The Near Future of Unmanned Vessels; A Complexity-Informed Perspective

Kees Pieters
Condast

ESSAY

Kees Pieters

The Near Future of Unmanned Vessels

A Complexity-Informed Perspective

The Near Future of Unmanned Vessels

A Complexity-Informed Perspective

ROTTERDAM UNIVERSITY
UNIVERSITY OF APPLIED SCIENCES

Hogeschool Rotterdam Uitgeverij

Colophon

ISBN: 9789051799538
first edition, 2015

Publications can be ordered by
www.hr.nl/onderzoek/publicaties

The Near Future of Unmanned Vessels

A Complexity-Informed Perspective

Kees Pieters

applied research professor Big Data for Deltatechnology

April 21, 2017

Introduction

Unmanned systems are all the hype today. Following the extremely dynamic developments in the automotive industry, the maritime industry is preparing for a future where human presence is no longer required in the logistical chains or on board ships. The advocates of these developments promise great opportunities and talk of 'Smart Ports', 'Smart Cities', 'Smart Vessels' and a lot of other smart things where "Big Data", "Deep Learning" and the "Internet of Things" are driving a strong technology push in this direction. There are also more critical voices, which stress the threats to job security and safety, and even warn against the consequences of robot supremacy.

In the past four years, Research Centre "Sustainable PortCity" has been at the forefront of these debates, both with regard to the maritime industry and Rotterdam Mainport, as a city where people live, work and spend their leisure time. As a research professor at this centre with 'Big Data for Delta Technology' in my portfolio, I have followed these debates with great interest. My portfolio focussed on smart, innovative solutions for water management, such as the inspection and monitoring of rivers, (other) waterways and coastal areas. As such, and in a typically Dutch fashion, I could not refrain from forming an opinion on the issue of maritime robotics. At the end of my four-year assignment at the Rotterdam University of Applied Sciences, I have welcomed the opportunity granted me by my employer to set my thoughts on these developments down in writing, in the hope that they may help decision makers and policymakers, technologists and other stakeholders involved in the issue of autonomy in their attempts to guide developments towards increasing robotisation and automation in a major International Mainport region.

CONTENTS

Robots in Mainport Rotterdam

When I started my term as a research professor at the Mainport Innovation Research Centre, as it was called in 2013, the buzz concerning robotics was mainly concentrated around Google Car, Uber and Tesla's car. These developments in automotive technology concerned themselves with the concept of (machine) autonomy, such as self-driving cars and platooning. In the Port of Rotterdam, the second Maas Area (Maasvlakte 2) was close to completion, a 2000 hectare land reclamation project off the coast by Hoek van Holland which added 20 per cent to the Rotterdam port area.[1] APM Terminal, one of the major terminals in Rotterdam, had claimed a significant portion of this area for their autonomous guided vehicles (AGVs), unmanned carriers which transport containers to and from the ships.[2] The cranes on this site that load and unload the containers from the vessels are remotely operated, which is another step in the direction of autonomy. In Norway, Rolls-Royce was already anticipating the first unmanned vessels to transport the containers across the oceans,[3] and so it was not difficult for me to select my first research theme. When Roel Bakker, one of the lecturers at the computer science department told me that he wanted to do something with robots, I suggested that he concentrate on ships. Everybody else was already busy with quadcopters and vehicles, and the robotisation of ships was most definitely very topical for Rotterdam.

As it turned out, there was a very successful project called 'Project Zeeslag' (project 'Naval Battle') at one of the other schools of Rotterdam University of Applied Sciences (RUAS), which concentrated on building vessels to clean up the 'plastic soup' in the ocean. Every semester, two teams of students were to engage in combat to pick up as many ping-pong balls as they could in a water basin with a vessel that they had built during the term. Emile Jackson and Maarten Dubbeld, the lecturers who had been running this programme from its inception in 2010, and Mart Hurkmans from maritime systems integrator RH Marine, who financed the programme, were reconsidering the format of the programme. When we were first introduced, it became clear that we would concentrate more on autonomy in order to adapt the programme to the requirements of applied research. We would stick to the hull size of one-and-a-half metres, mainly because this implied that the vessels could be transported by car and the components would be affordable. In addition we would concentrate on what was needed to ensure that these small vessels carried out tasks in real-world environments. The first goal we set for ourselves was to make a successful crossing of the river Maas between the St. Job Harbour, where our maritime school was situated, and the Dock Harbour in the Heijplaat area, some four kilometres further down the river. This was where the research centre and our colleagues from the RDM Centre of Expertise (RDM CoE) were located. The preparations for this event confronted us ultimately with the fact that we not only faced a technical challenge, but also with rules and regulations, and especially the absence of these where autonomous vessels were concerned.[2]

Ever since, we have seen time and time again that this pattern applies not only to the small vessels that we were making, but that it could also be scaled up to the sizes and dimensions of the vessels that are customary in the Port of Rotterdam.

Figure 1: Aquabot crossing the Maas River

The crossing in the summer of 2014 heralded the start of the Aquabots (research) programme and attracted some attention from the local media. Soon we were getting the first requests to use our vessels for monitoring and inspection purposes. The port authorities had a long-standing desire to automate their inspection of quays with maritime robots and Rijkswaterstaat—the Directorate-General for Public Works and Water Management—was looking into the use of autonomous vessels for the inspection and monitoring of the Dutch waterways.[5] Some smaller companies, such as Indymo of my colleague, Rutger de Graaf, were looking for small submersible ‘remotely operated’ vessels (ROVs) for inspection of floating structures. Soon we had a small team assembled to coordinate further efforts in this direction.

This essay is in part a reflection on the two-and-a-half years that we spent on this issue. For even though the size of the vessels we have been working with are relatively small, many of the issues we have faced and the technology we have used can be scaled up to the larger vessels that visit the Port of Rotterdam. Furthermore the projects we carried out with our students have been a great introduction to the challenges and opportunities of autonomy in an internationally oriented main port region.

Complexity Thinking

Before delving into the technicalities of unmanned vessels or vehicles, it may be good to introduce myself briefly, in order better to understand the perspective that will guide the rest of my argument. This is good practice in the 'complexity-informed' approach that I will use to build my plea, as it helps the reader to understand the logic of my reasoning.

I have a background in electro-technical engineering and artificial intelligence. I worked for more than a decade in industrial automation before switching over to small start-ups during the Dotcom hype at the turn of the millennium. During this period, I also started a PhD at the Utrecht-based University for Humanistic Studies, where I prepared my thesis on complex systems and complexity, assisted in the development of my thinking by my supervisor, Prof. Harry Kunneman, and my co-supervisor, Prof. Paul Cilliers. I like to believe that the three of us managed to make headway in a new methodological approach to science, based on insights into complex systems, that was (methodologically) inclusive, democratic and did justice to the complex nature of many real-world phenomena. Especially the latter became crucial to my appointment as a research professor, since the nature of *applied* sciences tends to be complex rather than complicated, to use a distinction that was introduced by Cilliers.[6] However, before I get ahead of myself, it may be good to introduce (critical) complexity thinking briefly, and to give an indication of where it differs from regular (linear) science.

Complexity-informed Methodology

In order to understand what 'complexity-informed' research entails, it may be good to recall the archetypes of scientific research. According to Henri Atlan and others, modern science sprouted from the search for 'God's Plan', and this quest came with a number of assumptions that, if embraced, would lead to 'pure' or 'exact' knowledge.[7, 8] The first assumption was that this quest was a search for a certain 'truth' that was universal, timeless and independent of location. This followed from the fact that God's presence was everywhere and His plan, that had been driving humankind since the Genesis, would inevitably accumulate in the end of time, as the prophets through the ages had already pointed out. God's presence could be found in the extremely small, and the enormous vastness of the Universe, so His plan would be visible regardless of time and space.

The second assumption, derived from the first, was that an observer would regard her object 'from a distance', and did not interact or influence the results. Everything was fixed, and no matter what we humans attempted, events would indeterminably take their course. By the early nineteenth century, the humanist movement in Western Europe had replaced God by a mechanical clockwork universe, that once wound up, would tick-tock its way through time in a predetermined fashion. Every cause had a singular, linear effect on our life-world, and by careful reasoning and logical deduction, the threads of causal relationships could be traced back in time *and* could be used to predict the future! The controversies with the dominant religions that opposed these ideas often obfuscated the fact that the underlying assumptions were still very much the same.

