TU DELFT ROBOTICS INSTITUTE

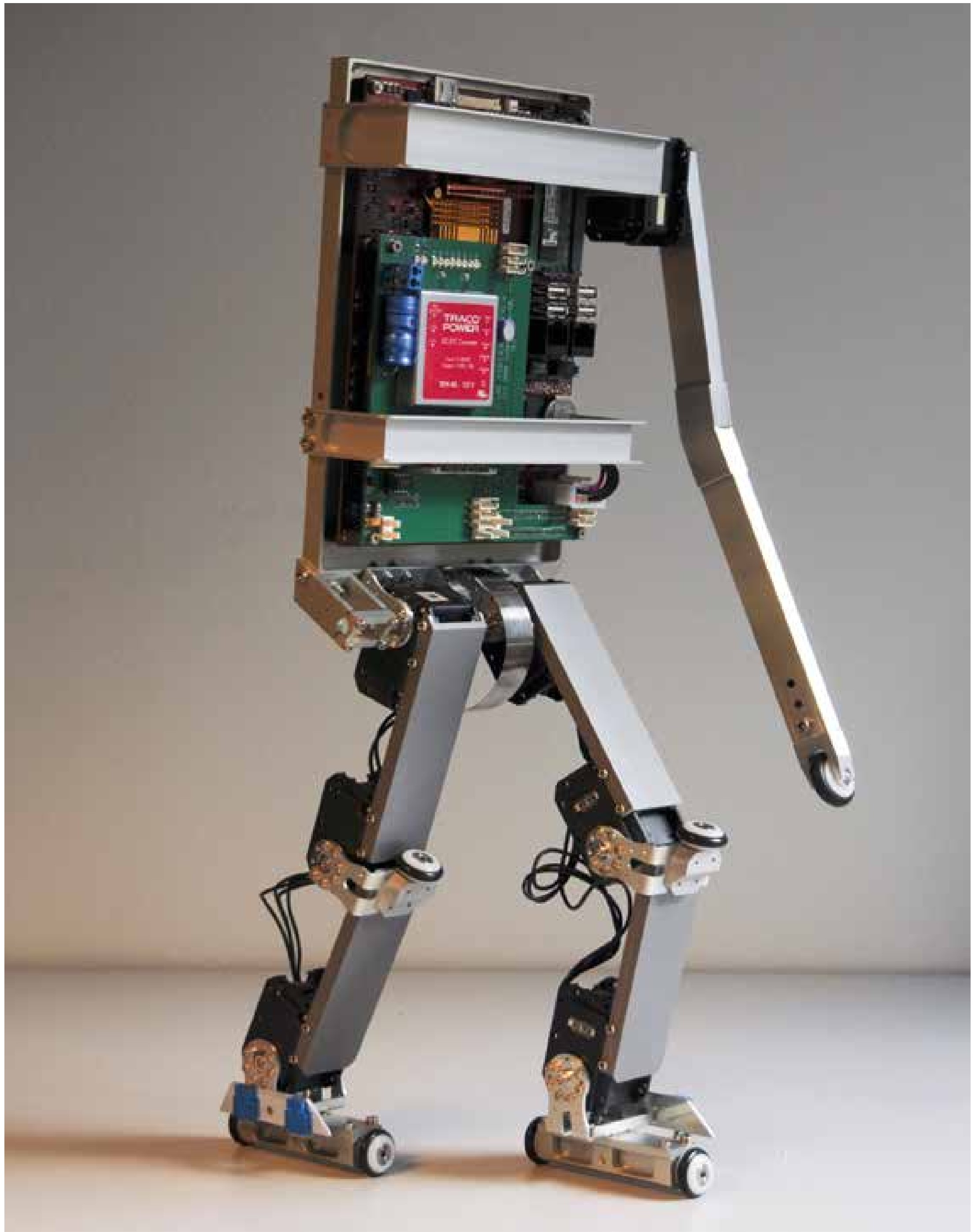
CREATING THE NEXT-GENERATION ROBOTS

Maja Rudinac *(cover photo, right)*
CEO and co-founder at Robot Care Systems
Managing director and co-founder at Lerovis
Co-leader of the interactive robotics theme at TU Delft Robotics Institute

Robby *(cover photo, left)*
A robot capable of a wide array of tasks, combining state-of-the-art speech recognition, object recognition, person tracking and autonomous navigation. It is designed and developed at the Delft Biorobotics Lab.

‘There was a time when humanity faced the universe alone and without a friend. Now he has creatures to help him; stronger creatures than himself, more faithful, more useful, and absolutely devoted to him. Mankind is no longer alone. Have you ever thought of it that way?’

