability for the tiny robots to self-organise, adapt to new environments and divide labour between themselves autonomously in many cases. This flexibility is opening up new avenues for use of the technology, including applications that have restrictive conditions based on size, sensor parameters, battery life and the robustness when faced with both physical and chemical effects.

"Phoenix does seem to lend itself very well to adapt to these different requirements since we don't need a single sensor ball that can do everything but instead can spread out the work," Baltus explains.

Rise of the Phoenix

The Phoenix team has been approached by a wide range of interested groups, who see a use for the technology in their line of work or research.

"It is great to see so much interest and enthusiasm for an idea that just a few years ago was often considered to be science fiction at best. I'm certain that we would not have been able to find any other funding source that would be willing to invest in such a risky idea – and therefore we would not have been able to explore and evolve this technology at all without Horizon 2020!"

PROJECT
Phoenix – Exploring the Unknown through Reincarnation and Co-evolution

COORDINATED BY
Eindhoven University of Technology in the Netherlands

FUNDED UNDER
H2020-FET

CORDIS FACTSHEET
cordis.europa.eu/project/id/665347

PROJECT WEBSITE
phoenix-project.eu

Taking inspiration from the animal world to lay the groundwork for more resilient and adaptive robots

Don't believe the wondrously robust robotic characters you see in science-fiction movies, today's robots can be, and usually are, far from being as resilient. One European Research Council-funded project has been developing new algorithms to make it possible for robots to autonomously recover from unexpected damage within the space of a few minutes.

Even after 50 years of robotics research, most existing robots are far from being as resilient as even the smallest, simplest animals – in short, they can easily stop functioning if they encounter difficult conditions or take an unexpected tumble. For robots to become more embedded in human societies and for them to be useful in emergency situations, they need to overcome their inherent frailness.

That's where the ResiBots (Robots with animal-like resilience) project comes in. "The objective of our project was to develop new algorithms to make it possible for robots to autonomously recover quickly without having to anticipate every possible damage condition," says Jean-Baptiste Mouret, the Principal Investigator of the project. "This is especially important when they involve mechanical damage that is very challenging to diagnose with onboard sensors – our vision is to develop robots that have the ability to 'improvise' when they need to complete a difficult mission."

Adopting a new way of thinking for more resilient robots

This vision is in direct contrast to the current approach to fault tolerance, which is inherited from safety-critical systems (such as for spacecraft or nuclear power plants). This is inappropriate for low-cost autonomous robots because it relies on diagnosis procedures, requiring expensive proprioceptive sensors and contingency plans – and these cannot cover all the possible situations that an autonomous robot operating on its own can encounter.

However, the algorithms developed by Mouret and his team circumvent this older-style thinking as they are specifically designed for data-efficient (aka with very little data) adaptation in robotics. "For instance, our algorithms allow a six-legged robot to find a new walking gait in less than 2 minutes," Mouret explains. "Overall, the general idea is to leverage a simulation of the 'intact' robot to accelerate the adaptation for a robot with unknown damage."

From diagnosis to reinforcement algorithms

Importantly for the project, this first result uses 'episodic learning', which means that each trial starts in exactly the same position. A more recent algorithm allows the robot to learn independently without any reset, whilst taking its environment into account. "For instance, there is no reason for the robot to try a gait that is likely to make it move forward if we know there is an obstacle in the way," says Mouret.