With all the historical nuances and critique that also travelled with these assumptions through the ages, one could say that the most dogmatic advocates of this view were ambassadors of one extreme methodological stance with regard to science. This view proved to be extremely important for the development of the natural sciences, which made the search for 'pure' or 'exact' knowledge through logical reasoning and mathematical proof the dominant approach in science until the latter half of the twentieth century.

The other extreme developed most strongly in the social sciences and the humanities. Its proponents saw a world that was not objective, allowed for multiple perspectives and where truths are social constructs.[9, 10] This 'relativist' view developed most strongly in the sixties of the previous century and is probably most vividly embodied by Paul Feyerabend's call 'Against Method', which questioned the dominant approaches of scientific rigour as a means of discovering our life world.[11] With hindsight, one might argue that the most extreme of these 'postmodern' views tended to mistake relativism with randomness and, in general, failed to explain why 'classical approaches' were so tremendously successful in the natural sciences. Notwithstanding this, the social sciences and the humanities tend to accept multi-interpretability of subject matter. Research in these areas can also be based on a plethora of theoretical frameworks and methodologies, both qualitative and quantitative, and sometimes inclusive of those of the natural sciences.

Complexity-informed methodological perspectives—we shall not speak of 'complexity theory' as we, like the social sciences, consider complexity to require an amalgam of methodological approaches that—with all their strengths and weaknesses—tend to explore the middle ground between the two archetypes described above. Solid research from the natural sciences brought (amongst many others) the concepts of non-linearity, fractals, (quantum) uncertainty and self-referentiality, while postmodern approaches made us more aware of the limitations of observation (most notably bias), the role of history, culture and normativity in a system or network. Problems between micro and macro effects in such systems, new methodological constructs, such as patterns and the concept of 'scale', help us to understand that knowledge is *designed* rather than 'found',[10, 11] and that this design is influenced by historical and cultural effects.[12]

However, these designs are not arbitrary; they are still constrained by the 'real' thing. Even if there are multiple models, there must be, at least to some extent, a means of transformation from one to the other. If not, there must be an account of why two models do not seem to match well, as this demarcates a boundary of methodological or epistemological uncertainty. At these boundaries the researcher has an obligation to state that 'she does not know', as the framing of her models are no longer adequate to address the issue at hand.

> *One of the most important contributions of complexity so far, is that at least some researchers are at ease with the ambiguity and uncertainty of this middle ground, and manage to find their way in the resulting 'swampy lowlands' of knowledge.*[13]

One of the implications of this stance is that academic research is in many ways a professional practice like many others. The differences lie mainly in the way that this particular practice is organised and in the fact that academia is a breeding ground for (future) elites. As a result, the specific biases of this practice tends to be quite dominant in society and the normative rationale behind this hardly tends to be questioned from the ranks outside of this culture. A complexity-informed perspective is more open to the incorporation of relevant voices from other practices, as this should contribute to the full picture of a complex phenomenon.

For the purposes here, one of the most distinctive differences with the classical (linear) scientific approaches—which by the way has also long been accepted in the social sciences— the fact that the observer (the scientist) is part of the system she researches. The observer is not an independent, disconnected entity in the research process. Rather she shapes her findings by the choice of her theoretical framework, the type of experiments she designs, her interests and the cultural background she brings with her to the research. Also, the models we make are distorted by the way our brain is organised and the fact that it is embedded in our body.[7, 8]

Our cognitive system has not evolved to discover 'truths' and scientific research therefore tends to be quite demanding on our brains.[17] For instance, humans are visual species, so we tend to project causal implications to observable change and are often oblivious to the processes that have been driving this change 'under the radar' prior to the visible events.

A complexity-informed methodology therefore *must* account for the resulting 'distortions' of the research, as these influence the outcome. One way to counter the inevitability of bias in the research that is performed is to cross-reference the scientist's observations with those in other independent scientific research areas that investigate the same phenomena. One could say that we use a different theoretical framework to provide the independent (meta-) perspective from another theoretical framework to observe another one as a replacement for the 'God' position in traditional science *and*, in true self-referential fashion, this works both ways! This *also* implies that with complex systems, different methodologies, frameworks and approaches *must* interact with each other (we call this methodological *interference*) and that these theories and frameworks are units with which we build or design our models of our lifeworld. The particular complexity-informed dialect that I will be using is based on the notion of *patterns*. This is derived from well-established methodological research in (building) architecture18 and software engineering.[19]

A last approach that is typical for a complexity-informed methodology is that the research and the *process* of researching are intertwined. When we research a certain phenomenon, such as robotics in a major main port, we often have to switch to a position where we can see the researcher who is performing that research, in order to account for the bias and to augment her findings with other insights. These insights do not necessarily have to be academic—the insights of professionals are equally important—but if we are to play the game of science then we are not allowed to use these insights to further our argument without solid scientific backing or a critique of such academic sources. A major issue for a university of *applied* sciences is whether the voice of professional practice should take a more equal position in these debates, since its knowledge is often more relevant than fundamental knowledge. Professional knowledge may be a strong source of methodological interference.

From the above it may have become clear that the complexity-informed dialect we propose here is an *inclusive* one, which allows insights and perspectives from many different sources, but where we must take care of moulding the models we make (which by definition are incomplete) to the specific games[20] that are required for certain areas. On the one hand, it prevents the knowledge that is designed using these models from becoming encapsulated in little bubbles of like-minded people who all preach to the converted. On the other hand, we must respect the rules of certain 'language games', such as the academic world, and tweak our models to fit the rules that apply there.

Complexity thinking is modest in the sense that its ambition goes little further than making models of certain aspects of 'reality', or the 'life world' as I prefer to call it. The life world is that part of 'reality' that is relevant for the observer. This implies that the life world extends beyond the horizon of that observer and often includes processes and dynamics that the observer cannot see or know. The models the observer makes are *relational*, by which I mean that the model and the life world is intimately connected. Besides, the relationships are not necessarily unidirectional, but the model and life world can interact with and mutually affect each other. This, as we shall see, has consequences when performing *applied* research.

Complexity and Applied Research

Figure 2: Applied research in action

One of the most distinctive differences between fundamental and applied research is that the latter research often results in actions in the life world. This creates feedback loops which affect the life world and therefore the models that drive these changes. This is not to say that fundamental research does not have these forms of feedback, but often the consequences are negligible (e.g. in astronomy), or it is *assumed* that this is the case. Either way, fundamental research tends to limit the scope of these feedback loops, based on normative choices which are usually implicit and not based on objective criteria. In the case of applied research, such implicit choices may affect the system dynamics as a whole, with the result that the entire model is dangerously incomplete and affects the life world in unexpected and undesired ways. Especially when the outcomes of these models are materialised in concrete products, services or policies, we have to ensure that they perform safely in a certain environment.

Just recently, I was made ultimately aware of the pitfalls, when I attended a meeting on unmanned vessels, and I heard one of the speakers – an engineer- say that, for him, a human on board of a vessel was a 'system that could be replaced by technology'. All it took was understanding the professional role of the human, and comparing this to technological feasibility. This stance may be perfectly valid in order to understand the primary function of a human operator, but it runs a serious risk of being blind to all the *other* tasks a professional often carries out, which are not primarily related to carrying out a certain function, but are necessary to keep things running smoothly. When technology replaces these professionals, you also replace these often mundane 'extra' functions, which are usually not in vogue of the tech guys.

Applied research therefore typically requires complexity-informed perspectives, since the research inherently concerns open, dynamic systems which interact intimately with their environment. Complexity-informed perspectives are vital for the research that is conducted at the Rotterdam University of Applied Sciences, especially when it has a focus on developing new forms of education. For instance, most researchers are also lecturers at the University and are actively involved in designing of new forms of education, which makes the research inherently self-referential. Self-referential methodology teaches us that:

the initial settings, conditions and mindset are going to influence the way that these projects develop;

- *'truths' and 'facts' which the research unearth may be the result of self-fulfilling prophecies, as a complex system tends to adapt itself to that what is measured;*
- *open systems are complex systems which interact continuously with their environment; Expressed more strongly, the environment is entwined in such systems.*[6, 21, 22] *This means that the traditional way of excluding the influence of the environment by carrying out research in the controlled environment of the laboratory, through the constraints of the theoretical framework or the experiment, or through a scientific culture is the result of a normative choice and is not justified by a deep 'objective' reality which implies that such choices do not affect the results. In other words, we have to accept the condition that our research has 'too many variables', for many of which the researcher has no prior schooling, training or background;*

- *scale (in)variance;*
  Patterns we discover can be observed at different levels. For instance, any patterns relating to autonomous agents will inherently apply to machine robots, social agents such as humans and social organisations. They will (therefore) also apply to a researcher who is looking into the issue of autonomy in MainPort Rotterdam.