Robopsychologist Susan Calvin in Isaac Asimov’s *I, Robot*



WHAT IS A ROBOT?
A robot is a machine that senses, thinks and acts. It is programmable and performs physical tasks automatically. Long the province of fantasy and speculation, robots are now a reality: man-made objects equipped with sensors to perceive the environment, a computer to process these perceptions and a versatile body to perform the appropriate physical actions. Robots are expected to operate autonomously, although in many cases, such as drones and robotic arms performing surgeries, they are tele-operated: some of their actions are controlled by humans. A robot that resembles a human is called 'humanoid,' or 'android' if it is almost indistinguishable from a person. This is in most cases more for the benefit of humans than for its actual functioning.

THE NEXT GENERATION

Robotics is the next big step in the digital revolution, with an unprecedented impact on the way we live. Robotics provides answers to some of the great challenges of the 21st century, such as shrinking labour forces in ageing European societies, hazardous work, and the provision of affordable healthcare.

Developments in robotics are coming at an accelerated rate, and robotics technology is now reaching levels where more complex tasks are within reach. Robots will soon be endowed with human-like communication skills, perception, reasoning and fine motor control. This in turn will facilitate effective human-robot interaction and autonomous task execution. We have been witnessing this progress already in the case of self-driving cars, autonomous aircraft and service robots, to name a few examples.

These new forms of robots operating in human environments pose challenges with respect to safety, human interaction and acceptance. Up till now the field of robotics was mainly technically dominated. But to meet the new challenges, it must become truly interdisciplinary. Only then will robotics be integrated smoothly into our lives.

The ambition of TU Delft Robotics Institute is to take a leading role in developing a new generation of robots in a responsible way, and in so doing, contribute to solving the great societal challenges that we face. We collaborate with experts all over the world and share our knowledge with other institutes, business enterprises and governments.

Creating the next-generation robots is truly a planet-wide collaborative endeavour, which we are happy to join. We share our vision on how to advance it in this position paper. It also contains a timeline of the most important developments in robotics, starting with the early dreams about robots, continuing with the first industrial robots in the 1960s, and ending with the service robots and self-driving cars of the 21st century.

We hope you enjoy reading this booklet and look forward to seeing you in Delft, or anywhere else in the world, so that we can join forces to build a beautiful future with robots.

Robert Babuska
Scientific Director TU Delft Robotics Institute

THE ROBOTICS REVOLUTION

We are entering a new era of automation, with robots leaving factories and acquiring a role in our everyday lives.

'Emotions aren't baggage for robots – they are the soil in which our trust can take root.'

Jo Geraedts
Professor of mechatronic design, associate of TU Delft Robotics Institute

THE STORY OF ROBOTS

9TH/8TH CENTURY B.C.
In the epic *The Iliad*, Homer mentions *'Automatones'*, robot-like machines built by the divine smith Hephaistos and the Athenian craftsman Daidalos. Among these were wheel-driven tripods to serve the gods at the table.

AROUND 400 B.C.
Archytas constructs *The Pigeon*: a steam driven wooden dove. The bird allegedly could flap its wings and fly, powered by a jet stream of compressed air.

Chances are you have never met a real robot: a machine that senses, thinks and acts. Yet, while remaining largely invisible to the public, and at a safe distance from most workers, robots have been toiling for half a century in factories, tirelessly welding car parts, picking goods in warehouses, milking cows on farms and servicing oil wells at the bottom of the sea.
But this separation is rapidly becoming a thing of the past. Robots are joining our daily lives. In millions of homes, a robot vacuum cleaner scurries around and sucks up dirt. Autonomous cars have already travelled millions of kilometres on public roads. In factories, robots work in closer proximity to factory workers – giving rise to true collaboration. This is the new industrial revolution.
Over the course of their first century, robots have proved themselves ideal for 'dull, dirty and dangerous' work. Today, millions of them perform meticulously prepared and repetitive tasks with aplomb. Despite being integrated into a production line, such robots often work at a safe distance from humans. As they are often heavy and powerful, it is necessary that these machines be kept at bay.
But in the beginning of the 21st century, this is becoming less necessary. Robots are rapidly becoming more intelligent, more aware of their surroundings, safer and cheaper. They are acquiring the capacity to react to new circumstances, meaning they are better suited to unfamiliar surroundings, unfazed by sudden changes of plans and even empathic in human company. This means they are increasingly capable of working for humans and in cooperation with humans. This Robotics Revolution will affect almost every industry and service – and indeed many other aspects of human life.
As robots acquire more capabilities, they also assimilate a larger set of technologies. A modern robot is the product of the joint effort of a whole range of engineers, bringing together different disciplines and combining hitherto disparate domains of knowledge: from engineering to psychology, from cognitive science to social science and medicine. This is the reason why

'Ubiquitous robots will put the incredible productivity of robotic technology in everyone's hands.'