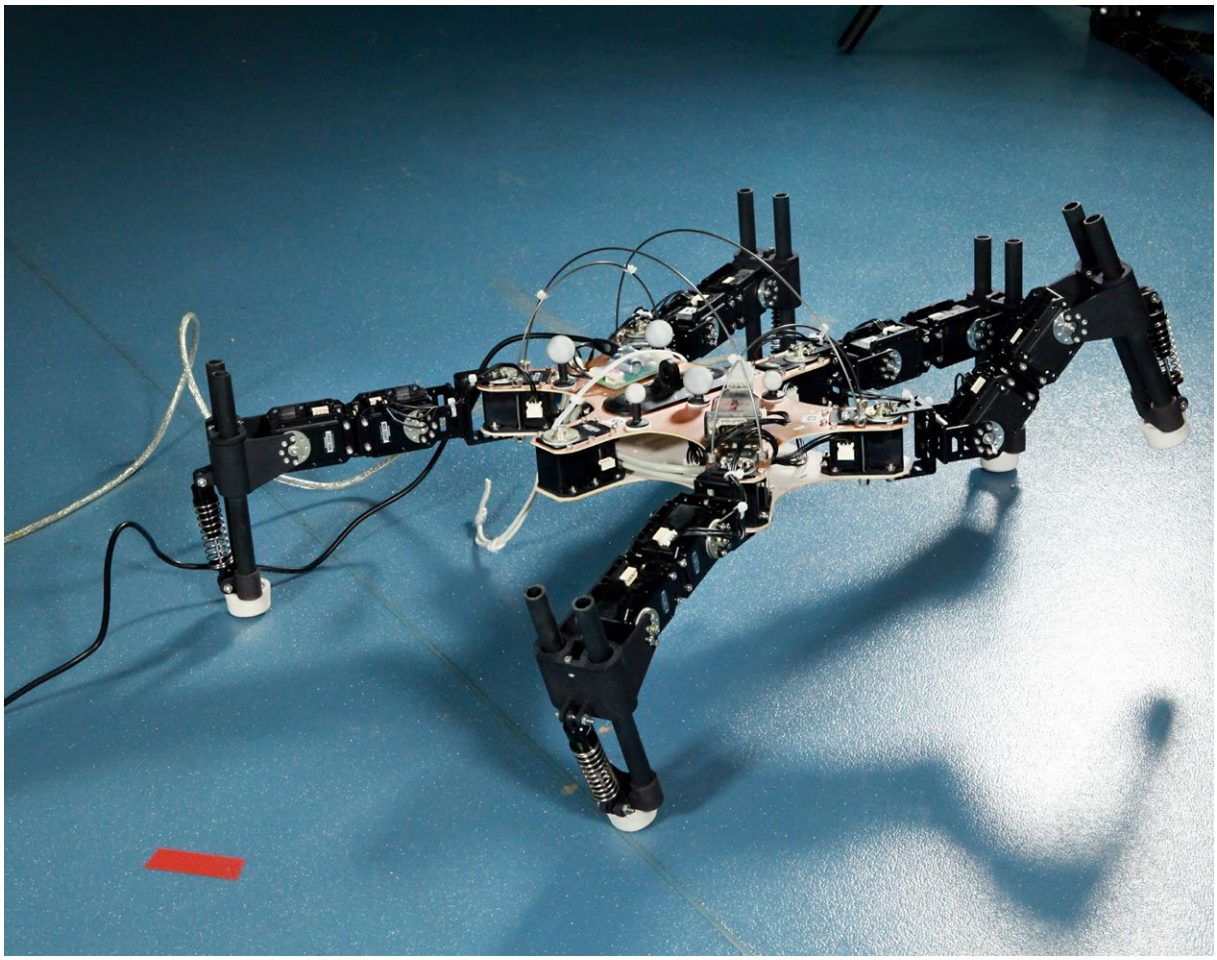
The objective of our project was to develop new algorithms to make it possible for robots to autonomously recover quickly from unexpected damage.

As he argues, machines – and particularly robots – have been essentially 'blind' thus far, where easy tasks for animals (such as recognising an object) have proven too difficult for robots' vision algorithms. But thanks to recent advances in deep learning, machines are now able to understand their surroundings much better, opening the gates to many possible applications, including those that are beyond the factory floor.

"However, if we want robots that can truly learn new skills and/or tasks, they need reinforcement algorithms and not only perception algorithms," warns Mouret. "For this to happen, we need to make them more data-efficient before they can be deployed outside research labs." He does not envision the deployment of robots that can learn to undertake new tasks by themselves within the next 5 years but is optimistic that it could happen within the next 5 to 15 years.

