Automatic berthing

Rotterdam Mainport University of Applied Sciences

Maritime officers

Project Group 6

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1. Preface

This report was made by students of the Rotterdam Mainport University, second year maritime officer. We did research for several weeks and our findings can be found in this report. After doing extensive desk research and also conducting interviews with experts, we have come up with solutions to the problem.

We have learned a lot from this project. Not only about the topic itself, but also on planning and executing such a large project. There have been some ups and down along the way, but we consider this as learning moments for the future.

We would like to thank Mr. P.C. van Kluijven, for guiding us through the project.

Furthermore, we also would like to thank Mr. S. Sprong, Mr. M.P. Bakker, Mr. E. Fiktorie and Mr. W. van den Burgh for letting us conduct an interview with them and providing us with a lot of relevant information.

Rotterdam, April 17, 2017

Project Group 6

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2. Management review

This report will discuss how berthing and pilotage operations in the shipping industry can be made more safe and efficient by introducing unmanned automated systems. To understand which problems might arise when applying conventional berthing methods, one must know how it works. Thereafter, solutions have been found to completely delete these problems.

Qualitative desk research has been the main method of researching on what the conventional way of berthing is. This way uses mooring lines which are secured by shore men on a bollard. Different types of mooring lines are used in the shipping industry: High Module Polyethylene, Polyamide, Polyester and steel cables. Winches are used to hoist, hold or slacken the mooring lines. The conventional berthing process is not very efficient. Firstly, it is a time-consuming event, which inevitably costs money. Secondly, many accidents still happen during the process. Shore men who secure lines are in danger, for example when lines brake and there is always a chance of falling in the water. Lastly, there are financial disadvantages, such as paying shore men, tugs and the ship has to keep her engines running.

By making the berthing process automatic, these disadvantages could be eliminated as well as the human factor, which causes the most incidents. The berthing process has been split up into two factors. Getting alongside the quay, with help of sensors and propelling systems, and pilotage.

Without the help of crew, a ship needs extra eyes to make sure she gets alongside the quay safely. By doing extensive desk research, several types of sensors that can be applied on the vessel have been found. With use of ultrasonic sensors, distances to certain objects can be measured. A transmitter sends out an impulse, which is reverberated by an object. The time between transmitting and receiving says something about the distance. With use of LiDAR scanners, a 3D map can be created of the surroundings. The technique is the same of that of Radar, but LiDAR uses light. By creating a 3D image, a computer can assess the situation and determine what the best manoeuvre is, to get the vessel to her berth.

Not only sensors have to be used to let the ship berth automatically, the vessel must have the right propelling systems in order to make manoeuvres. With use of a Dynamic Positioning system and the sensors as discussed before, it is possible for the vessel to make her own decisions as to what the best manoeuvre is. Nevertheless, with only the use of an internal combustion engine and bow thrusters, it will be very hard. After doing desk research, it can be concluded which systems are best applicable. An all-electric ship with azimuth thrusters, a ship with conventional propelling system and jet thrusters, or a ship with jet propulsion and thrusters.

Another part of the automatic berthing, is not having a pilot on board at all. One way to achieve this, is by using shore-based pilotage. Here, the pilot will give advice to the vessel, but is actually not on board. Nevertheless, SBP is not always used, there are some disadvantages such as
communication, visual awareness of the surroundings and navigational competence. Shore based pilotage could be improved with help of drones, as this will increase the visual awareness of the pilot.

It can be concluded that it is possible to let a ship berth automatically. With use of ultrasonic and LiDAR sensors and the right propulsion system, it is possible to let the vessel make her own and best manoeuvres as to get to her berth safely. When considering pilotage in the overall process, shore-based pilotage with help of drones could be used.
3. Introduction

Problem description

Even the best and most experienced sailors make mistakes. One tiny mistake can lead to huge costs or even injured persons. Especially during the berthing process of the ship, many accidents happen. There have been reports of people losing fingers, falling in the water or even fatal accidents have happened. Even though there already are systems which do not require the use of ropes, the main cause of berthing accidents is due to the human factor. This project will look into automating the berthing of a ship. Automated vehicles have been around for some time now, so this should also be able to be applied on vessels. The same accounts for pilotage. The pilot has to come on board with use of mostly just a basic ladder which can also be dangerous. Both the berthing and pilotage also require a lot of time, manpower and therefore money. Basically, berthing and pilotage are a problem in modern day shipping both safety and moneywise.

Problem definition

The conventional ways of the berthing and pilotage process are dangerous and inefficient.

Objective

The objective of this project is to create methods of safe and efficient berthing and pilotage operations by introducing automated unmanned systems.

Project assignment

Main question: How can berthing and pilotage operations be made safe and efficient by introducing automated unmanned systems?

Sub questions:

- What are the conventional ways of berthing a ship?
- Which methods of automation are applicable for berthing and pilotage operations?
- What type of machinery is required for automatic berthing and pilotage operations?
- How can drones be utilized in the overall berthing process?

Research methods

The first question has been answered through extensive qualitative desk research. This means information was found in articles on the internet and in books. Also, an interview had been conducted with several field experts.

The second sub question was answered through desk research. The desk research consisted of finding several articles on the internet and in books.

The third sub question has been answered through thorough desk and field research. The qualitative part of the research consisted of finding out what type of machinery is used and how they work. Then a comparison was made between several systems and concluded which systems were more applicable.
The fourth sub question has been answered with help of desk and field research. Again the desk research consisted of articles found in books and on the internet. The field research consisted of several interviews with Dronology and a pilot.

Project boundaries

This project will look deeper into the following topics:

- Berthing, and how this process can be made fully automatic

- Pilotage, and how the human factor can be erased

We will not build any type of ship on our own. Neither will we build and create any machines, sensors and programs.
4. The conventional ways of berthing a ship

Mooring lines are used to keep a vessel in its place alongside a quay so she can be loaded or discharged. Most people are not aware of the fact that a whole operation has to take place when berthing a ship. In this chapter the conventional ways of berthing a ship will be discussed as well as the dangers these conventional ways bring forward. Also, newer methods of berthing will be discussed which could be applied.

4.1 The conventional ways

4.1.1 Mooring equipment

In order to understand the procedures of mooring a ship, one must understand which equipment is used and the function of it.

Mooring lines or hawsers are still used to keep a vessel alongside a quay or jetty. For centuries this has been the only way to keep a vessel on its berth. Different types of mooring lines are used depending on the function of the vessel and the size, i.e. bigger vessels need larger and stronger lines.