Martijn Wisse
Professor of biorobotics, associate director research, TU Delft Robotics Institute

Delft University of Technology has integrated the different strands of its robotics research activities into one joint entity: TU Delft Robotics Institute. This is now fast becoming the epicentre of robot development in the region – so much so that we can speak of a RoboValley – and indeed in Europe.

TU Delft Robotics Institute is a major centre for the development of robotic technology, but it also wants to be a leader in the debates about its consequences for the structure of industry, for the future of labour and for the role of robots in everyday life. Robotics can contribute to the solutions to some of the great societal challenges that are facing us: energy, sustainability, mobility, security and the ageing population. Yet robots may also compete with humans for jobs, may change the nature of war, and could induce other, still unknown social changes. These are serious issues that require foresight on the part of managers in industry, politicians and investors.

ROBOTS AS CO-WORKERS

The Industrial Revolution of the 19th century brought with it specialised machines, operated by ever more specialised workers. This led to a vastly increased division of labour, exemplified by Henry Ford's iconic assembly lines, where each operation got its own dedicated place in the factory. This rigid division of labour eventually made possible the outsourcing and offshoring of many routine tasks.

Now that robots are becoming more versatile, these trends are all being reversed. There are now flexible machines that are able to perform many different operations. As a result, car manufacturers are able to produce quite different models on the same production lines. Increased flexibility and better cooperation with humans will mean robots will be of more interest to small and medium-size enterprises; and, for that matter, to larger, agile companies, those that need to switch rapidly between projects, and therefore need to have unstructured and changeable factory floors. With more capable machines, outsourcing elements of production becomes both less practical and less profitable.

This is leading to a 'reshoring' of hitherto offshored production – shifting production back to the home market. It is also leading to important shifts in the employment of labour and the deployment of capital. Robotisation may be a way to keep production and standards of living sufficiently high in ageing societies, in which fewer workers are available. It may also bring sustainable technology, which is often more labour-intensive, within reach. Yet there are also worries about the availability and nature of future jobs.

It is still a great challenge to let robots work side-by side with humans, or let them cooperate more closely with other robots. That is why the mantra of one of the Robotics Institute's research themes is *robots that work*. This research mostly concerns robotic arms and mobile robots as used in factories, warehouses and service vehicles. Scientists equip them with additional hardware sensors and special software that facilitates interaction with their environment.

FIRST CENTURY A.D.
Heron of Alexandria designs and builds various mechanical *automata* ('devices that run by themselves'), including a three-wheeled cart powered by a falling weight.

AROUND 800
Abdullah al-Ma'mun, the caliph of Baghdad, commissions *The Book of Ingenious Devices*. Written by three brothers, collectively known as Banu Musa, it describes more than one hundred devices, among them a couple of automatic machines.

EARLY 13TH CENTURY
Al-Jazari of Persia builds a robotic orchestra of four musicians and a programmable drum machine. He also writes a treatise on automata containing automatic hydraulic and pneumatic devices.

> *'Hello robot, goodbye robot: total immersion of robotics in specified building blocks will give us intelligent and swarm behaviour of everyday objects and environments.'*
>
> **Kas Oosterhuis**
> Professor of digital design methods, associate of TU Delft Robotics Institute

Photo: courtesy of KUKA

> *'Humans and robots should learn to work together!'*
>
> **Frans van der Helm**
> Professor of biomechatronics and biorobotics, associate of TU Delft Robotics Institute

ROBOTS AS COMPANIONS

As robots are becoming more flexible and aware of their surroundings, they are gradually leaving their reservation, the factory floor. Autonomous cars and drones have received much media attention, but robots are also trickling into operating theatres, logistics services and construction sites. Our interactive robots research theme aims at assisting humans outside the domain of industrial production, as with, for example, a service robot in a hospital or a nursing home. One of the great challenges is to make the interaction with these robots more social and intuitive. This research focuses on three main areas: different types of direct feedback, control concepts and social aspects. For example, tactile, visual and other forms of feedback are studied, but so are partnerships, educational values and motivation.

Progress in these areas will not only make robotic household appliances more manageable and fun to use, it also is essential for such applications as remote surgery or control of submarine vehicles.

As robots move out of the factory, they may contribute to the resolution of certain pressing societal challenges. They may, for example, play a part in caring for the elderly. Just as wheeled walkers extend the range of many elderly people, a powerful mechanical valet may one day lift them out of bed. Robots may help with many other routine tasks that now require humans to perform or direct them. This comes as a welcome relief, as the ageing of the population will become a pressing problem in our societies. While the need for care is increasing, fewer and fewer people are available to provide that care. For younger target groups, too, projects at Delft are developing social robots. One, for example, is a 'pal' for children with diabetes to help them to cope with their disease. This robot has both a physical embodiment in the home (the Nao-platform) and a virtual one (its 'avatar') on computers and smartphones, so that its support is available everywhere.