Figure 3: RoboLAB at RDM

This section of this essay contains many concepts and ideas that may be tough to digest, especially for those who are trained to think in linear, hierarchical ways and in distinct causality between cause and effect. This is probably one of the most profound consequences of learning to think in terms of complexity, that we are subject to a 'fundamental limited knowing'.[21,23] If we are dealing with a complex system, then we cannot capture this system in an abstract or a 'management summary'. These forms of simplification are often necessary, but are the result of the limitations of the observer and will not automatically make our lifeworld simpler. Put more strongly, actions based on these simpler, coarser models will sooner increase the risk of creating undesired effects than a more fine-grained, detailed one. If one really wants to think in a complex way, one must realise that the observer has to change and has to subject herself to a regime of continuous learning. Unlike Occam's razor, a simple answer to a complex problem is usually (but not always) the wrong one!

One of the most practical consequences of this methodological stance is that many of the projects we started at RDM were multidisciplinary. We sometimes had student teams from six or more programmes and from different schools within RUAS working together on a certain project, closely supported by lecturers and experienced professionals from maritime companies and other organisations. Another consequence was that in time our robotic research became more focused on the issue of situational awareness to cater for the environment in which the robots have to perform their tasks.

The Deconstruction of Autonomy

In order to arrive at a balanced view on the near future of unmanned vessels, it is necessary to break this complex issue down into a number of separate, but related issues. For this reason, I will 'deconstruct' this topic along three dimensions, namely along the three dominant rationales or narratives for automation or robotisation of work processes, the difference between man and machine, and lastly, a functional deconstruction of a vessel.

The above qualifications are obviously made to be set against the main contender in the work process, namely the robot or the machine. However, before delving deeper into the man-machine distinction, it is worth deconstructing the robot—or intelligent machine—along two well-known discussions in the field of artificial intelligence (AI), or computer intelligence as it is recently more often called.[24]

Agents and their Environments

When a robot is said to have 'intelligence', this usually means that the robot can perform certain tasks in a predictable way and usually it is more or less responsive to changes in the environment while carrying out these tasks. The robot has a certain repertoire of actions which it can perform at a given time. These actions are, for an external observer, adequate for the task at hand. With the current state of technology, however, the robot is not capable of asking itself the 'why' question prior to these actions. Unlike human beings, robots (currently) do not have the ability to reflect critically on (the consequences of) their choices. Someone has instructed the robot to carry out a certain task and the robot starts doing so until the stop button is pressed. For most robots, this also applies to the 'intelligence' it contains. Many everyday robots, such as the ones that are found in production halls, are 'intelligent by design', which means that smart engineers and designers provide the actual intelligence and the robots dumbly carry out the required tasks over and over again. This usually means that the intelligence of these robots is constrained by:

- *what the designers can foresee when the robot is designed;*
- *the choice of technology that is needed to make the robot adaptive to its surroundings.*

As a result, this technology usually works quite well in predictable, stable environments. Usually the surroundings of these robots are isolated from the dynamics of everyday life by walls, fences or otherwise. People who enter these confined areas are usually trained professionals who handle the technology with the necessary care. The current developments in robotics are primarily focused on allowing these robots to perform in these confined spaces with increasing autonomy, which results in gated compounds where human presence is no longer desired. The APM-T terminal at the second Maas Area I mentioned earlier is a good example of such an environment for these types of robot.

There are some schools of thought in the AI community which do not consider these robots to be truly intelligent and certainly not 'autonomous'. According to those who hold these views, an autonomous machine should be able to make its own decisions, given certain circumstances and goals, and to decide which course of action to take. The robot should be able to make decisions that the designer could not foresee in advance based on the conditions of its environment and previous experience. One of the most vital consequences of this stance is that these machines must be able to make mistakes, in order to learn from them. However, the prevention of mistakes is one of the main reasons why most organisations are interested in robots in the first place! As a result, most practical applications of robots tend towards the first, pre-programmed type, although some elements of truly autonomous machines are being integrated into these robots. Some robots get trained prior to their introduction into a production plant, which limits the chance of errors once they take their place in the assembly line. However, this training is subject to the same constraints that apply to the pre-programmed robots, so this usually works well in stable environments. Another major focus lies on automating processes where human actions are prone to error and are potentially hazardous.

Practical robotics tends to take up all kinds of intermediate positions on the scale from 'pre-programmed intelligence' to 'true autonomy'. The majority of today's robots are positioned on the former end of the scale and are usually referred to as 'machines'. Truly autonomous robots are still quite rare and usually have limited practical application. There is a strong development towards augmenting machines by given them the capability to learn and adapt, which in a sense mimics the way that organisms operate. Organisms are usually also equipped with an 'instinct', which is enriched by means of learning. In this sense, there is therefore little difference between a machine and an organism.

Another related issue is the *design* of the robot. The sensors and actuators that a robot has at its disposal is also predominantly pre-determined. A robot can be extremely intelligent, but if it has no ability to interact with its surroundings its intelligence remains hidden. This issue is usually called the *situational awareness* of the robot. One can say that the robot's environment can be split up into two parts, namely the environment 'as is', and a subsection thereof of which the robot is aware. We will call this the 'surroundings' of the robot,[1] although one must realise that these surroundings do not correspond with the immediate vicinity. After all, if a robot cannot sense water, the robot will be totally oblivious of the fact that it is submersed in this liquid after it has just fallen of a bridge! The surroundings of that robot will not provide any clues of the predicament which that robot faces!

The surroundings of a robot are (currently) also predominantly provided by its builders. Therefore the ability of the robot to operate efficiently in a certain environment is largely determined by the foresight and expertise of its creators. In general, this means that such robots will usually perform best in predictable, stable environments.

One of the consequences of truly autonomous machines is that they increasingly resemble biological organisms. This is not surprising, as *any* agent who has to establish itself in a complex environment is subject to the same rules and conditions. A silicon-based computer has some distinct features that can help it to maintain itself in these environments, which are different to a biological carbon-based organism, but the rules of the game remain fairly similar. Interestingly enough, much of the sensory apparatus of organisms is as yet unknown. New receptors for certain stimuli are regularly found and often some that were considered redundant prove to be more important than expected. As a consequence, we tend to underestimate the complexity of the sensory apparatus of organisms and robotic replacements are often of too simplistic a design to really take over the tasks of these organisms.

Google Car, the most striking current development in autonomy by the well-known American software company, reveals one of the most telling consequences of this fact. Google and Tesla spurred on a technology race in driverless cars, which is currently attracting investment running into hundreds of millions of dollars. In 2015, a consortium led by General Motors invested half a billion dollars in Lyft, a promising start-up in autonomous vehicles,[25] so that these vehicles can achieve what an average human being can achieve in thirty or so driving lessons. Of course, this is a somewhat cynical way of putting it and the argument certainly does not nullify the efforts made by these companies, but it does put the current state of robotics in perspective.

1 This distinction is very similar to the previous discussion on the difference between 'reality' and the 'life world' of an observer or researcher.

From the previous discussion it may have become clear that 'autonomy' is not necessarily a distinctive feature of a certain agent, but it bears a relationship to the environment in which that agent has to perform. This basically follows from two dominant narratives in the scientific community and the popular press. The *techno-positivist* narrative is dominant in the Anglo-American world and tends to consider (robot) intelligence as an *atomic* property of the corresponding material object. Coarsely stated, they think that if one puts enough computer power into a material object the object will become increasingly 'intelligent'.[26]

The second narrative is stronger on Continental Europe. This narrative considers intelligence to be a relationship between an object and its environment. If the environment is complex, it requires more intelligence to cope with this complexity. Conversely, a complex environment also allows more opportunities to train this intelligence, which makes the object smarter. A machine with great capabilities for intelligent behaviour will not reach its full capacity if it gets no proper training and this, of course, not only applies to machines. Proponents of this stance will usually prefer to use the term 'adaptiveness' instead of 'intelligence', as the ability to adapt is considered to be the key property of an intelligent agent. As the latter narrative does not necessarily exclude the former, I will follow this line of reasoning.