Different types of material are used for mooring lines. On seagoing vessels either steel wire or synthetic fibres are used whereas manila rope practically is not used anymore. The size and function of the vessel play a role in the choice of mooring lines.

(Dokkum, 2013) Synthetic fibres can have different properties:

- The density of the rope will determine if it sinks or stays afloat.
- The elasticity of the rope cannot be too big, but has to be big enough to be able to compensate for any dynamic forces on the ship.

The different synthetic mooring lines can be narrowed down to the following:

**High Module Polyethylene**
On a weight basis, the high-grade cables are five times stronger than steel cables and are also very stiff, it hardly creeps and is fire resistant. Other advantages are its lightweight, easy handling and small backlash. However, the cable has a low heat-resistance and the price of HMPE is way higher than steel cables.

**Polyamide**
Also known as Nylon will sink in water and will also absorb water—adding weight to the rope. The sinking might form a problem as the rope could get entangled with a propeller. The absorbed water will reduce the MBF (Minimum Breaking Force, which is the force required to make equipment fail) by 20%. Polyamide mooring lines also have a large elasticity, which can result in a large backlash, which can be dangerous. The material does have a high heat-resistance, a low elongation and excellent strength-to-weight ratio.

**Polyester**
The mechanical characteristics resemble that of nylon rope, but it is more resistant to water. The density of Polyester is relatively high, but the absorbing capacity is higher than that of Polyamide
lines. This will make it more suitable to absorb large force variation. Also, it is very durable in both wet and dry conditions, which makes it quite expensive.

**Steel cables**

Steel cables are used where the circumstances allow or demand it, such as mooring wires for tankers and bulk carriers, towing wires for fishing and tugboats. The cable is strong, cheap, has little elongation under tension and has a high wear resistance. The disadvantages of steel cable are that they are heavy and will suffer from corrosion.

A brief overview of the different cables:

<table>
<thead>
<tr>
<th>Type</th>
<th>Characteristics</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>HMPE</td>
<td>- High strength-to-weight ratio</td>
<td>US$ 35 / Kg</td>
</tr>
<tr>
<td></td>
<td>- Hardly creeps</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Easy handling</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Small backlash</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Low heat resistance</td>
<td></td>
</tr>
<tr>
<td>Polyamide</td>
<td>- Water absorption causes strength reduction</td>
<td>US$ 4.8 / Kg</td>
</tr>
<tr>
<td></td>
<td>- High heat-resistance</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Low elongation</td>
<td></td>
</tr>
<tr>
<td>Polyester</td>
<td>- Keeps strength when wet</td>
<td>US$ 2.6 / Kg</td>
</tr>
<tr>
<td></td>
<td>- High absorbing capacity</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Moderate elongation</td>
<td></td>
</tr>
<tr>
<td>Steel cable</td>
<td>- Strong</td>
<td>Between US$0.1 and US$1.00 per feet.</td>
</tr>
<tr>
<td></td>
<td>- Cheap</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Heavy</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Rust</td>
<td></td>
</tr>
</tbody>
</table>

4.1.2 **Winches**

Winches are used to exert a force on a mooring line when human strength fails. Especially on larger vessels where mooring lines are very heavy, winches are used. The winch basically has three functions: heave or hoist, holding and capping, and slackening. Hoisting requires most of the power.

When steam engines were still running, the winches were driven by a smaller steam engine. Where tankers still used this method, as it was sparkless so safe to use, other merchant vessels used a diesel engine to drive the winches. Nowadays, winches are powered electrically, hydraulically or pneumatically. (Smit, 1997)

**Electric winches**

Electric winches use an electromotor as a power source. The electric winch has the advantage that it is quite easy to use and can be operated from the bridge if necessary. Besides, electric winches do not require much maintenance and the noise from the motor is limited which is of importance on passenger vessels.
Hydraulic winches

The winch is driven by a hydraulic motor, which is connected to a hydraulic pump system located below deck. The motor can either be directly mounted on the axis of the winch or via a reduction gear, usually the case when an axial piston pump is used. The working of the hydraulic motor will not be discussed, as it is not of much importance to the project. The advantages of such a system are that there is no risk of electrical sparks which is always dangerous. Besides, the hydraulic winches are fitted with an overpressure valve, which will prevent the lines from snapping.

4.1.3 Other equipment

Bollards

Bollards are used to secure the ship’s mooring lines on the shore. The mooring lines are not directly thrown towards land, they are simply too heavy. A heaving line is attached to the mooring line which is thrown towards a person standing ashore. The mooring line is then heaved in by that person. Sometimes, on very large vessels, mooring lines are brought ashore with help of a work boat. Using these bollards can be dangerous for people who put lines over them, because they are located near the water and there is always a danger of falling in.
Leads

The lines are guided via a (Panama) lead from shore through the bulwark to a bollard or winch. The lead must be curved to prevent wear in the rope. Leads can also be fitted with rollers as to reduce the wear in the lines.

Figure 3 Mooring lines are led through a lead

Bitts

They transfer the mooring forces onto the ship’s hull.

Figure 4 Mooring lines secured on a ship’s bitt
4.1.4 Mooring procedures

The amount of mooring lines depends on several factors:
- The size of the vessel
- The strength of the mooring lines
- The prevailing weather conditions
- The windforce
- The possibility of swell
- The density of passing ship traffic
- Current
- Demands from captain, company or locals

When approaching the designated berth, the mooring lines have to be prepared. This takes quite some time, depending on the size of the vessel and the amount of lines used. When everything is prepared and everybody is in position the mooring procedure can commence. As mentioned before, with help of a heaving line the mooring lines are pulled ashore and are then secured onto a bollard. When securing the lines, they must be kept slack as the linesman can get dragged into the water when the line suddenly tenses. More about the dangers of the conventional way will be discussed in the next chapter. Usually for larger vessels a headline, forward spring, aft spring and stern line are used to secure the vessel. When a lot of shore wind is expected, an additional forward and aft breast line will be used.