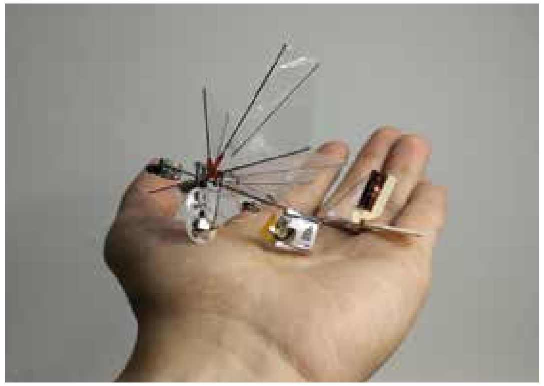
AROUND 1500
Leonardo da Vinci designs a robot knight (with cable-driven arms, head and jaw) and a robot cart. The cart was powered by clockwork springs; Leonardo's explanation of how the robot was powered has not survived.

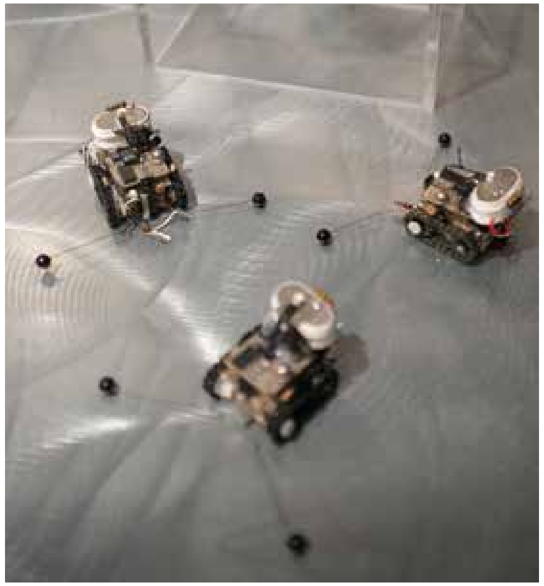
17TH/18TH CENTURY
In the Japanese Edo period, artisans build a wide variety of automatic mechanical dolls, called *karakuri*. They could carry a cup of tea to a guest or shoot with bow and arrow.

1738
Jacques de Vaucanson develops *The Duck*: a mechanical device that can flap wings, and eat and digest grain. He also builds a humanoid automaton that plays the flute.

‘Creating complex robots is not hard. Giving complex behaviour to something simple is.’

Just Herder
Professor of interactive mechanisms and mechatronics, associate of TU Delft Robotics Institute





DISTANT EYES

Taking our cue from nature, we can let robots cooperate to perform tasks that lie beyond their individual capabilities. Just like an ant colony can perform feats of impressive sophistication, employing a ‘swarm’ of relatively simple and cheap robots may prove a better approach than designing a single, much more complex machine. Another advantage of a swarm is its resilience – one malfunctioning robot will not necessarily prevent the others from doing the job; extending a task is simply a matter of deploying more robots; and many tasks can be performed in parallel, providing a faster result as more robots are dedicated to them.

There is a trade-off here: The individual robots should be small and simple enough to be able to exploit these advantages, yet intelligent enough to perform their task and be aware of their position and role within the swarm. Projects at Delft in the field of swarm robots have drawn worldwide attention, with nano-satellites and highly miniaturised drones carrying cameras and other sensors. Scientists are now working to increase their degree of autonomy, and to operate swarms of these drones and satellites in a wider field of applications than is possible with single robots.

1805
Joseph-Marie Jacquard invents an *automated weaving loom* programmed by punch cards.

1921
First use of the word *‘robot’* by the Czech writer Karel Čapek in his play *R.U.R.* (*Rossum’s Universal Robots*). In the play, though, robots are organic humanoid beings, not mechanical men.

1942
Isaac Asimov describes *‘Three Laws of Robotics’* in his short story *Runaround*.

‘A future with robots is a certainty. Our task is getting there responsibly.’

Jeroen van den Hoven
Professor of ethics, associate of TU Delft Robotics Institute

This requires us to push the boundaries of software and hardware technologies, and also makes new regulations necessary, to allow their application in air and space. But above all it requires a rethinking with respect to control technology. How should individual robots behave in order to obtain a desired outcome for the swarm as a whole? And how can this behaviour be adjusted when a swarm has no leader or other central control mechanism?

When robots have reasoning capabilities and share a knowledge base, they can act as team members that perform reliably in safety-critical domains. Ground and aerial platforms are being developed in Delft, together with the knowledge representations they need, that could be used, for example, in urban search and rescue.