Looking to the future

ResiBots has truly been a trailblazer in lighting the path to reach this goal and Mouret and his team plan to keep their research going even after the project's official end in April 2020. "We want to introduce trial-and-error learning to humanoid robotics – humanoid robots are the 'next frontier' of robotics because they combine all of the challenges of robotics at the same time," says Mouret.



These challenges include the need to synchronise many joints (typically 24) and they need to react quickly and keep their balance. Whilst no current humanoid robot is currently using trial-and-error learning to adapt to changes in its environment, Mouret and his team want to be at the forefront of changing this.

And when asked what he is most proud of from ResiBots? "We routinely have robots that learn to walk right in front of our eyes, in just a few minutes, compared to hours or even days before," Mouret concludes. "I have to say, these were the kinds of robots I really dreamed about when I was a child!"

PROJECT
ResiBots – Robots with animal-like resilience

HOSTED BY
Inria in France

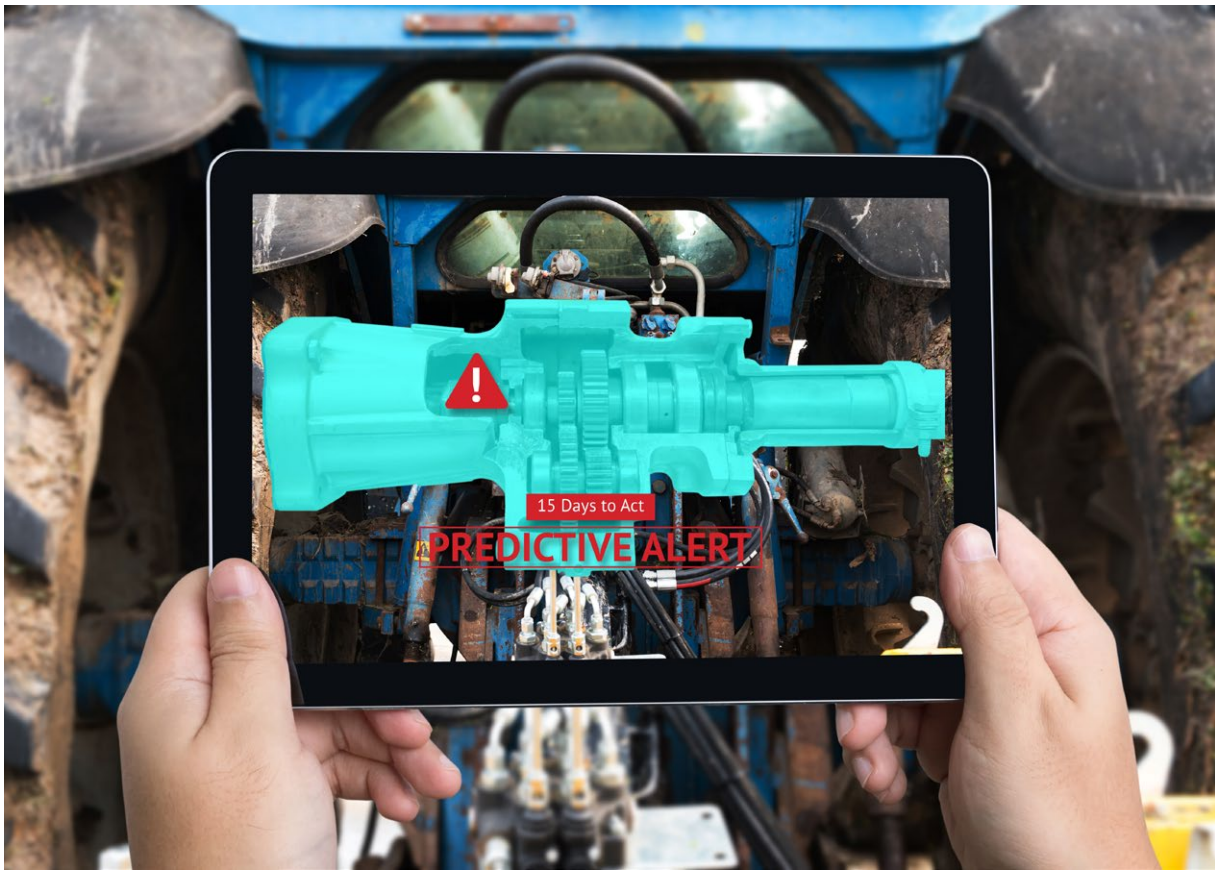
FUNDED UNDER
H2020-ERC

CORDIS FACTSHEET
cordis.europa.eu/project/id/637972

PROJECT WEBSITE
resibots.eu

Rolling out predictive AI condition-based maintenance solutions for advanced manufacturing