![Figure 5 Different mooring lines with different functions](image)

<table>
<thead>
<tr>
<th>Number</th>
<th>Name</th>
<th>Purpose</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Head line</td>
<td>Keep forward part of the ship against the dock</td>
</tr>
<tr>
<td>2</td>
<td>Forward Breast line</td>
<td>Keep close to pier</td>
</tr>
<tr>
<td>3</td>
<td>Forward spring</td>
<td>Prevent from advancing</td>
</tr>
<tr>
<td>4</td>
<td>Aft Spring</td>
<td>Prevent from moving back</td>
</tr>
<tr>
<td>5</td>
<td>Aft Breast line</td>
<td>Keep close to pier</td>
</tr>
<tr>
<td>6</td>
<td>Stern line</td>
<td>Prevent forwards movement</td>
</tr>
</tbody>
</table>
Berthing a ship the traditional way, using ropes and bollards, is a very old method to berth a ship. It is a dangerous task and can take up quite a lot of time. Over the past years many fatal accidents have happened while berthing (accident, http://maritimeaccident.org/, sd). People got stuck in the lines and drowned or, if they were lucky, they only lost their hand. To replace this rather old method, much research is needed for a better and safer way to berth a ship. This chapter is about the problems and disadvantages that need to be solved to make berthing safer and if possible, autonomous.

Many maritime accidents still occur during the berthing process. It shows that every day someone has a fatal accident with berthing. In most ports, ropes have to keep the ship in place while loading and discharging the vessel. The ropes experience huge forces from the ship. To berth a vessel, someone has to pull these lines on the quay and put them around a bollard. This is a risky job and can be seen as a problem which the conventional ways of berthing bring forward.

Another problem is the time-consuming process that can easily take up to 45 minutes (fiktorie, 2016) to berth a ship. During this process, the engine has to be running and the ship must manoeuvre into position. These 45 minutes can count up to a lot of fuel that is wasted every year. An example of this is the ferry between Den Helder and Texel. Without using the engine for berthing, a single one of these ferries can save up to 908,000 litres of fuel per year. (Studio WTB, 2016) . Also, while the engine is running and the propeller is turning, soil on the seabed gets loose and will damage the port’s foundation over time. This damage has to be repaired once every while and that comes with its own problems as well. If the port needs maintenance no vessels can berth and the harbour company will lose even more money. Mooring with running engines is bad for the quality of life and can cost a lot of money in the end. The cost of 1 ton HFO in the port of Rotterdam cost $172.5. This amount will also add up to the total costs. (International prices of imported raw materials - Heavy fuel oil (Rotterdam), 2016)

In this report the problems of modern day mooring are put in a row. The principal investigator to alternative mooring systems in the port of Rotterdam was mister E. Fiktorie. In order to shine a light on these problems, contact had been made with mister Fiktorie. He also provided us his final report on berthing which has been of great use. The main problems of present day mooring will now be discussed.

A concise description of the problems is listed below:

- Inefficient Time use
- Safety issues
- Financial

**Inefficient time use**

Nowadays, a ship will be moored with help of tugs. The tugs lead the ship to his berthing place. When the ship is in position, shore men will secure the ship to the quay. This process of berthing a ship is very time consuming. When this part of the berthing process can get shortened, the berthing
process will of course be much shorter. Mister Fiktorie found out that the traditional way of berthing a ship will take on average 45 minutes.

**Safety Issues**

The conventional ways of berthing can get very dangerous. Especially the people who secure mooring lines are in much danger as well as those who transport the lines to shore when handling very large vessels. When conveying the mooring lines, they will be between ship and quay. Besides, the boats are much smaller than the vessel which has to be moored. This means that the tiny boat could get crushed when the vessel suddenly starts to shift. Also, mooring lines can be dangerous, because very large forces can act upon them. As mentioned before in the chapter, the lines might snap and cause a backlash which can seriously injure a seaman. Another group who are working in a dangerous zone are the shore men, who will put mooring lines over bollards. There is always the chance that they fall into the water or even get dragged into it via a mooring line.

**Financial**

The conventional ways of berthing also have financial disadvantages. The shore men, who will put mooring lines over bollards, all have to be paid fair. The same goes for when a work boat has to be used to transfer the mooring lines. All add up to the total cost of operation.

Another financial disadvantage is the fact that a vessel will keep her engines running while in the berthing process. This of course means more unnecessary fuel consumption and again adding up to the total cost of operation. An alternative way of berthing has to be found without unnecessarily running the engines.

4.3 Alternative mooring systems

Besides the conventional ways of berthing vessels with the use of ropes, which can be dangerous and can take up to 45 minutes, there are other ways to berth a ship. The most common alternative ways to berth a ship without the use of ropes is by using magnetic forces, vacuum or hydraulics. These three principles can be made fully automatic or are already fully automatic.

4.3.1 Hydraulic berthing

**Semi-automatic**

This method, designed by TTS-Group, uses a hydraulic rod instead of ropes that connects to the ship. The ship must have a special bollard that the rod can connect to. Once the vessel is in position, the operator uses a joy-stick to guide a mooring arm from the quay to the bollard in the ship’s side. When the mooring arm is in place the operator switches to automatic mooring mode. (TTS-Group) The unit on the quayside automatically adjusts to the motions of the ship. Once the ship is ready to depart the operator again has to use the joystick to guide the rod away from the ship.

This process does not require any quayside personnel and is therefore extremely safe to use.

**Grip based**

This method is in many ways the same as the semi-automatic mooring unit, except that in this case the unit can move fully automatic. With the push of a button the beam moves towards the ship and
can find the bollard. Then the beam connects to the bollard completely automatically and holds the ship in place.

Both systems can withstand forces up to 1000 kN, but the ship has to have a special bollard built in to its hull which is a disadvantage compared to the other systems described below.

4.3.2. Magnetic mooring

This method uses electromagnets that connect to the vessel's hull. These magnets are extremely strong and can hold great forces from the ship, but not as great as the hydraulic beams described before. It is also fast and efficient. Together with vacuum mooring it is one of the safest methods to berth a ship. The magnets can connect to all ships with a steel hull.

There already has been some research done on this type of mooring. Erik Fiktorie, researcher at Movares, did research commissioned by Gemeentewerken Rotterdam on magnetic mooring. Port of Rotterdam chooses magnetic mooring because it is safer and more cost efficient than mooring with ropes. It would cost around 660,000 euro to implement a system that can keep a large container vessel in place with the use of magnets.

The magnetic system would contain 52 electromagnets with a surface of 1 by 1 meter, and a quarter meter thick. A magnetic field of 1 Tesla can be reached with 384 Volts and a 2 Ampère current. 768 Watts is needed to supply enough power for 1 magnet. If the hull is thick enough there will be no direct danger for vessel and crew. Each magnetic pole needs 1,200 windings to achieve the right force. The magnet itself would contain 35,000-meter cooper wire, with a 2-millimeter diameter. Magnets will be placed above water level so maintenance can be done easily.