Such technology could also be used in the surveillance of large areas, for purposes as different as monitoring agricultural production and verification of international treaties. The latter application comes to mind easily in Delft, close as it is to The Hague, the ‘international city of peace’ that hosts both the International Court of Justice and the monitoring organisation of the Chemical Weapons Convention.

1948
Grey Walter and his wife Vivian develop mobile robots, the electromechanical three-wheel ‘tortoises’ *Elmer* and *Elsie*. These animal-like machines move in complex and sometimes unpredictable ways in reaction to even minute changes in the ambient light level.

They are considered to be the first real robots. Walter built the ‘tortoises’ to demonstrate his ideas about the functioning of the human brain.

1954
Self-taught inventor George Devol builds *the first digitally operated programmable robotic arm*.

TU DELFT AND ROBOVALLEY

New collaborations arise around robotics research at TU Delft. The area is a hub for industrial research and a fertile test bed for new technologies.

Delft University of Technology (TU Delft) is by far the largest of the three technical universities in the Netherlands, with around 19,500 students. Within TU Delft Robotics Institute over 160 researchers, distributed over six faculties and 13 departments, carry out world-class robotics research.

When TU Delft Robotics Institute was established in 2012, it was a grass-roots initiative of Delft scientists who had joined forces after having recognised that robotics research requires intensive multidisciplinary cooperation. A number of previously isolated fields such as computer science and mechanical engineering were brought together. The university board embraced this idea and made the Robotics Institute one of the principal institutes of the university. Within only a few years, the Robotics Institute has become an important robotics hub, because it combines research (both fundamental and applied) with the development of robot prototypes (in the labs as well as in spin-off companies) and the transfer of knowledge and technology to industry and education.

Worldwide, the institute is at the forefront of five research fields: bio-inspired mechanical design, robotic vision, control algorithms, human-robot cooperation and value-based design.

In the field of bio-inspired mechanical design, our researchers develop bipedal robots that walk with close-to-human efficiency, robots with grasping hands and flexible arms and flying robots. All of these are inspired by efficient solutions nature has evolved over hundreds of millions of years. First learning from nature, then improving on nature.

1961
Joseph Engelberger, the 'father of robotics,' founds Unimation Inc. It sells the ro-botic arm *Unimate*, developed by Devol. The main performance goals are repeatability, precision, adaptability and safety. Until Unimation was bought by Westinghouse in 1984, the company sold approximately 8,500 Unimates. Sixty percent of those were used in the car industry, which became the main driver of the robotics industry.

1967
Swedish company Svenska Metallverken (ABSM) is the first European company to install a Unimate robot.

'Endowing social robots with human values will start the co-evolution of humans and robots in a beneficial partnership.'

Mark Neerincx
Professor of human-centred computing, associate of TU Delft Robotics Institute

‘Long-term human-robot teamwork requires empathy and can help us use our planet sustainably and comfortably.’

Catholijn Jonker
Professor of interactive intelligence, associate of TU Delft Robotics Institute

Delft researchers have also developed the concept of a ‘Factory in a Day’ – robots that are easy to use and adjust to different tasks, which are especially suitable for small and medium size enterprises.
In the same way that human vision is more a matter of the brain than of the eyes, robotic vision is more a matter of the robot’s artificial intelligence than of its cameras. Delft is at the forefront of vision-based robotics. Our researchers have, for example, developed the innovative onboard vision of the micro aerial vehicle DelFly, which has received worldwide attention.
As robots should move in a stable way without harming people, other robots or their operating environment, they need clever control systems.

1969
Shakey becomes the first mobile robot that reasons about its own actions, at Stanford Research Institute. It has to be programmed with a two-dimensional map of its surroundings.

1969
GM installs the first spot-welding robot at an assembly plant. Norwegian company Tralfa installs the first commercial painting robot.

1979
At Stanford University, Hans Moravec builds the *Stanford Cart*, an autonomous vehicle that navigates across a room. It plans its own path based on the visual information it collects.

In this field our researchers build computer algorithms for capabilities such as walking, learning, motion planning and the fusion of information coming from different senses.
In the area of human-robot cooperation, the Robotics Institute specialises in tele-operation, recognising objects by touch, shared control, and creating synergy between human and machine intelligence.

Finally, in the field of value-based design, our researchers stand out in designing new robotic technologies, starting with the question of how these technologies can best contribute to those human values society considers important. Building robots for people, not just because some new technology makes them possible.

As should be the case in a world-class university, at Delft University of Technology education and research are closely intertwined and reinforce each other. In its robotics courses, for example, many scientists from different departments cooperate in teaching. Students build robots, drawing from disciplines such as computer science, electrical engineering, mechanical engineering and industrial design. Students graduating from TU Delft are also the lifeblood of a robotics industry that surrounds the city: They actively form spin-outs and create start-ups, or find jobs at established robot manufacturers.