Artificial Intelligence potentially offers many rewards for the manufacturing sector and not only. As such, SERENA, an EU-funded project, has taken a big leap forward with the development of a scalable and resilient Industrial Internet of Things platform enabling Artificial Intelligence services that aim to reduce costs and improve productivity.



Artificial Intelligence (AI) could be the next major technological leap that drives human technological prowess, and the EU-funded SERENA (VerSatilE plug-and-play platform enabling remote pREdictive mainteNAnce) project is at the forefront of this gathering revolution. Specifically designed for manufacturing, its platform is based upon four key technologies: remote condition monitoring and control, AI condition-based maintenance, Augmented Reality (AR)-based tools for remote assistance and human operator support, and finally, a Cloud-based platform for versatile remote diagnostics.

In summary, we have developed a distributed, lightweight and scalable Industrial IoT platform which, through the collective use of its integrated services, will provide predictive maintenance solutions to 'shop floor' personnel.

"In summary, we have developed a distributed, lightweight and scalable Industrial Internet of Things (IIoT) platform which, through the collective use of its integrated services, will provide predictive maintenance solutions to 'shop floor' personnel," states Massimo Ippolito, SERENA project coordinator.

Introducing you to the SERENA system

The platform uses a lightweight micro-services architecture, utilising Docker containers to wrap the offered services into deployable units.

The SERENA AI components for predictive analytics, both distributed and centralised, are used for estimating potential failures in manufacturing equipment, allowing for the planning and scheduling of maintenance activities in a specific timeframe, thus, ensuring that the overall production process within the factory is not interrupted. On top of this, the SERENA system facilitates maintenance personnel remote support via VR/AR-based technologies that assists them with assessing the status of machinery and overall equipment within the factory. These are accessed through the use of smart glasses, smartphones and tablets.

Overcoming challenges

Whilst these innovations show the SERENA platform is indeed very promising, it wasn't always plain sailing for the project team. "It became evident from the first phases of the project that predictive analytics is a matter not only of data availability but of data of the proper quality as well," explains Ippolito. "In case the data does not contain the features that correspond to the potential failure [of equipment], then they are of no use."

In addition, there is no single rule for every case. Human analysis and complex correlations are required to extract meaningful correlations as well as the expert's knowledge. "Nevertheless, SERENA moved a step beyond those limitations by introducing a self-assessment mechanism and a methodology that could potentially be generic enough to capture a variety of problems," Ippolito adds.

Finally, another set of challenges encountered and conquered was the need to deploy the SERENA system in versatile environments with different connectivity capabilities and legacy systems – the difference for example between a state-of-the-art Apple iPhone-producing factory and a centuries-old factory specialising in a traditional industry. Hence, the SERENA system had to be designed and implemented to be able to support many versatile cases – and thus the system supports deployment via the Cloud or physically on the premises.

Looking to the future

Regarding the future, Ippolito strongly believes that overall, now is the time that commercially viable AI-based solutions will gradually begin to filter through onto the market. "In the future, it is expected that AI applications will keep extending into new areas providing interpretable results of increased accuracy and reduced response time," he predicts.

And finally, what of the future of the SERENA team, as the project officially ends in September 2020? Ippolito is rather coy about this but does confirm that activities to disseminate the results will continue and future initiatives to extend the SERENA system and its myriad solutions are under investigation – so watch this space.