The way this method functions is rather easy. Once the vessel is in her final position and ready to berth, it has to be moved to the magnets. This can be done with or, if possible, without tug assistance. Depending on the size of the vessel the amount of magnets needed is calculated. To adjust to vertical currents in the port the magnets have to release, move up or down, and then reattach to the vessel one by one as the height of the tide changes. This is happening constantly and automatic. Disadvantage of strong magnets is the effect they have on other electronics. Strong magnets can influence digital components such as computers, hard disks, cell phones and other commonly used apparatus. This can cause damage to electric structures in the vessel that are near the magnets unless the hull is at least as thick as the magnet.

4.3.3. Pneumatic mooring

Cavotec uses industrial vacuum suction pads that can connect to almost any ship designed this method. If the ship is in position of its berth the operator pushes a single button on the bridge and the pads will automatically connect to the vessel. Multiple units are used on the quayside that connect to the vessel. This system is fully automatic and very fast and is already used in some ports.

In the Netherlands, the ferry between Texel and Den Helder uses the Moormaster system, with vacuum technology from Cavotec to reduce their costs and speed up the berthing process. According to Teso the time used for mooring ferries with vacuum pads is less than 30 seconds.
Once the units are ready to moor, the mooring sequence for the units is activated by the Moor button on the system control page (or individually on the unit control pages). Confirmation is required.

The units extend to the vessel until the pads touch the hull. The vacuum pads will form a vacuum against the vessel’s hull if it is free of obstructions or any other source of leaks. The unit is moored if sufficient vacuum pressure against the vessel’s hull is generated in both of the vacuum pads. The green Moored lamp for each unit will flash indicating the required vacuum pressure has been achieved at the pads.

The vacuum pumps will run after the pad is moored until the vacuum pressure is above 100% for at least 30 seconds, after which they will stop. If the vacuum drops below 100% after the pump has stopped, the pump will start again until vacuum pressure is above 100% for at least 30 seconds. If the vacuum stays above 100%, the pump will not start again until required for the next mooring. (Ging, 2014)

Before TESO used the Moormaster, ferries were pushed in rubber heads at the quay. This was faster but costs additional fuel. TESO uses this system to reduce on fuel cost and not because it is faster or safer.
5. Applicable methods of automation for berthing and pilotage operations

A ship has to be created that can do the mooring process without the help of the crew. Extra eyes are needed to make sure this is possible. These extra eyes can be found in the laser and sensor technology. By looking at the automotive industry, there has been determined which sensors and lasers could also be applied on ships. The sensors that are now used in automotive engineering are mainly ultrasonic sensors, but lasers are also used. These types of sensors could also be implemented in the shipping industry.

5.1 Ultrasonic sensors

The ultrasonic sensor sends sound impulses at a high frequency. These waves usually have a frequency of about 18kHz to 200kHz. A human ear will not be able to hear this type of sound. These pulses continue with the speed of sound through the air (340 m/s). When this pulse hits an object, it gets reflected back to the sensor as an echo. By measuring the time interval between the transmission of the sound pulse and the reception of the echo signal, the ultrasonic sensor internally calculates the distance to the object.

Almost all materials that are detected, reverberates sound. Also, the colour of a material does not matter. Even crystal clear materials or thin films are not a problem for ultrasonic sensors. The ultrasonic sensors can measure a distance of 30 mm up to 10 m and due to the propagation time measurement, the measurement value is accurately determined. Some of the sensors even have a resolution of less than 0.18 mm.

The sensors measure through dusty air and fog. Also, thin deposits on the sensor membrane have no unfavourable influence on the operation of the sensor. Depending on the accuracy of the used transmitter, the sensor can be used in a humid and dusty area. Also, a glass or translucent surface in some devices can be detected. However, the accuracy in such situations is decreasing. Sponge-like textures, clothing and rubbers can give serious problems for an ultrasonic sensor due to the high absorption capacity of this material.

Basically, the sensor consists of a transmitter and a receiver:

As a transmitter, the piezoelectric effect is responsible of generating waves of a certain frequency. The piezoelectric effect is the phenomenon that crystals of certain materials under the influence of pressure, for example, by bending, produce an electric voltage, and vice versa: deform when an electric voltage is applied on. This energy is put into a mechanical vibration. An oscillator then provides the desired frequencies.

When the wave is received by the receiver, the piezoelectric effect is used to return the received energy in the form of waves to be converted to a voltage which can then be compared with use of a comparator

Applications

Ultrasonic sensors are used in all kinds of applications, such as the measurement of wind
velocities, the (anemometer), robot positioning, person detection, quality control, distance measurements, cars, control of charge carriers and medical purposes.

**Benefits**

- Ultrasonic sensors are independent of the colour and optical reflectance of an object.
- No (artificial) lighting needed: it works in the dark.
- Detection of (invisible) cracks and fissures.
- Simple and inexpensive converters (transducers).
- The speed with which the wave is obtained is linear with distance. It can therefore be used as a parameter.

**Disadvantages**

- Cannot be used in areas with a high density of objects. This is because the reflection in these areas is no longer correct.
- Cannot be used on objects with a too high absorption (sponges, rubber, clothing).
- Without temperature compensation sensor, an ultrasonic sensor cannot be used at very low and high temperatures. This is because the velocity of the transmitted wave is dependent on the medium used.
- Ultrasonic sensors are also influenced by air humidity, air pressure and certain types of particles in the atmosphere.
- They have a minimum measuring distance.

5.2 LiDAR

5.2.1 How does LiDAR work?

The principle behind LiDAR (Light Detection And Ranging or Laser Imaging Detection And Ranging) is really quite simple. The technique is similar to that of radar, but radar uses radio waves and LiDAR uses light. The time between the transmission of a small light that is pointed on a surface and the reflection of the light to its source is measured. Light travels very fast, about 300,000 kilometres per second. The equipment required to measure this needs to be able to operate extremely fast. The actual calculation for measuring the distance of a returning light photon is as follows:

\[
d = \frac{c \cdot t}{2 \cdot n}
\]

Where
- \(d\) = distance in m
- \(c\) = speed of light in vacuum (299 792 458 m/s)
- \(t\) = time in seconds
- \(n\) = refraction index

The LiDAR fires fast pulses of laser light at a surface, some at up to 150,000 pulses per second. A sensor on the Lidar measures the time it will take for a pulse to bounce back. Because Light moves at a constant and known speed, the LiDAR can calculate the distance between itself and the target with high accuracy. By doing this with each pulse, the LiDAR can build a complex map.
of the area. As the sensor is moving, location and orientation of the Lidar must be known to determine the position of the laser pulse at the time of sending and the time of return.