1989
Rodney Brooks and Anita M. Flynn publish the article *Fast, cheap and out of control*, promoting the development of small autonomous, biologically inspired robots (Behaviour-Based Robotics), instead of clumsy humanoids. An example is the six-legged insect-like *Genghis*, which teaches itself to walk over obstacles.

1989
HelpMate is the first service robot to be used practically. In the Danbury Hospital (Connecticut), HelpMate carries trays of food to patients. The company HelpMate Robotics was founded by Joseph Engelberger.

1993
Rodney Brooks, Lynn Stein and Cynthia Breazeal of MIT start building *COG*, a humanoid robot that is meant to learn like a child. The aim is to develop the behaviour of a two year old child within five years, but this turns out to be too challenging.

'The hard days for robotics are over. Software rules!'

Koen Langendoen
Professor of embedded software, associate of TU Delft Robotics Institute

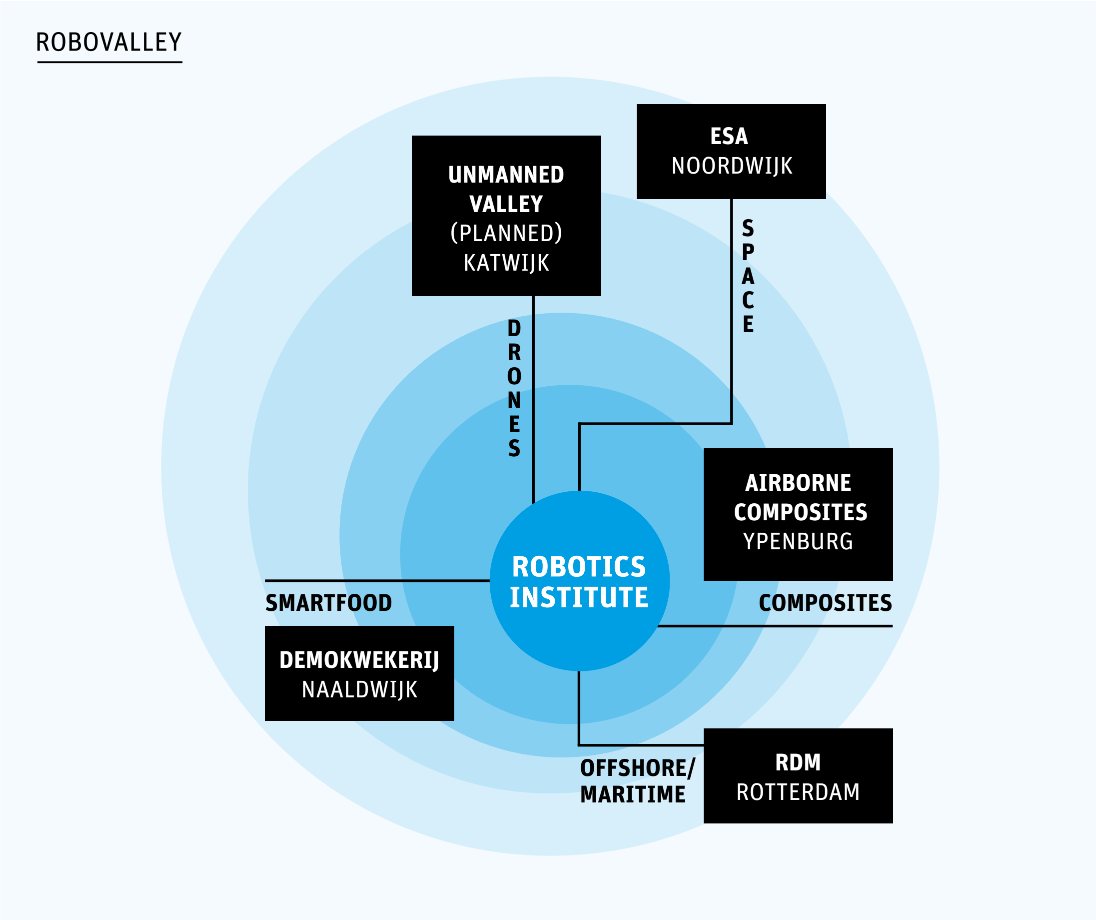
ROBOVALLEY

These research and commercial activities are necessary, but in themselves not quite sufficient conditions for the development of a thriving, advanced robotics industry. Because of the complexity and novelty of the technology, only through a large critical mass of participants from academia, business and government can an effort such as this reach the stage of a sustained economic activity.

In order to accomplish this, TU Delft Robotics Institute is now taking the next step: the development of RoboValley. As the western part of the Netherlands is quickly becoming the focal point of many robotics-related activities, the RoboValley initiative fosters interaction in the region between academic research, high-level education, governments and enterprises in the development of new robot technology. RoboValley stimulates start-ups and invites existing companies that are active in this field to establish an office, a plant or a laboratory in the area. Several manufacturers of specialised robots already have their headquarters in this part of the country. An example is Lely, one of the largest manufacturers in the world of machines for agriculture, such as milking robots.