PROJECT
SERENA – VerSatilE plug-and-play platform enabling remote pREdictive mainteNAnce

COORDINATED BY
Comau S.p.A. in Italy

FUNDED UNDER
H2020-LEIT-ADVMANU

CORDIS FACTSHEET
cordis.europa.eu/project/id/767561

PROJECT WEBSITE
serena-project.eu

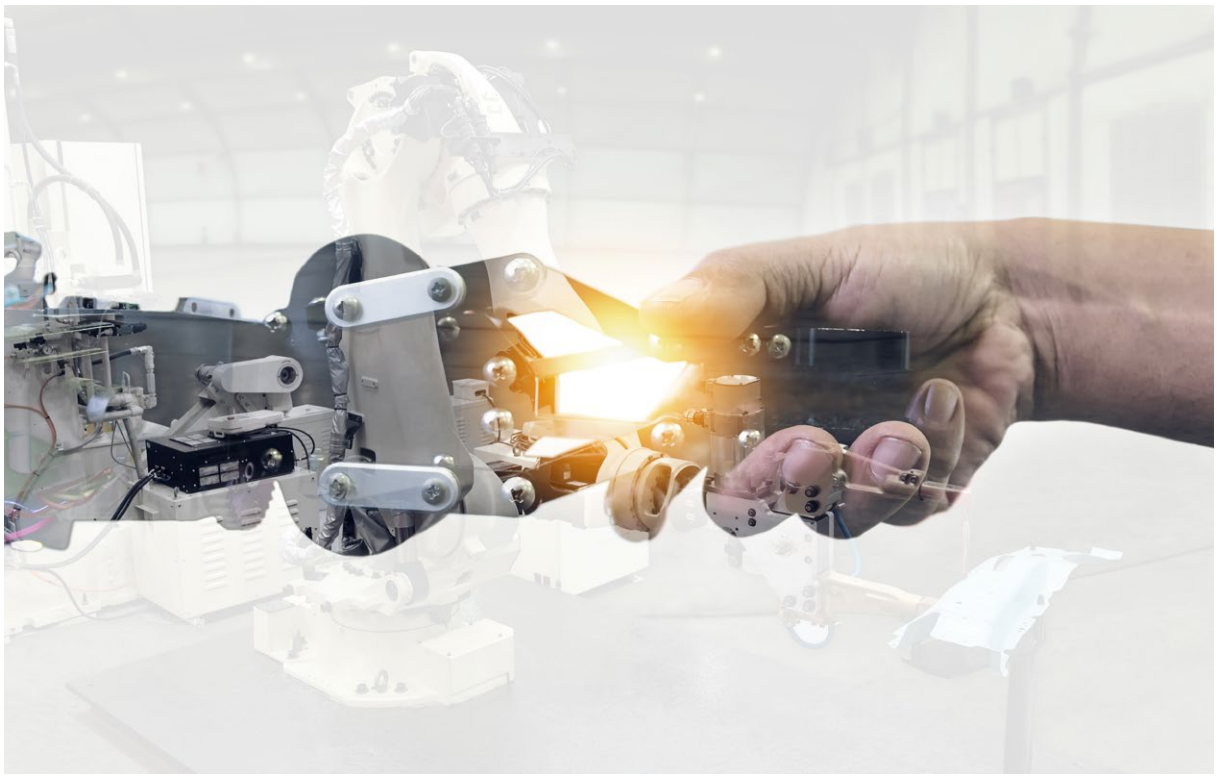
Intelligent robots to play vital role in the factories of the future

Leveraging artificial intelligence and advanced automation, a team of EU researchers is developing a dual-arm configured robot capable of moving freely around a factory floor and performing complex tasks.

For decades, industry has depended on the serial production or assembly line model for producing goods. However, as European industry becomes increasingly customer-centric, there is a growing need for a more flexible way of producing parts and products – one that can quickly adapt to varying customer demands while minimising the costs of large inventories.

One possible solution is the use of intelligent robots, which is the focus of the EU-funded project THOMAS (Mobile dual arm robotic workers with embedded cognition for hybrid and dynamically reconfigurable manufacturing systems).