Generally there are two types of LiDAR detection methods. Firstly, direct energy detection, also known as incoherent, which is basically an amplitude measurement. Secondly, coherent detection. Coherent systems are best for Doppler or phase sensitive measurements and generally use Optical heterodyne detection. Because of that they can operate at much lower power, but they need a more complex transceiver so it is more expensive. In both types of LiDAR there are two main pulse models: micro pulse and high-energy systems. Micro pulse lasers are lower powered and are classed as 'eye-safe' allowing them to be used with little safety precautions. High energy systems are more commonly used for atmospheric research where they are often used for measuring a variety of atmospheric parameters such as the height, layering and density of clouds, cloud particles properties, temperature, pressure, wind, humidity and trace gas concentration.

5.2.2 LiDAR components

Lasers

Lasers are categorised by their wavelength. 600-1000nm lasers are more commonly used for non-scientific purposes but, as they can be focused and easily absorbed by the eye, the maximum power has to be limited to make them 'eye-safe'. Lasers with a wavelength of 1550nm are a common alternative because they are not focused on the eye, so they are eye safe at much higher power levels. These wavelengths are used for longer range and they are less accurate.

Scanners and Optics

The speed at which images can be developed depends on the speed at which is scanned. Some methods for scanning azimuth and elevation include: dual oscillating plane mirrors, dual axis scanner and polygonal mirrors.

Photodetector and receiver electronics

The photodetector is the device that reads and records the signal being returned to the system. There are two types of photodetector technologies namely: solid state detectors, such as silicon avalanche photodiodes and photomultipliers.

Navigation and positioning systems

When a LiDAR sensor is mounted on a mobile platform such as satellites, airplanes or automobiles, it is necessary to determine the absolute position and the orientation of the sensor to retain useable data. Global Positioning Systems provide accurate geographical information regarding the position of the sensor and an Inertia Measurement Unit (IMU) records the precise orientation of the sensor at that location. These two devices provide the method for translating sensor data into static points for use in a variety of systems.

Lidar uses ultraviolet, visible, or near infrared light to image objects. The Lidar can target a wide amount of materials, such as: non-metallic objects, rocks, rain, chemical compounds, aerosols, clouds and even single molecules. A narrow laser-beam can map physical features with very high
resolutions; for example, an aircraft can map terrain at 30 cm resolution or better.

To conclude, it could be possible to apply both type of sensors in the shipping industry when it comes to berthing. Ultrasonic sensors can be used to determine for example the distance to a certain point. This could be the quay itself, a buoy or any other navigation object. LiDAR can be used to make 3D images of the surroundings. By doing this, a computer can assess the situation and manoeuvre the vessel to her berthing spot.
6. Required machinery for automatic berthing operations

With use of sensors discussed in the previous chapter, the ship is able to determine several factors when willing to berth automatically. With use of only a conventional propeller and bow thruster it will become very hard to make the right manoeuvres. Especially the three linear motions a ship makes whilst berthing are of importance.

The ship must be fitted with the right machinery in order to compensate for the motions. Also, the vessel must account for wind and drift. Nevertheless, the machinery must make sure that the vessel can manoeuvre safely to her berth.

6.1 Dynamic positioning

Dynamic positioning is used to maintain a ship’s position and heading by means of a computer. It does so by using thrusters and propellers. The input of this computer consists of position reference sensors, motion sensors and gyrocompasses. The computer programme consists of a mathematical representation of the ship. Together with the input information and the model of the ship, the computer will calculate the required steering angle and thruster output in order to keep the vessel on its place. Dynamic positioning can either be absolute, where the vessel is in a fixed position over the bottom or relative to another object.

The position can be determined by different types of systems:

- **DGPS**: Where a normal GPS system is not accurate enough, a DGPS is placed on a DP vessel. Here, a fixed ground-based reference station is used, which will compare the GPS position to the known position of the station.

- **Light taut wire**: This system uses a clump weight which is lowered to the seabed. The amount of wire paid out and the angle is measured by a gimbal head. By doing this, the relative position can be calculated. This system can be used in shallow waters. In deeper waters the current will curve the wire, which will affect the calculations.

- **Fanbeam and Cyscan**: These are laser based position reference systems. Laser sensors calculate the range and bearing of reflections from a retro-reflective target installed in a target, which can be a platform or other vessel. If more than one target is used, the heading can also be calculated.
**Artemis:** Uses radar technology to determine the ship’s position. One unit is placed on the ship and one is placed on a nearby structure.

DP also requires a heading reference system. This can either be determined by a gyrocompass, Ring-Laser and fibre optic gyroscopes.

Lastly, the system requires several other sensors that can measure certain variables:

- **Motion reference units:** Determine the ship’s roll, pitch and heave.

- **Wind sensors:** Measure wind force and direction. The sensors are fed in the system’s feedforward, so the system can anticipate wind gusts.

- **Draught sensors:** A change in draught can influence the effect of current and wind on the ship’s hull.

These are just some of many types of sensors used in a DP system, but give a clear overview of what type of sensors are required.

### 6.2 Propulsion systems

In order for a vessel to manoeuvre to her berth or to maintain a fixed position when a vessel is fitted with DP, a combination of Azimuth thrusters, bow thrusters, stern thrusters, water jets, propellers and rudders will have to be used. The vessel must be able to overcome difficulties concerning the manoeuvring without the use of tugs, thus on her own.

The conventional way of propelling a vessel is with use of a two- or four stroke engine. The propeller is either connected via a stern tube to the main engine or via a gearbox. The combination engine-propeller provides the ship with a thrust to let her make way through the water.

Another way to propel the vessel is with use of Azimuth thrusters. This type of configuration consists of a propeller placed on a pod that can be rotated horizontally. This makes the use of rudders unnecessary. An Azimuth pod can be propelled in three different ways.

- **Diesel electric:** Diesel engines drive a generator which produces electricity. The electricity is then led to an electric motor that is fitted in the pod itself. The electric motor will drive the propeller.

- **Mechanically:** A motor inside the ship is connected to the thruster by gearing. The motor usually runs on diesel fuel. The arrangement of the azimuth thrusters can either be a L-drive or Z-drive. A L-drive thruster has a vertical input shaft and a horizontal output shaft with one right-angle gear. A Z-drive thruster has a horizontal input shaft, a vertical shaft in the rotating column and a horizontal output shaft, with two right-angle gears.

Stern- and bow thrusters are mounted inside a ship’s hull, as the name says, in the stern or the bow. This makes it possible for the ship to make transversal movements, hence making it more manoeuvrable. Especially during the berthing process these types of thrusters come in handy, otherwise the main propulsion mechanism requires forward motion turning.