As the relational stance of intelligence draws attention to the environment as well as the machine, it may be good to look into the environment in more detail. On one extreme there are stable, predictable environments in which relatively simple robots can adequately perform their tasks, while on the other extreme there are such volatile environments in which only the most rugged agents can survive.
In the middle ground of a practical lifeworld that we inhabit, one can speak of *complex environments*, which *at least* have a number of distinct characteristics. They are:

- *predominantly* ***unknown****: an agent cannot make an exact, complete representation of its surroundings*
- ***np-complete****: the relations between entities in the environment tend to grow exponentially, resulting in a* ***combinatorial explosion*** *of the search space. As a result, an agent is not able to make a best decision by testing all the available options one by one.*
- ***dynamic****: the conditions of the environment may change before the agent has made an appropriate model of its surroundings*
- ***reactive****; the surroundings change due to the actions of an agent*
- ***contingent****: the environment is subject to unexpected events of which the agent has no adequate models*

To summarize the above, the differences between man and machine have to be set against the environments in which these agents have to perform their duties. With this, we can start our deconstruction of the man-machine discussion.

The Rationality of Robots

When considering the issue of machine autonomy, we often hear two stories or narratives that aim to rationalise the need to deploy this technology:

- *To replace people in the work flow, as they are considered to be the weak link in the process. Humans are fallible, expensive and a source of risk to the operations*
- *To reach areas which are hazardous for humans. In the maritime sector, one of the most captivating examples is the prospect of deep sea mining, which captures the famous slogan from Star Trek "To boldly go where no man has gone before"*

I will return to these rationales later on, but first I would like to include a third rationale, which for me was a real eye-opener. This was a realisation by dr. Stephania Giodini from TNO, with whom we have worked quite extensively in recent years. She introduced what I call the 'Stoffel de schildpad' (Stoffel de Turtle) argument, after one of the characters from *De Fabeltjeskrant*, a famous Dutch animation series of the seventies. The father of one of my lifelong friends had appropriately named his robot lawn-mower after this character, as it tended to work its way over the grass in a slow, but determined manner. When we organised a conference on 4 November 2016, with Maurits Huisman and Danny Blind from TNO, on a platform for underwater communication at RDM that Maurits had conceived, I realised that for the application of autonomous robots for maintenance purposes, the continuous, gradual interventions of "Stoffel" robots would be able

- to provide a less invasive means of maintenance than the incidental, tougher interventions that humans often have to carry out.

Figure 4: Platform for Underwater Communications (image from Maurits Huisman, TNO)

This argument is particularly potent when robots are used for inspection and maintenance in vulnerable ecosystems or other environments where small, continuous and gradual interventions are preferable to incidental invasive ones. This type of robot can also be very successful when changing a certain environment to a preferred condition, for instance when a lake that has decreased biodiversity due to human intervention needs to be restored to its original state. The 'Stoffel robots' can take their place in the ecosystem until the desired conditions are reached and the interventions provided by the artificial beings are no longer required. Another interesting area of application can be found in maintenance tasks in enclosed spaces of vessels, such as tanks.

Interestingly enough, the 'Stoffel robots' take a position in-between the two other rationales. On one hand, these robots can exceed human capabilities, not because the environment is potentially off-limits, but because continuous human presence is not an option or it is not desirable. 'Stoffel robots' will therefore most likely replace human interventions in environments that are predictable in the sense that the consequences of intended intervention in such an environment are known in advance. The ‘Stoffel robots’ will have a limited form of autonomy and/or adaptive behaviour, such as navigation, collision avoidance, charting and planning.

The Platform for Underwater Communications as was perceived by TNO has interesting implications for so-called *swarming and platooning* solutions. I will return to this in a later stage.

Man and Machine

Figure 5: Unmanned Port (published with permission from Universal Studios)

The first rationale in the discussion on autonomy is one that receives the most attention. When automation and robotisation become the focus of the public media, this usually revolves around the loss of jobs, the ethics of intelligent man-made machines and the possible threat that robots will become the dominant species on Earth. I will concentrate on the use of robots (and humans) in the workplace and point out some of the differences between a human and a machine.

Human agents are a product of evolutionary adaptation. In the struggle for survival, humans have found a particular niche in which cognitive and artificial adaptations occur at a faster rate than biological adaptation. This is not to say that biological processes are no longer relevant; many of our social structures (hierarchical) can also be seen with other primates, monkeys and other social species.[27] The famous Dutch primatologist Frans de Waal has argued that we, as primates, can be positioned in-between our close relatives, the chimpanzees, and the bonobo apes, and therefore mix extreme aggression with gentler social interactions.[28] At the deepest core of our cognitive centre, the amygdala controls our most elementary impulse, namely the fight, freeze, flight or flock impulses.[15] Even though there are conscious feedback mechanisms that temper the effects of the amygdala, this nervous centre is responsible for the most primitive actions of any higher organism. As a result, human agents are finely tuned to respond strongly to anomalies, experiences that are uncommon, unexpected and rare. Consequently we humans have a paradoxical tendency to strive for regularity and calmness, while our brain gives the best performance when (moderately) challenged by unusual and unexpected events, under influence of the hormones adrenaline and endorphins.[29]

This touches on the issue of robotics. When humans are said to be the 'weak link' in a work process, it usually is the result of repetitive, monotonous labour which is not challenging. Humans in general become distracted, sloppy and distraught under these circumstances, especially when they occur for extended periods in time. At the other extreme, humans tend to become overly stimulated when contingencies and unexpected events become the norm. Only few people, such as fighter pilots, are capable of handling the resulting stress and can do so only for a limited amount of time.

A third distinctive feature of our brain is that it is a relatively slow information processor, especially when compared to a computer. However, the brain can process patterns in a massive parallel fashion, which allows for a very rich contextual 'picture' of certain events. For instance, in their mutual interactions humans can quickly combine instrumental, social and ethical considerations to assess the situation, predict possible outcomes and include past experience. The recent science fiction movie *Arrival* catches this information-rich means of information processing quite aptly, although interestingly enough it also shows that humans have to revert to a more linear, sequential way of communicating, when switching to voice or, to a lesser extent, when writing. As a result, humans tend to perform poorly when tasks are (perceived as being) relatively unimportant, or are of little meaning for the entire process.

This issue touches on many of the popular debates on artificial intelligence (AI) that are currently being waged, for instance in a recent report from the European Parliament.[30] We are told that AI is currently developing at such a fast pace that we need to consider the consequences of robot ethics and other issues that consider the robot as an equal to human beings, or even as a superior being. Often the successes of computers, such as IBM Watson, in playing chess, GO or poker, are introduced into these debates to underline the advances that are currently being made. However, in my view, these examples also demonstrate the biggest weakness of the current state of technology, which is their inability to process entirely different tasks concurrently. Even though humans are also poor multitaskers, we are still superior to these robots. Humans, to some extent, are perfectly capable of playing multiple games with multiple rules simultaneously, and this rich playing field is usually called ‘everyday life’. We drive, communicate, check calendars, work, do the groceries and all this (usually) with apparent ease. If we set this against a large, energy consuming mainframe that is dedicated to one task at a time, or maybe at best a few tasks, then human beings currently still have a significant edge over these computers. Furthermore, we are extremely mobile.

The current state of computers such as Watson is undoubtedly impressive, but they are comparable to a toddler’s mastery of a game of *Memory*; they will beat their parents time and time again because they have the luxury that they can dedicate their time to mastering the game, but we intuitively know that this does not make them superior to a grown-up.

Considering robot ethics—the question of which rights and responsibilities a robot with superior intelligence will have in a future society—I take, as a rule of thumb, the rights of animals as a benchmark. In the Netherlands, we currently have a political party that considers the rights of animals to be an essential part of a civilised society. The ethical position of robots is currently still very much the same as any other machine. If, in the near future, we are considering a political party for robots, then it is time to start worrying about robots and their place in our society.

A last, very important feature of (human) organisms is their ability to repair themselves. When something goes wrong, a carbon-based organism is able to a certain extent to correct mistakes that were made and heal itself when it gets wounded. Repair in this sense is a materialised form of learning; a mistake or unwanted event results in a material response to correct the damage. With the current state of technology we cannot expect this from robots, or at best to a severely limited extent. Besides this, the ability to repair oneself requires energy and other resources to be dedicated to this task. If an organism is considered ‘weaker’ than the robot, it often means that the organism is less efficient in performing a certain task, but the reason for this is usually that the organism was not built for this purpose in the first place and that a significant portion of the energy and resources of that organism are required for self-maintenance and for repairing itself. As a result, a definite strength is portrayed as a weakness, due to a limited, normative perspective on the existence of an organism.