The Delft area is an ideal hub for robot applications, because the region has a number of industries that have a strong tendency to use robots. One of the largest ports in the world is in nearby Rotterdam, and one of the largest concentrations of greenhouses in Europe can be found only a few kilometres from there. One particular TU Delft Robotics Institute programme, called 'Smartfood,' is dedicated to robotics applications in agriculture.
In the context of medical applications, TU Delft is part of a European initiative on ageing. It also participates in the Medical Delta, which includes the medical centres of both Leiden University and Erasmus University Rotterdam.
The European space agency, ESA, has a main office in the area. Shell has its headquarters and research facilities nearby. There is also the RDM Centre of Expertise for maritime and offshore industry in the port of Rotterdam, and the former airport, Valkenburg, is destined to be a drone research hub. Meanwhile, Ypenburg has an Airborne Composites Cluster, with the strong involvement of Siemens.
RoboValley takes advantage of the physical proximity of all these players. It is a tremendous help for researchers, entrepreneurs and investors to exchange ideas and bring new robots quickly to market.
Robotics research takes advantage of the support the Dutch government gives to science and technology through its agencies NWO and STW, and through the government's sectoral programs for 'High tech systems and materials' and 'Smart industry'. Over the next decade, the European Union will also be investing heavily in robotics, for example via the Horizon2020 programme.

Thanks to quintessentially Dutch assets, such as a good education system, sound logistics, a stable and favourable fiscal climate and an open culture that has made many Dutch people proficient in English, RoboValley is ideally positioned to become the gateway to European robotics for partners from all over the world.



1995
First use by the US military of the remotely piloted aircraft *Predator*.

1997
First *RoboCup* soccer match played in Japan.

1999
Sony starts selling the *Aibo* robotic dog.

2000
Cynthia Breazeal (MIT) demonstrates *Kismet*, a robot face that expresses emotions.

2000
Honda introduces the humanoid robot *Asimo*.

2000
Introduction of the robotic *Da Vinci surgical system*.

‘Robots must learn to learn. Humans must learn to teach them.’

Pieter Jonker
Professor of vision-based robotics,
associate of TU Delft Robotics Institute

2001
Search and rescue robots such as iRobot’s *PackBot* are used at Ground Zero after the September 11 attacks on the World Trade Center in New York.

2002
iRobot starts the sale of its disc-shaped robotic vacuum cleaner *Roomba*. It will become the most successful domestic robot to date.

2002
First use of military tele-operated robot *PackBot*, built by iRobot, in Afghanistan. PackBot is used for reconnaissance, bomb disposal and other dangerous missions.

‘Drones now do our dirty, dull and dangerous work. Next, they will be our fun-providing, flying friends.’

Max Mulder
Professor of aerospace human-machine systems,
associate of TU Delft Robotics Institute

A START-UP CULTURE

A strong component of the growth of RoboValley will be the establishment of specialised firms that spin off from the research institutes in the region. TU Delft Robotics fosters smart use of the strong domestic market to test the viability of novel ideas, allowing the successful ones to be quickly scaled up to a global level and grow into established products.

TU Delft fosters start-ups and spin-offs by building partnerships with potential robot users to link research with demand. Such cooperation may lead to joint research, and eventually a robot prototype. For the next – costly – step on the road to market, a proof of concept in a real production environment, a fund has been established jointly with the Dutch ministry of Economic Affairs. Once that hurdle is cleared, it will be up to the market to finance the next stage: upscaling to commercial production.

In the course of the last decade, a number of successful robotics companies have grown out of research at TU Delft: Lacquey (for handling fruit and vegetables), Delft Robotics (industrial robots with 3D vision), Type22 (for luggage handling), Delft Dynamics (robot helicopters) and Fleet Cleaner (hull cleaning and inspection equipment), to name just a few.

2004
NASA’s robot rovers *Spirit* and *Opportunity* start exploring the surface of Mars.

2004
Start of the EU-project *RobotCub*: the 1-meter-high humanoid robot *iCub* is created as a platform for research into human cognition and artificial intelligence.

2005
Researchers at Delft University of Technology, Cornell University and MIT demonstrate *bipedal robots* that walk with close-to-human efficiency.

THE DELFT TOUCH: ROBOTS FOR HUMANS

We build robots so that workers can be more efficient and citizens more empowered. That is why we study how humans and robots can join forces.