A water jet or pump jet in marine propulsion creates a jet of water for propelling the ship. Water is usually sucked underneath the vessel into an engine through an inlet. The pump increases the water pressure and with help of a nozzle forced backwards. Reversed thrust can be achieved with help of a so called reversing bucket. Also, jet thrusters can be fitted in the ship’s hull with the same function as stern- and bow thrusters. Water is also sucked from beneath the hull and forced out through nozzles in the ship’s hull.
Overview of propulsion systems:

<table>
<thead>
<tr>
<th>Propulsion</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional propulsion</td>
<td>-Inexpensive fuel</td>
<td>-Heavy</td>
</tr>
<tr>
<td></td>
<td>-Low cost installation</td>
<td>-Takes up valuable space</td>
</tr>
<tr>
<td></td>
<td>-Long lasting</td>
<td>-Pollutant</td>
</tr>
<tr>
<td>Azimuth diesel electric</td>
<td>-Effective design</td>
<td>-Very expensive</td>
</tr>
<tr>
<td></td>
<td>-Reduced noise and vibration</td>
<td>-Difficult maintenance</td>
</tr>
<tr>
<td></td>
<td>-Redundancy</td>
<td>-High quality distributing network</td>
</tr>
<tr>
<td></td>
<td>-Efficiency</td>
<td>-Level of safety more significant</td>
</tr>
<tr>
<td></td>
<td>-Manoeuvrability</td>
<td></td>
</tr>
<tr>
<td>Azimuth mechanically</td>
<td>-Manoeuvrability</td>
<td>-Gearbox needed</td>
</tr>
<tr>
<td></td>
<td>-Hardly any need for tugboats</td>
<td>-Expensive</td>
</tr>
<tr>
<td></td>
<td>-No rudder needed</td>
<td>-Less efficient than conventional propulsion</td>
</tr>
<tr>
<td>Stern- bow thrusters</td>
<td>-Turning of vessel</td>
<td>-Only effective up to speeds of about 3 knots</td>
</tr>
<tr>
<td></td>
<td>-Docking without tugboats</td>
<td>-Increase vessel’s resistance</td>
</tr>
<tr>
<td>Water jet propulsion</td>
<td>-Manoeuvrability</td>
<td>-Less efficient than propeller at low speed</td>
</tr>
<tr>
<td></td>
<td>-Improved shallow water operations</td>
<td>-Expensive</td>
</tr>
<tr>
<td></td>
<td>-Noise reduction</td>
<td>-Clogged intake grill</td>
</tr>
<tr>
<td>Water jet thrusters</td>
<td>-Smaller hull penetration</td>
<td>-In need of powerful pumps</td>
</tr>
<tr>
<td></td>
<td>-More efficient than bow thrusters when advancing</td>
<td></td>
</tr>
</tbody>
</table>

6.3 Integrating propulsion systems in automatic berthing operations

As mentioned previously, the vessel must overcome linear motions as well as wind and current. Besides these factors she must be able to manoeuvre automatically to her berth. Combining the sensors mentioned in the previous chapter and perhaps a dynamic positioning system, it should be possible for a vessel to berth automatically. The only question remains, is with which propulsion systems should the vessel be equipped.

When considering different propulsion systems, one must think of certain factors:

- Cost
- Maintenance
- Effectiveness / manoeuvrability
- Resistance on vessel making way
- Protruding
An example of how a ship might berth automatically is given in the following picture:

Figure 9 Possible route in Rotterdam

This is merely an example of where a vessel might berth in the Port of Rotterdam. As one can see, the vessel must be able to make both slight and sharp bends as well as a linear motion towards the quay. With only the use of a conventional propulsion system it will be very hard to make these motions without the use of tugs. The vessel has to be able to turn on itself.

This leads to the following question: What type of propulsion(combination) is best suitable for automatic berthing:

**All electric ship with azimuths**

The ship is fitted with several electric azimuth thrusters. This will make it easy for the ship to make turns, as well as propelling the vessel for passages. As shown in picture..., the vessel has to make both sharp and slight bends. With help of the sensors discussed in chapter 4 of this paper, it should be possible for the vessel to make the most suitable manoeuvre. The linear motion will not be problem when using azimuth thrusters. The most suitable design of the ship, would be placing two thrusters at the stern and two fore. This would make it possible for the ship to turn 360° along a vertical axis as well making the linear motion.

**Ship with conventional propelling system and water jet thrusters**

The vessel is fitted with an internal combustion engine as well as water jet thrusters. The jet thrusters are placed at the bow, side and quarter of the vessel. The jet thrusters are more efficient than bow thrusters when the vessel is advancing, so it should be possible for the vessel to make the motions as described in the picture above. Both the propeller with rudder and jet thrusters will have to be used when making turns. When making the linear motion at the end, only the jet thrusters will have to be used.
Ship is fitted with jet propulsion and jet thrusters

The ship is completely reliable on water jets. This makes it easier for ships to manoeuvre in shallow waters. The motions described in the picture could form a problem though, as jet propulsion is less efficient when advancing with slow speed.
7. Utilizing drones in the overall berthing process

Unmanned aircrafts or drones are used very often nowadays. Drones can fly autonomously through flight plans created by software, for example, to inspect agriculture and support SAR operations. There are two types of drones, fixed wing and rotary wing. Fixed wing drones look like airplanes whereas rotary wings have more similarities with helicopters. Fix wing drones are capable of traveling fast over a long range. Rotary wing drones are slower but can hover in a fixed position. A feature that the fixed wing drone lacks.

To find out if drones can be used in the overall berthing process, this research will analyse the possibilities that drones bring forward and look at the benefits and drawback of drones in the berthing process.

7.1.1 What drones are used for

Over the last few years, the drone industry has had a real boost and technique is still improving. Drones can be used for a variety of tasks.

Drones are used to view machinery, processes, farmlands or any other object from above. With drones it is possible to observe anything from a high perspective fast and efficient. Compared to helicopters, drones are cheap and accessible.

For individuals, drones are used for fun. It is possible to capture professional looking scenery from above. In the shipping industry drones can be used to control processes from ships. For example: port processes, tug boats, search and rescue operations, deliver goods or maybe in the future by autonomous ships. The US army uses drones to search for and spy on other ships that are fitted with excellent cameras.

7.1.2 Advantages and disadvantages

As mentioned before, drones are used on a variety of tasks. Even though there are advantages to the use of drones, there are also some disadvantages.