Another pattern amplifies this effect, especially in discussions concerning the human workforce. This pattern concentrates around the notion of *risk*. In many discussions on safety and security, the resulting weight is often defined in terms of risk:

"risk = probability x impact"

A loss with high impact with low probability can therefore be equal to a low impact with a high probability. As we have seen that the probability of loss is strongly tied to the complexity of an environment, this means that an experienced human being operating in such an environment may still embody a higher risk than a robot that performs significantly poorer. The argument that humans are the "weak link" in a work process usually refers to this risk, especially if this has to be covered by life and health insurance or if human loss may be detrimental to the public image of an organisation. Technology push in robotics is currently predominantly targeted at replacing high-risk human presence with robotic replacement of lower risk. This push is also amplified by a social pressure that does not accept human loss. In many ways, we currently live in one of the safest periods in human history, but as a result the loss of a life, especially if it is work related, is not considered to be acceptable, even if the work is known to be hazardous. The 'weak link' argument therefore often does not mean that humans perform poorly, but rather that robots can perform the same tasks adequately, but that the risk of loss is relatively low. This also applies where risks involved in the *consequences* of human error is high. The Exxon Valdez accident in 1986 and more recently the BP oil spill in the Gulf of Mexico provide interesting scenarios for the application of fail-safe robotic alternatives that obviate human error. However, in the latter case, robot error will be subject to the same judgement as human error would.

The Exo-Skeleton

Ever since the Industrial Revolution we have seen a development in which human beings have been fitted with certain kinds of artificial, mechanical suits that make them stronger or faster, or allow them to enter areas that were previously off-limits to human presence. Currently these exoskeletons have many names, such as cranes, trucks, tractors, aeroplanes and rockets and they have become so commonplace that we hardly regard them as such. The current movement in robotics aims to replace the humans in these exoskeletons with artificial or computer intelligence (bio-computing is currently still too limited for practical use) and so the main distinction between man and machine lies in the specific characteristics of computers.

For one, computers at present predominantly require electricity for their energy needs. Especially in the West and most developing countries, we have finely meshed electricity grids, so it is not difficult to access this source of energy.

With recent developments in solar power, the possibilities increase even further. Ongoing improvements in the efficient transformation of electricity into work also provide a perfect ecosystem for robots. The majority of robots are designed to perform one task very well. As with all tools, this does not mean that they are constrained by this, but the degrees of freedom for alternative applications are usually limited. Furthermore, the design of the exoskeletons is usually optimised for a certain environment or task, so similar tasks will have different designs depending on their intended use. A knife used in the kitchen is very different to the scalpel that a surgeon uses. Again this touches on the previous discussion, where we saw that a robot, if it is to be effective, must adapt to a certain environment and intended purpose, just as organisms do.

This immediately begs the question whether there is an artificial design that is extremely adaptive and can mould itself to a wide variety of circumstances. Humans are amongst the most versatile of carbon-based organisms. This begs the question whether there is a 'universal robot' that can outperform humans in this sense. Currently most robots designed with this aim in mind mimic the human form with two arms, two legs and an information processing unit at the top of the shape. There are a number of reasons for doing this.

- *Human beings are the result of millions of years of evolutionary trial and error. This means that there is a good chance that the human form is one of the most optimal designs when it comes to multi-purpose behaviour.*
- *Most robots are meant to perform in human environments, which are designed specifically to facilitate the human form.*
- *Mimicking the human form is a way of increasing the acceptance of robots when they need to interact closely with humans.*

This is not to say that alternative forms are not being tested. In fact, a specific class of robots—*swarm robots*— are, in my view, extremely good candidates for the universal robot.

Swarming and Platooning

Professor Chris Verhoeven, supervisor of the Swarm Theme of the Robotics Institute of Delft University of Technology, is someone who believes that swarm robots are going to be the first robots to enter the public domain.[i] Swarm robots are autonomous robots of relatively limited individual intelligence, but which as a collective display surprisingly complex behaviour. This also stands at the core of Chris's argument that people are likely to accept that the individual robots

i 2014, personal communication

present little danger to them, which makes their presence in public domains less problematic. There is also another reason why swarm robots are good candidates for practical application, which is that robot swarms tend to be very robust, which makes them well suited for complex environments. At present swarming robots are still very much an academic pastime, but we can see them as one extreme possibility on the following scale:

1. *A single human agent or robot*
2. *A few dedicated robots working together with human agents*
3. *A massive collective of robots and human agents*
4. *Pure robot swarms*

The majority of the discussions on robotics have so far concentrated predominantly on the first two scenarios on this scale, but the technology is pushing into scenario three, most notably in the automotive industry. Remember the exoskeleton argumentation? Well, if there is one area where smart exoskeletons are currently being wrapped around human agents it is on our streets and highways!

Despite our own conceptions of our driving skills, most humans are bad drivers. When we are forced to engage with others in a relatively limited, often scarce space, and the interactions with others are predominantly contrary to our own goals to travel from A to B as fast as possible, we fall prone to a tendency to claim our own space without regard to the consequences for others. In game theory this is often observed as a problem where individual gain impairs collective gain, and *vice versa*.[31, 32] On the road we often see this problem occur when there is quite a lot of traffic. Theoretically speaking, this should not have to lead to any congestion, provided that everybody travels at *exactly* the same speed. Since this is not the case in practical situations, this means that some stretches of road will get cluttered with cars, while other parts of the road remain empty. If one suddenly applies one's breaks, this will create a cascade effect of other drivers applying their brakes, often a bit harder than the cars before them, which results in all cars stopping a few hundred metres behind the original event. A traffic jam is born!

This problem is exacerbated by the phenomenon that on a busy road people tend to stick to the left lanes (or the right lanes in the UK and some other countries), resulting in large stretches of unused road in the right lanes, which in turn increases the chance of congestion. Most drivers also do not care too much about merging, which gives the drivers who *do* select the right lanes ever less incentive to do so. As we humans therefore tend to use available, scarce space inefficiently, there is a strong tendency to let technology make the correct decisions for us. It is a matter of time before our cars will be forced to slow down to a predetermined fixed speed when there is congestion. This is technologically feasible, and will result in a much more efficient use of the roads and highways. It will also reduce the probability of traffic jams, which will provide a considerable economic advantage. This technology will therefore create the first massive swarm robots in the public domain. People will gradually lose their responsibility as drivers and become passengers in their own cars. As the technology advances, the cars will evolve into luxury cabins where people can enjoy leisure activities or work, while the coaches take them to their destination. This development is currently already underway and is a realistic scenario for the near future.[31]

The development of swarm robots in the public domain, in my view, will follow the scale that I introduced above. The first swarms will consist of a mix of human and technological agents, of which the former will usually command the swarm, if only because current rules and regulations require a human agent for reasons of legal responsibility. This is particularly the case in maritime environments, where human agents, who can be held liable if anything goes wrong, are required to be on board a vessel. On the basis of current developments in the automotive industry, it is only a matter of time before a serious accident happens involving an autonomous vehicle, which will spur on the development of case law on legal liability.

> *Considering the current legal situation, it is not unthinkable that software engineers will be held liable for accidents, as the robot was 'merely carrying out what the designers had programmed it to do'.*[30]

It is likely that in the future vessels will increasingly take over technology that has already been implemented in aeroplanes, such as the automatic pilot and fly-by-wire technology.

One consequence of this gradual transfer of human control to machine control is that humans will continuously need to perform different tasks as the technology advances. Instead of applying the brakes and operating switching gear, at present we often already rely on the buttons of the cruise control. Interventions will decrease even more as technology takes over and cars are switched to 'auto pilot'. However, this also means that humans will increasingly be invited to engage in other kinds of activity. The result will be that it will take some time to get the driver back in her seat and to be fully prepared for the situation that caused the event when action is required. The technology that is gradually replacing human control, will therefore need to be augmented with sufficient predictive capabilities to signal the human in time for an impeding event that requires human intervention. For this reason, paradoxically enough, the transition to fully autonomous vehicles, vessels and (other) drones is going to require quite some effort in relation to the human factor.

One of the first applications of these combined man-machine swarms is currently being tested in the automotive industry, namely *platooning* applications. In 2015 a number of successful tests were carried out on Dutch public roads with a line-up of trucks, of which the first truck was driven by a human chauffeur, while the other unmanned vehicles drove behind it like an Australian road train, but then disconnected.[33] In a platooning line-up, a swarm is controlled by a (human) master agent, while the others—the robots—support the main task. This scenario is also often envisioned for inland shipping, but I do not see this happening very soon as most barges are operated by small family businesses with very little incentive to adapt to a line-up. Besides this, there already is a very successful equivalent, namely the push barge.