"THOMAS aims to create dynamically reconfigurable factories through the use of autonomous, mobile robot workers," says Niki



Kousi, a researcher at the University of Patras' Laboratory for Manufacturing Systems and Automation (LMS).

"Thanks to their dual-arm configuration and ability to move freely around a shop floor, these robots are capable of performing advanced tasks, thus creating a new production paradigm," adds Sotiris Makris, head of the Robots, Automation and Virtual Reality in Manufacturing group at LMS.

Robot perception libraries

What makes the THOMAS robot unique is its ability to perceive its surrounding environment. The robots are also capable of advanced reasoning, which allows them to cooperate with each other and other production resources – including human operators. Each robot is equipped with certified sensing devices that allow it to safely move and interact with humans within a fenceless environment.

Behind these advanced capabilities is an innovative technology called robot perception libraries. Leveraging the power of artificial intelligence, these perception libraries allow the robots to navigate without colliding, properly align themselves and virtually dock at different workstations, and detect the positioning of the various tools used during the assembly process. "These robot workers can autonomously navigate their way through a factory, undertaking multiple tasks like screwing, handling and drilling – to name only a few," explains Kousi.

THOMAS aims to create dynamically reconfigurable factories through the use of autonomous, mobile robot workers.

While some could view THOMAS as another example of jobs being lost to automation, Makris is adamant that this is not the case. "THOMAS is designed to act as an assistant to its human operators, taking over the most dangerous and strenuous tasks," he says. "Not only will this increase the safety of our factories, it will also allow humans to focus their attention on the most advanced, high-level tasks – including robotic programming."

Overcoming barriers

Although THOMAS represents a breakthrough in mobile dual arm robotic manipulation, there are still several issues that must be addressed. "At the top of our list are limitations in perception accuracy, constraints in the real-time continuous detection of objects, and network bandwidth issues when multiple sensing devices are involved," explains Kousi.

Another barrier is current safety regulations, which prohibit human operators from working close to, in parallel with, or in the same area as robots. "Building better synergy between technology developers and safety experts – a synergy that exploits the latest advances in AI – will allow us to build new innovative solutions that may eventually boost standardisation," comments Makris.

Regardless of these limitations, the project has successfully introduced a new way for factories to operate – one that leverages advancements in mobile robotics and AI. The project team is now conducting industrial pilot cases in two factories, one located in France and another in Spain.

"Implementing THOMAS in real production plants offers a unique opportunity to prove our original ideas and prototypes," concludes Makris.

PROJECT
THOMAS – Mobile dual arm robotic workers with embedded cognition for hybrid and dynamically reconfigurable manufacturing systems

COORDINATED BY
University of Patras in Greece

FUNDED UNDER
H2020-LEIT-ADVMANU

CORDIS FACTSHEET
cordis.europa.eu/project/id/723616

PROJECT WEBSITE
thomas-project.eu

CORDIS Results Pack

Available online in six language versions: cordis.europa.eu/article/id/417992

Published
on behalf of the European Commission by CORDIS at the
Publications Office of the European Union
2, rue Mercier
L-2985 Luxembourg
LUXEMBOURG

cordis@publications.europa.eu

Editorial coordination
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This Results Pack is a collaboration between CORDIS and the Directorate-General for Research and Innovation

PRINT	ISBN 978-92-78-42177-9	ISSN 2599-8285	doi:10.2830/14832	ZZ-AK-20-009-EN-C
HTML	ISBN 978-92-78-42169-4	ISSN 2599-8293	doi:10.2830/136698	ZZ-AK-20-009-EN-Q
PDF	ISBN 978-92-78-42170-0	ISSN 2599-8293	doi:10.2830/481728	ZZ-AK-20-009-EN-N

Luxembourg: Publications Office of the European Union, 2020

RESEARCH*EU MAGAZINE ISSUE 91
Infusing the digital into European education

To be successful in the modern workforce, students need to be equipped with the skills that are most in demand from employers. Digital skills need to be embedded right from the very beginning of formal education, right through from kindergarten to tertiary studies. This issue of Research*eu features seven projects that are giving a digital boost to Europe's education systems.

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