Advantages:

- Silent; drones are very silent. Which means that they are hardly noticeable for other people.
- Large surface area to view; Drones are able to fly quite high, which means that the area which can be surveyed is large. An example is the farming industry, where large pieces of land have to be monitored.
- Small, light; Drones are not heavy, so travelling with them is not a problem at all.
- Safe; When operated professionally, drones are very safe to use. Nevertheless, there is always a chance of accidents happening.
- Electric; Drones do not require any type of fuel. This means that they are non-pollutant.
- Fast; Drones are able to reach speeds of up to 80 to about 100 km/h.

Disadvantages:

- Expensive; High quality drones are still quite expensive to purchase.
- Not perfect for bad weather conditions; In bad weather the drones will not work well. For this problem a solution is still needed.
- Privacy; Many people think their privacy will be violated if a drone is fitted with a video camera.

Even though drones are a recent invention, it should be possible to use them in port operations.
7.2.1 The pilotage process

Pilots are located in almost every big port around the world. The main function of a pilot is to ensure that the vessel sails safely into or out of the port but the captain will always be responsible for the ship. Also, the pilot ensures that the berthing operations goes as fast as possible, as he controls the ships manoeuvrability directly and tugs and linesmen via radio. The pilots know every little detail of their port, all depths, berths, lights, wind and current, regulations and dangerous areas. Highly trained maritime pilots and other staff members work closely together to ensure safe and efficient operations in all circumstances.

When climbed on board, the pilot is guided to the bridge where he will give any orders. Legally, the master still has full responsibility for safe navigation of his vessel, even if a pilot is on board. He can dismiss him from his duties and ask for another pilot or, if not compulsory to have a pilot on board, navigate the vessel without one. Only in transit of the Panama Canal does the pilot have the full responsibility for the navigation of the vessel. The pilot ensures a safe passage to the port by using all of the possible navigation equipment.

7.2.2 Shore based pilotage

In the current shipping industry there is already a new form of pilotage in development, namely “shore-based pilotage”. It is used in some pilot districts in accordance with national legislation, it is already in use in some European ports, such as in the Netherlands, Belgium, France and Germany. It is an extension of the pilot’s task to improve the safety and efficiency of maritime traffic, but it also has some limitations that should be understood. (Lutzhoft, 2016)

Shore-based pilotage consists of advice, which is intended to directly influence the course to be steered, the engine manoeuvres and the speed of the vessel. (Bruno, sd)

Shore-based pilotage is a kind of pilotage by a pilot licensed in a designated area, from a position other than aboard the vessel concerned to conduct the safe navigation of that vessel.

Shore-based pilotage has quit some advantages already:

- SBP is much more efficient than the original pilotage method. If the situation allows, the pilot could handle multiple vessels at once. In the conventional method of pilotage this would be impossible since a pilot cannot be on multiple vessels. With the use of digital equipment and the use of drones this would be made possible.
- Another advantage of SBP is that it is time saving. The pilot no longer has visit the vessel physically. Once arrived at his work station, the pilot can get to work to guide the vessel to its berth. This completely removes the voyage time of the pilot and allows him to guide more vessels in to port.
- It is more safe since the pilot can stay ashore and no longer needs to climb the moving vessel with a pilot ladder. The pilot ladder is often just a rope ladder that hangs against the ship hull. When the vessel is moving, a dangerous situation for the pilot is created. SBP completely removes the chance of falling from the pilot ladder.
- Pilots can work together more easily in doubtful situations when they are located in the same work station. An experienced pilot knows exactly what to do in almost any situation. But if things become unclear, the combined experience of multiple pilots would be better. In the conventional method a pilot can only call their colleagues but in the case of shore based pilotage, working together would be made much easier.
7.2.3 Disadvantages of SBP

When chosen for Shore-based pilotage, there are three important safety factors: (authority, 2014)

- Communication
  One of the biggest differences between Shore-based pilotage and the conventional way of pilotage is communication. When a pilot is on board of a vessel, he or she can communicate directly with the captain and the other crewmembers on the bridge. That is obviously not possible with Shore-based pilotage. In this case communication will be handled with VHF. The international spoken language on board is English, but not just normal English. On board the Standard Maritime Communication Phrases (SMCP) are used. If the pilot or the navigator does not speak English well it could happen that information is misinterpreted. This could lead to a dangerous situation.

  The communication must be limited to brief, precise, polite and professional commands. The navigator has to listen, confirm and repeat through the VHF what the pilot has to say. This is to ensure that the navigator understood what the pilot said. Also the captain has to report immediate when he deviates from an advice he gets from a pilot.

- Visual awareness of surroundings
  The other big difference between Shore-based pilotage and the conventional way is visual awareness. Pilots have a full overview of the vessel’s surroundings when on board. Navigation is all about visual awareness of land, buoys, ships, weather etc. A pilot ashore will not have all of this data and information to make decisions.

  This means that a Shore-based pilot needs to learn to evaluate situations by other means.

- Navigational competence
  Both the pilots’ and the navigators’ ability is very important in Shore-based pilotage. A condition for Shore-based pilotage is that a pilot can carry out the conventional way of pilotage duties.

  All the instruments and information required for Shore-based pilotage are almost the same, except that the pilot is not on board but ashore.

  This implies a form of blind navigation, so as already been said: pilots must be trained very well, and also know how to communicate very direct and precisely.

  The crewmembers on the bridge are also important for the safety of Shore-based pilotage, as they are the eyes of the pilot, so to say.

  Safe pilotage is defined as professional skills and experience. So maybe Shore-based pilotage is not for everyone, but only for skilled experienced navigators.

7.2.4 Improving SBP with drones

A major drawback of shore based pilotage is the limited visual awareness. The pilot can only see vessels that are suited with proper equipment on his screen, but not the smaller or older vessels. To compensate this lack of visibility drones can be used.

In the situation of Shore based pilotage, drones can be utilized to assist the pilot by improving visual awareness. The drone can be used to overview the surrounding area of the vessel and give a clear image of the situation. The pilot ashore will be able to move the drone around the vessel to have an optimal field of view. Also, the drone could fly further away from the bridge, to get a greater
understanding of the situation down the planned route. In the harbour itself the drone can be flown around corners and make hidden area’s visible.

Shore based pilotage is only used in bad weather condition because of strong winds that make boarding the vessel dangerous. In the case of bad weather, it is nearly impossible to fly drones. Ideally drones are flown in sunny weather conditions with few to zero wind. However, if using drones in the pilotage process is useful, shore based pilotage will be much more efficient than the conventional pilotage process.