At the Rotterdam University of Applied Science we used this idea for a project with Rijkswaterstaat (part of the Dutch Ministry of Infrastructure and the Environment) to measure the depth of the Dutch waterways. Currently every year the main waterways have to be checked to ensure that they are still deep enough for barges. A small vessel with a very accurate multi-beam ultrasonic sensor is used for this type of inspection. These inspection vessels are usually small motorboats, and due to the fact that the sensor can only measure a small portion of the width of the waterway, the boat needs to zig-zag along the width of the river for every mile or so that is inspected. An inspection of a certain stretch of river typically requires five sweeps, and as a result, a waterway such as the 90 kilometre long IJssel river, requires a 450 km inspection run. At RUAS we developed the idea of a platooning line-up, where the master vessel was flanked by two or four unmanned boats—Aquabots—which were also equipped with relatively cheap and less accurate depth sensors. The rational for this choice was that cheap sensors can often make a very accurate *relative* measurement. With one accurate reference, one can easily make corrections for the inaccuracy. Furthermore the accuracy of the current sensor was not really necessary for the task at hand. A tolerance of one millimetre is not very important when centimetres of soil are swept over the bottom at any given moment due to the current and the boat itself. A solution involving platooning would reduce five sweeps to two or three and would result in an immediate cost reduction of this type of inspection by 40 to 60 percent. The project was carried out with students over the course of two years, with two demonstrations in the IJssel river. Sadly the project had to be discontinued due to the difficulty of obtaining adequate funding.

Figure 6: Demonstration of Aquabots in a platooning line-up

The platooning line-up envisioned above was only one step in the direction of a full swarm solution, where 'artificial jellyfish' as we called them would carry out the inspection as a swarm. They would have been thrown in the river upstream, and would have followed the current over a number of weeks, measuring the full width of the waterway as they moved along. They would have been able to communicate their distance from each other and would have been able to detect and evade obstacles, such as passing vessels. If one or two were to have broken down or to have become entangled, it would have been a minor problem, as long as the swarm had had enough jellyfish to complete the survey. Once they reached the end of the inspection, they would collect at a single spot, so that they could be reused.

Figure 7: Artificial jellyfish (photograph by Christian Charisius/Reuters with permission)

Currently robot swarms usually consist of exactly the same robots, which are programmed to perform the same tasks and achieve a common shared goal. This type of swarming solution has been proposed for a project in *automated evasive manoeuvring*, where vessels in a shipping lane try to stay clear of each other in an efficient manner.[34] In the proposal this technology is presented as an additional aid to the helmsman, but the aim is eventually to apply this technology to unmanned systems. This demonstrates that in practice there are gradations between fully manned and unmanned systems.

There is an interesting design of swarming solutions where the robots carry out *different* tasks and the individual designs vary. In this configuration only the common goal is mutually shared. The mixed configuration, with human and machines, is obviously an example of such a swarm. In the next section, I will return to a more elaborate example which involves demersal fishing.

A Deconstruction of Vessels

We can now home in on a specific class of robots, namely unmanned vessels. This is not to say that the line of reasoning I will pursue here does not apply to vehicles or airborne drones, but I will concentrate on vessels, as this is the main type of robot that we have been focusing on in Rotterdam over the past four years.

In line with my reasoning so far, we will deconstruct a vessel into a number of functional units that are concentrated in a confined space. These functional units have become so tightly knit, mainly for historical reasons, and they are often so self-evident, that most people have learned to see a vessel (or another exoskeleton) as an indivisible unit. However, when one looks at the possible *functions* that a vessel has, one can quickly discern the following:

- *a transport function*
- *a carrier function*
- *a hospitality function, i.e. hosting people on board*
- *dedicated tasks (most notably in the case of highly specialised vessels, such as barges, cutters, hoppers and fishing vessels)*

When considering the issue of autonomous vessels, this discussion basically needs to be broken down into the various functions that a vessel (or another exoskeleton) has. For instance, the current developments in unmanned shipping mainly concern the transport function of a cargo vessel, which is clearly the main function of this type of vessel. Autonomy would adversely affect the hospitality function of a vessel, since the main aim would be to remove human presence from the vessels, at least on the long stretches over the oceans. The carrier function typically requires most effort during the loading and unloading of the cargo (containers), which also requires the majority of dedicated tasks. An analysis of the development of autonomous cargo vessels may therefore be quite simple. If one considers the typical timeline of this particular form of transport, the complexity of the tasks and complexity in the environment is mainly concentrated around the time that these ships are in coastal waters and loading and unloading containers. This is (ideally) a relatively short period of time, in comparison to the time these vessels are in open waters. Aside from an occasional tropical cyclone or hurricane, the oceans are fairly stable environments for *this type of vessels*, the task at hand is fairly simple and technologically feasible. If one takes into account the fact that the absence of human presence reduces the risks relating to this kind of transport, it is therefore fairly safe to assume that the development of unmanned cargo vessels is going to happen in the near future, once the rules and regulations of the international agencies, such as the IMO, have embraced these developments.[33]

This does *not* mean that these vessels are going to be fully unmanned. The relatively short periods near the coastal regions and in the national waterways are of such complexity that human presence is going to be required for at least a number of decades. This is partially due to physical constraints, but also to social and regulatory factors. As a result, one of the scenarios that one could envision is the instalment of hop-on captains, employees of the ship owners who live near the ports and are brought on board the vessels once they approach the coast or are outbound to the sea.

> *With respect to ocean-going cargo vessels, we can therefore see that autonomy:*
> - *is technologically feasible;*
> - *significantly reduces the risks of human loss or failure;*
> - *has benefits that extend across a significant part of the time travelled;*
> - *allows for significant construction savings due to the reduction in the hospitality function of a ship, leading to a more efficient design of the main transport function.*

We can therefore conclude that this development is going to accelerate in the coming years, due to technology push and commercial interest.

The Near Future of Demersal Fishing

A more complex issue involves the near future of demersal fishing. In 2015 I was asked to attend a number of brainstorm sessions on the future of demersal fishing on the North Sea. These sessions were organised by Jules Dock, one of our partners at RDM Rotterdam, at the request of the Dutch Ministry of Economic Affairs.[36] The Netherlands still has a significant stake in North Sea fishing, but it is becoming increasingly difficult to maintain a fleet, due to overfishing, regulations and otherwise. The Dutch fishing fleet is on the decline, which not only affects the fishermen, but also the industry that processes and sells fish, and the local harbours along the coast that have a significant tourist appeal.

In the two brainstorm sessions that Jules Dock organised at RDM, I was reintroduced to an industry that I had not been part of since my internship in the fishing port of Harlingen in 1986. The group consisted of fishermen, fleet owners, equipment suppliers and various research institutes, all with direct or indirect stakes in the future of demersal fishing. For me, one of the big eye-openers of these sessions was to learn how much innovation there had been in netting. Fishing vessels are able to control the flow of fish in the net by the size of the holes in the grid at various locations in the net. This way small or young fish, or some forms of bycatch can leave the net before they get squashed by the bulk of the catch.