Robo-hubs are appearing all over the world. What makes the Delft touch special in relation to robotics is its focus on technology for people. Although robots can be fun, we study them for a very serious purpose: extending human capabilities. This means that we do not try to mimic Homo sapiens by constructing humanoid robots; instead, we build robots that provide people with strong hands, the ability to see over long distances and other improved abilities, so that workers can be more efficient and citizens more empowered.
At the heart of this Robotics Revolution is the idea that people can be more successful through the use of robotics, in much the same way that the Industrial Revolution of the 19th century made production more efficient. Machines have never replaced human labour, but they have always changed the nature of a given task and challenged paradigms. Machines have the potential to make human workers more powerful and more effective. Yet they will also, doubtless, take on labour previously performed by humans. This may be to the detriment of some – but it may also bring benefit to others in an ageing pool of employees, where it falls to fewer and older workers to keep society running.
Robots have – for the foreseeable future, at least – no will of their own; instead, we consider humans to be responsible for their design and implementation. This means that even during the design phase of robots, societal, ethical, moral and legal requirements need to be considered. At Delft we believe that this is integral to attaining responsible innovation. Our approach to robotic development promotes cooperation with humans – the antithesis of destruction. For that reason, we have also made the choice not to actively develop military robotic technology.
Right from its earliest days, the institute has received a lot of media attention. Flying, walking and rolling autonomous machines are not just attention-grabbing gadgets; people have quickly come to realise that robots will have a profound influence on their work and on their lives in general.

2005
Robotic car *Stanley* wins the second DARPA Grand Challenge, a race for driverless vehicles over 212 kilometres in the Mojave Desert. Stanley is built by a Stanford University team led by Sebastian Thrun. At the first DARPA Grand Challenge in 2004, no driverless car had managed to complete the course.

2006
French company Aldebaran Robotics builds the interactive, programmable and affordable robot *NAO*. Nowadays, more than 3,000 NAO's are used in schools and universities in 70 countries.

2009
Start of the EU *RoboEarth project*: a worldwide web through which robots and share information and learn from one another.

'Building robots leads to questions about our future that the humanities, art, literature and philosophy must help us answer.'

Sabine Roeser
Professor of ethics, associate of TU Delft Robotics Institute

Photo: courtesy SAM Security

2010
Willow Garage releases robot PR2, a hardware and software platform for robot researchers.

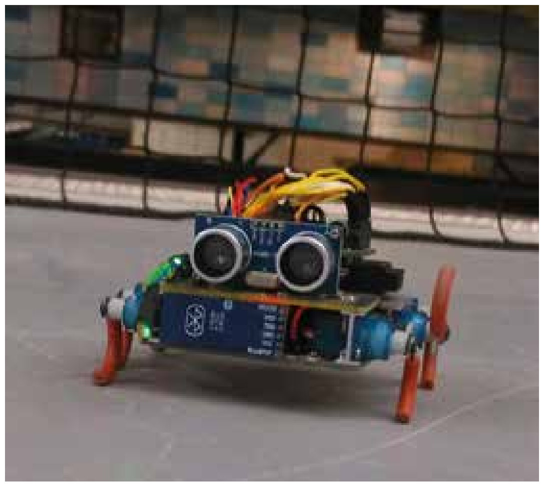
2012
Google demonstrates its first driverless car.

2012
Tech United, the Dutch robot soccer team of the Technical University Eindhoven, wins the world title in the league of medium size robots.

‘Progress in machine learning and control will enable robots to become true human companions.’

Robert Babuska
Professor of intelligent control and robotics,
scientific director of TU Delft Robotics Institute

The Netherlands has a strong tradition of public consultation, resulting in collective labour agreements and a common approach to the energy transition. Likewise, the opportunities and dangers associated with robots are now broadly discussed within the country, with experts from Delft contributing enthusiastically. The well-known British roboticist Alan Winfield predicted in his book *Robotics – A very short introduction* (2012) that: ‘by 2020 many households will have one or more robots, perhaps a driverless car, several cleaning robots and an educational or entertainment robot. Not many years later and a gardening robot could be taking care of garden weeds and pests. Limited-function robot companions could well become a reality, if not commonplace, by 2025 [...] The pace at which robotics is advancing is accelerating, so there are likely to be significant developments in the near future, including some big surprises.’
And although by definition we can’t know what these surprises will be, we are confident that some of them will be conceived of and developed in RoboValley.



2015
Aldebaran Robotics and SoftBank Mobile start the sale of the ‘emotional’ humanoid robot *Pepper*. Pepper is an interactive robot that is larger than NAO, but has wheels instead of legs. It can communicate using hand movements and voice.

ROBOTS IN THE LIMELIGHT
For Delft University of Technology, 2016 will be the Year of Robotics. In 2017, Delft will be hosting RoboBusiness Europe, one of the premier business events in the world of robotics.

RESEARCH CHAIRS OF TU DELFT ROBOTICS INSTITUTE

Robert Babuska
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Jo Geraedts
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