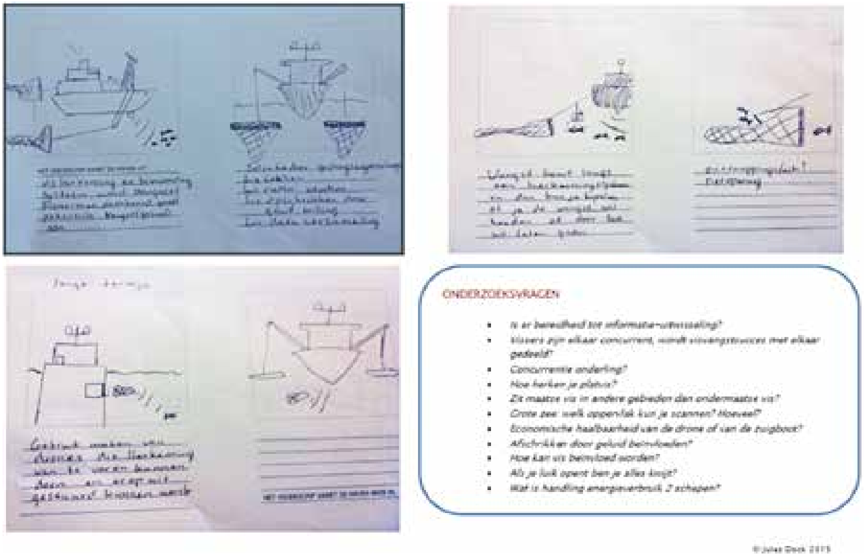


Figure 8: Mind-map of the brainstorm session demersal fishing

A fishing boat differs significantly from a cargo transport vessel, in the sense that the 'dedicated task', namely fishing, is the primary function and that the other functions are subordinate to this. For various reasons—most notably cultural—unmanned demersal fishing is highly unlikely in the coming years, which means that the hospitality function will remain an important part of the overall design of the ships that are used. However, the current designs also predominantly stem from historical traditions and combine various functions in one concrete vessel. As a result, the ships' design is often optimised for one function—usually the carrier function—and the necessity of the other functions affect each other. For example, the typical situation with regard to a fishing vessel is that it starts with an empty hold and carries out a survey of a stretch of water for hours to days until a shoal of fish is found. Ships that focus on bottom-dwelling fish such as halibut will travel to a predefined location, throw out their nets and start fishing by trial and error. This means that this phase of the fishing process is time consuming and fuel intensive, as the weight of the nets are continuously in friction with the water. Some ship owners currently implement a functional decomposition where a number of fishing vessels and one or two large vessels that mainly serve as a factory ship to process and store the fish. This construction is often used with ocean-going vessels. The fishing ships can save fuel by concentrating on their main function, while the processing ships can concentrate on the other functions.

As the nets fill up with fish, there is a continuous friction between the desired catch and the bycatch. As was mentioned earlier, the design of the nets may influence this process, but as the actual fishing is a process that cannot be stopped once it has started, there is only so much that can be done. As a result, the nets will still contain a significant amount of bycatch, which will have to be removed or taken back to land for further processing. Some bycatch can still be sold, but if this includes endangered species or young fish, the ramifications can be quite considerable. Bycatch that is brought on board is usually severely wounded or dead, so the chance of survival after it has been thrown back into sea is fairly low. Young fish are quickly plucked up by seagulls which forage in the wake of the vessel, while larger fish and mammals sink to the bottom and will probably die soon afterwards.

One of the ideas that we came up with, and which I personally really liked, was based on a platooning solution, where the fishing vessel was flanked and fronted by a number of small underwater drones (AUVs), whose main aim was to prevent bycatch from getting into the nets. The noise of a fishing ship often elicits an instinctive response from the fish. As different fish have different responses, we could use this fact to steer bycatch away from the trawlers and funnel the desired catch towards them. Often the sound of the motor and the pressure waves of the oncoming ship will ignite a response which, like all other creatures, boils down to fight, flight, freeze or flock. As a result, some species of fish move away from the ship, others move towards it, while yet others remain where they are. If the hunter AUV's could use these responses to guide fish to or bycatch away from the oncoming fishing boat, a first selection could be made before the fish enter the nets. This would reduce the amount of bycatch that gets injured. It would also save energy because the vessel would not have to drag the bycatch along with it. A similar approach could be applied around the net(s), where hunter AUVs could support the netting in guiding the desired catch into the net. However, if we are going to break down a traditional fishing vessel into its various functional parts, we might as well tackle the transport function, the hospitality function and the carrier function as well. As was mentioned earlier, some of these ideas are already being implemented, but the idea of a platoon that consists of hunter AUVs, a netting vessel that would automatically plug itself into a carrier vessel, while the crew would assemble on a floating hotel in the evening to discuss the catch with colleagues from other vessels in the vicinity, was a radical new way of conceiving the future of demersal fishing. The success or failure of these visions are predominantly a matter of economics and cultural acceptance. The current state of technology can support this vision, the circumstances of demersal fishing are such that the environment would accept such an approach and the potential benefits comply with many rules and regulations which at present weigh heavily on the industry.

Predicting the Applicability of Maritime Robots

In the previous sections I have introduced a way to deconstruct the discussion of the application of robots. The various perspectives that I used for this decomposition are summarised below:

1. Agents and their environments:
   a. Intelligence 'by design' versus autonomy/adaptivity
   b. Atomic intelligence versus relational intelligence
   c. The complexity of the environment; predictable versus complex
2. Rationality of robots:
   a. Reduction in the risks involved
   b. Extending human capabilities
   c. Small and gradual interventions
3. Man and Machine:
   a. Organism versus machine
   b. Risk
4. Functional deconstruction

I have argued that in order to assess the applicability of a robot or unmanned system, a functional deconstruction is needed, as many (human) activities consist of a set of functions that are all needed to perform a certain task. For each of these functions one can ask the following questions:

- Are the tasks required currently carried out by humans or is the function currently not possible?
- Is the environment in which the activities take place stable / predictable or complex, or can the environment be *made* stable?
- If the environment is predictable, can technology be designed to operate safely in that environment?
- If the environment is complex, can a robot learn to deal with that complexity?
- If the environment is complex and currently beyond human capabilities, is an exoskeleton a viable option?

Following this line of reasoning, the environment in which the agent will have to perform its tasks is a good predictor of an unmanned system. A *stable* environment does not suffer overly from the five characteristics of a complex environment in the sense that the technology can be designed to cope with this. The following table may assist in predicting what kind of agent is best equipped for a certain function.

Function:	**............**				
Environment	Stable		Complex		
Rationale	Replace Humans	Gradual Interventions	Limited Complexity	Within Human Capabilities	Extend Human Capabilities
Approach	Intelligence by Design	Autonomous / Adaptive Systems		Risk Reduction	Exoskeleton
Agent	**Machines**	**Robots**		**Humans**	

Table 1: Type of agent in relation to the complexity of the environment

For complex tasks or environments, human presence is likely to remain necessary in the coming years, but technology will advance in order to reduce the risks involved. Of course, the table is only indicative as a measure of the applicability of man or machine for a given function, but hopefully it will give some insight into this topic, especially for policymakers and potential end users of this technology.

Conclusion

In this essay I have covered a large number of topics relating to unmanned systems and robot technology. Most of these topics set markers on a scale of current developments relating to unmanned systems. The scales are summarised below:

- Environment: predictable/controllable versus unpredictable / complex
- Robot intelligence: pre-programmed versus ‘truly’ autonomous / adaptive
- Rationale: replacement of humans, extending human capabilities or allowing small, gradual interventions
- Risk: the consequences of human versus machine failure
- Man or machine: The exo-skeleton
- Swarming and platooning
- Functional decomposition: the various functions that are combined in one vessel

Humans and machines take up positions along these axes, based on technological feasibility and human possibilities. I have argued that this can often be expressed as a (relative) measure of risk. The near future of unmanned vessels will very much be determined by the assessment of this risk, with respect to their intended functions. Despite the hype, I strongly believe that human flexibility still will allow humans to outperform robots in many real life circumstances in the coming two decades. However, autonomous technology will change the way that tasks are currently carried out and sometimes this may even make human presence obsolete. The biggest threat of automation and robotisation is not in places where manual tasks are required. Rather it will be found in office functions.
As a result, the near future of vessels will still be very much as we know it today. However, between the barges, the trawlers and the coasters, small vessels and AUVs will increasingly swarm to monitor and inspect the infrastructure and guide the larger vessels in performing their intended tasks.

This essay has provided a view on the current developments in unmanned systems and robotics that tries to steer clear of hypes and hopes. In fact, this rather down to earth position couldn’t have been voiced more clearly in a recent Article in the Dutch newspaper *de Volkskrant* of March 25th 2017, in an interview with Greg Corrado, co-founder of Google Brain, the division of Google dedicated to machine learning.[37] When he was asked about the current developments in machine learning, and what the public could expect in the near future, his answer was that we could expect machines to become ‘less stupid’. I think that this view quite aptly captures my own on the near future of unmanned systems.

Literature

1. Rotterdam opens first phase of €3 billion Maasvlakte 2 project. *Port Technology* (2015).
2. APMT Maasvlakte 2 officially opened. *Port of Rotterdam* (2015).
3. Reynolds, M. Rolls-Royce unveils concept fleet of self-driving drone ships - and it could launch by 2020. *Wired Magazine* (2016).
4. Verschuur Jackson, K. Tugging for the Future. in *Proceedings of the second International Plugboat Conference* (2015).
5. Schultz van Haegen, M. & Sonneveld, J. Robots in de Openbare Ruimte. *Lichtkogel* (2016).
6. Cilliers, P. *Complexity and Postmodernism: Understanding Complex Systems.* (Routledge, 1998).
7. Atlan, H. *Enlightenment to Enlightenment: Intercritique of Science and Myth.* (State University of New York Press, 1993).
8. Schon, D. A. *The Reflective Practitioner: How Professionals Think In Action.* (Basic Books, 1984).
9. Fay, B. *Contemporary Philosophy of Social Science: A Multicultural Approach.* (Wiley-Blackwell, 1996).
10. Hacking, I. *The Social Construction of What?* (Harvard University Press, 2000).
11. Feyerabend, P. *Against Method.* (Verso, 1993).
12. Simon, H. A. *The Sciences of the Artificial - 3rd Edition.* (The MIT Press, 1996).
13. Taylor, C. *Sources of the Self: The Making of the Modern Identity.* (Harvard University Press, 1992).
14. Pieters, C. P. Donald Schon en John Holland: over toegepast onderzoek in drassige gronden. *J. Humanist. Stud.* **2016**, 77–90 (2016).
15. Edelman, G. M. & Tononi, G. *Consciousness: How Matter Becomes Imagination.* (Allen Lane, 2000).
16. Hawkins, J. & Blakeslee, S. *On Intelligence.* (Holt Paperbacks, 2005).
17. Donald, M. *A Mind So Rare: The Evolution of Human Consciousness.* (W.W. Norton & Co., 2002).
18. Alexander, C. *A Pattern Language: Towns, Buildings, Construction.* (Oxford University Press, USA, 1977).
19. Gamma, E., Helm, R., Johnson, R. & Vlissides, J. M. *Design Patterns: Elements of Reusable Object-Oriented Software.* (Addison-Wesley Professional, 1994).
20. Wittgenstein, L. *Philosophical Investigations.* (Prentice Hall, 1973).

21. Cilliers, P. Knowledge, limits and boundaries. *Futures* **37**, 605–613 (2005).
22. Cilliers, P. Boundaries, Hierarchies and Networks in Complex Systems. *Int. J. Innov. Manag. IJIM* **5**, 135–147 (2001).
23. Pieters, C. P. *Into Complexity: A Pattern-oriented Approach to Stakeholder Communications.* (Dissertation.Com, 2010).
24. Pieters, C. P. in *Computational Intelligence in Optimization-Applications and Implementations* **7**, (Springer, 2010).
25. Solomon, B. GM Invests $500 Million In Lyft For Self-Driving Car Race With Uber, Tesla And Google. *Forbes* (2016).
26. Weinberg, G. M. *An Introduction to General Systems Thinking.* (Dorset House Publishing Company, Incorporated, 2001).
27. de Waal, F. de. *Primates and Philosophers: How Morality Evolved.* (Princeton University Press, 2006).
28. de Waal, F. D. *Our Inner Ape: The Best and Worst of Human Nature.* (Granta Books, 2005).
29. Damasio, A. *Looking for Spinoza: Joy, Sorrow, and the Feeling Brain.* (Mariner Books, 2003).
30. Delvaux, M. *DRAFT REPORT with recommendations to the Commission on Civil Law Rules on Robotics.* 22 (Committee on Legal Affairs, 2016).
31. Axelrod, R. *The Evolution of Cooperation: Revised Edition.* (Basic Books, 2006).
32. Luce, R. D. & Raiffa, H. *Games and Decisions: Introduction and Critical Survey.* (Dover Publications, 1989).
33. Zwijnenberg, H., Janssen, R., Blankers, I. & de Kruijff, J. *TRUCK PLATOONING DRIVING THE FUTURE OF TRANSPORTATION.* (TNO, 2015).
34. Pieters, C. P. *Application of Swarming Algorithms for Evasive Manoeuvring Toepassing van zwerm algoritmen in het ontwijken van tegenliggers voor slim en veilig varen.* (Nederland Maritiem Land, 2016).
35. Visser, R., de Vleesschouwer, S. & Zeijlstra, M. Blauwdruk 2050, de maritieme wereld voorbij de horizon. *Stichting ondersteuningsfonds NISS 100 Jaar* (2016).
36. de Lange, J. & Verwayen, E. *INNOVATIEBIJEENKOMSTEN SELECTIVITEIT IN DE DEMERSALE VISSERIJ;ONTWIKKELING VAN SLIMME VISTECHNIEKEN.* (Jules Dock Consultancy B.V., 2015).
37. Keulemans, M. Kunstmatige intelligentie gaat uw leven veranderen, en deze man speelt daarin een sleutelrol - Economie - Voor nieuws, achtergronden en columns. *De Volkskrant* (2017).

Overview publications

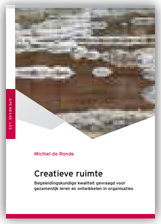
Hogeschool Rotterdam Uitgeverij

Een goed begin is het halve werk

Auteur	Hanneke Harmsen van der Vliet - Torij
ISBN	9789051799521
Verschijningsdatum	maart 2017
Aantal pagina's	132
Prijs	€ 14,95

Professionele identiteit

Auteur	Martin Reekers
ISBN	9789051799514
Verschijningsdatum	maart 2017
Aantal pagina's	54
Prijs	€ 14,95

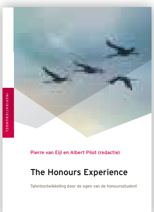


Creatieve Ruimte

Auteur	Michiel de Ronde
ISBN	9051799373
Verschijningsdatum	juni 2016
Aantal pagina's	96
Prijs	€ 14,95

Ongebaande paden

Auteur	Paul van der Aa
ISBN	9789051799385
Verschijningsdatum	juni 2016
Aantal pagina's	86
Prijs	€ 14,95

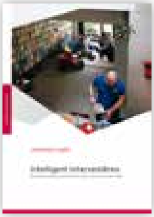


The Honours experience

Auteurs	Pierre van Eijl, Albert Pilot (redactie)
ISBN	9789051799361
Verschijningsdatum	mei 2016
Aantal pagina's	272
Prijs	€ 26,95

Design in een genetwerkte ecologie

Auteur	Anne Nigten
ISBN	9051799330
Verschijningsdatum	april 2016
Aantal pagina's	54
Prijs	€ 14,95



Intelligent interveniëren

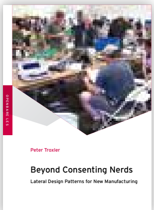
Auteur	Josephine Lappia
ISBN	9789036540094
Verschijningsdatum	december 2015
Aantal pagina's	319
Prijs	€ 28,95

Veranderstad

Auteur	Gert-Joost Peek
ISBN	9051799217
Verschijningsdatum	november 2015
Aantal pagina's	108
Prijs	€ 14,95

Informatierevolutie in de delta

Auteur	Kees Pieters
ISBN	9051799225
Verschijningsdatum	november 2015
Aantal pagina's	80
Prijs	€ 14,95



Beyond Consenting Nerds

Auteur	Peter Troxler
ISBN	9051799233
Verschijningsdatum	november 2015
Aantal pagina's	104
Prijs	€ 14,95

Zorgtechnologie: dwarsliggers voor de zorg

Auteur	Linda Wauben
ISBN	9051799195
Verschijningsdatum	november 2015
Aantal pagina's	72
Prijs	€ 14,95

Exemplaren zijn bestelbaar via www.hr.nl/onderzoek/publicaties. Hier zijn ook eerder verschenen uitgaven van Hogeschool Rotterdam Uitgeverij beschikbaar.

Kees Pieters

The Near Future of Unmanned Vessels

A Complexity-Informed Perspective

ISBN 90-5179-953-5
9 789051 799538

In this essay, Kees Pieters presents his view on the current developments of unmanned systems and maritime robots. Based on his experiences in Rotterdam, and collaboration in various initiatives regarding unmanned vessels, he offers a pragmatic view that tries to see beyond the hypes and hopes of autonomous systems, and argues why humans still play an important role in this near future of robot technology.

In the past four years, Kees Pieters has been at the forefront of new innovations In the maritime industry, as research professor at Research Centre Sustainable PortCity. With a background in electrotechnical engineering, computer science and artificial intelligence, Pieters understands the technological capabilities and limitations of this new technology, but his Ph D research in Humanistics on complex systems and complexity thinking has been vital in looking beyond the hypes, and see the societal impact of robotics and machine learning.

His central thesis is that the complexity of the environment is paramount in understanding whether technology can replace or augment human presence, as technology will be subject to the same criteria as any organism in practical situations. By assessing the strengths and weaknesses of both technology and (human) organisms, he develops a balanced view on this very topical development in the maritime industry.

ESSAY

applied **research**

Hogeschool Rotterdam Uitgeverij

ROTTERDAM UNIVERSITY
UNIVERSITY OF APPLIED SCIENCES