7.3 What is needed to replace pilots by drones
Using drones as a replacement for pilots is something that will become a possibility once drones and computing are better developed.

7.3.1 What is needed to automate drones
To make drones autonomous, large data networks are needed to communicate with the drones. Drones would also need to be integrated in the overall airspace to avoid collisions with other aircraft.

Since drones are a recent thing, legislation is changing and becoming more strictly. Besides the need of an operator license for commercial use, it is forbidden to fly drones near waterways, roads and approach lanes for airports. This would make it impossible to fly drones near vessels unless legislation is changed.

7.3.2 What the current drones are capable off
Current drones are useful for inspections and visualisation of certain happenings. The drone can be equipped with high detail camera’s that can zoom in to see details close to ground. Also thermal imaging is an option and can be used by police and fire departments.

Drones are not very suitable in heavy weather conditions but can stand up to windforce 5-6. In this type of weather drones become unstable and have a hard time hovering in a certain position. Besides wind, drones cannot fly in rain or hail.

According to Wim van der Burgh, drones will quickly improve to make a greater flight time and capable of carrying heavier loads.

7.3.3 Replacing pilots by drones
To replace pilots, drones should be capable of flying for long periods without the need of charging. Current drones can fly 20 minutes which is not enough to pilot a ship. The entire network of drones, data and computing should determine the position of vessels and find perfect piloting solutions to guide ships to their destination. The system should know what to do in certain situations and how to react on unplanned behaviour of other vessels.
8. Conclusion

The main question of this project is “How can berthing and pilotage operations be made safe and efficient by introducing automated unmanned systems”? After doing extensive desk and field research, it can be concluded that it is possible to pilot a ship to its berth with use of shore based pilotage and the help of a drone, and then moor it with the cooperation of a DPS, a LiDAR system and Ultrasonic sensors. When an alternative mooring system is positioned in the port, it is even possible to moor the ship without the help of shore men.

Ultrasonic sensors can be used to determine for example the distance to a certain point. This could be the quay itself, a buoy or any other navigation object. LiDAR can be used to make 3D images of the surroundings. By doing this, a computer can assess the situation and manoeuvre the vessel safely to her berthing spot.

Not only sensors must be fitted on a vessel, she must also have the right propulsion mechanisms. With only the use of an internal combustion engine and a bow thruster it will become very hard for the vessel to berth by itself. Simply because she would not be able to make both slight and sharp turns as well as advancing towards the quay. Several propulsion systems and combinations have been thought of, which could be applicable. A ship fitted with several azimuth thrusters, a ship with a conventional propulsion system and jet thrusters fitted on several parts of the vessel and a vessel fitted with both jet propulsion and thrusters.

The conventional ways of pilotage brings forward problems. This is a safety and cost factor. Complete autonomous pilotage is not being used in present day, simply because it is too dangerous. There is an option which is already in use, called shore based pilotage. Shore based pilotage is used when a pilot is unable to board a vessel because of bad weather conditions. A pilot will give advice to the vessel from a location ashore, just as he would do when aboard that vessel. A major drawback of shore based pilotage is the limited visual awareness. With the help of a drone the pilot can see much more. In fact the pilot has an overview of the situation. The pilot ashore will be able to move the drone around the vessel to get a greater understanding of the situation down the planned route. When the ship is in the harbour the drone can help by flying to places which the pilot normally can’t see.

Even though the technology to let a ship berth automatically already exists, it is unsure whether such a vessel will berth in the port of Rotterdam the coming years. Some parties are opposed to the idea, some are in favour. It would be a technological breakthrough, but at the cost of the ordinary seamen. Needless to say, there will still have to be people who have knowledge on the subject.

All in all, it is feasible to say that it is possible to let a ship berth automatically. The technology already exists and could be applied on any ship already. Nevertheless, automatic pilotage is still too dangerous, as pilots feel more comfortable piloting ships themselves.
Recommendations

Even though in theory it should be possible to let a vessel berth by itself, more research should be done on several matters.

Firstly, more research should be done on which alternative mooring system would be most applicable in the port itself. This all depends on the port itself and the demands. When applying magnetic mooring pads, thought should be put into whether the magnetic fields will interfere with ship electronic systems.

Furthermore, more research should be done on the discussed propulsion systems and combinations. Research should be done on whether or not jet thrusters could be applied on larger vessels, as they are mostly used on smaller boats.

What else should be looked into is the use of sensors in ports and how the use of these sensors and the ones discussed in this paper could be used on board vessels. Meaning how the vessel will react to factors such as, speed, windage, distance to the quay, swell, navigational aids and other traffic.

Lastly, more research should be done on the use of drones in ship traffic. This not only means legislation, but also improving the drone itself. Perhaps a special type of drone, fitted with very good cameras and a high capacity battery could be applicable.
References


Appendix 1

Interview with Erick Fiktorie, employee at Movares, about magnetic mooring.

- **How long would it take to moor a ship with the use of magnets, and what is in the mooring process?**
  The mooring operation would take 25 minutes. It requires a tug to push the vessel to the quay. The magnets will attach when the vessel is within reach.

- **What time would it take to moor a ship using ropes instead of magnets?**
  It would take 45 minutes to moor a ship using ropes.

- **Would this system cost jobs for quayside personnel or seafarers?**
  Boatmen’s will not be needed to carry the ropes.

- **Why did Rotterdam choose for magnetic berthing instead of other alternative systems such as vacuum?**
  I researched the request for alternative mooring methods by Gemeentewerken Rotterdam for mooring solutions without the use of ropes. The result from my research about magnetic mooring has more influence than other systems that are not developed in cooperation with them.

- **What are the disadvantages of this system?**
  Magnets can fail, if a combination with permanent and electro magnets are used, the ship will be kept attached to the quay if the magnets fail. Besides that, electro magnets can interfere with equipment on board. Unless the hull is thick enough.

- **Is this system safer than mooring with ropes?**
  Yes, fewer boatsman are needed and there are less moving parts to get wounded by.

- **Will this reduce air pollution?**
  I do not expect that it will directly have impact on air pollution. Assistance by tugs are necessarily to get enough accuracy to put the vessel in place with those speeds. A ship can’t maneuver with speeds this slow.
Appendix 2

Interview with M.P. Bakker, head technical engineer from the Royal Dutch TESO, about vacuum mooring and the Cavotec Moormaster.

Advantage:

- **How long does it take to moor a vessel?**
  Less than 30 seconds.
- **What is covered in the mooring process?**
  We push with the head of the vessel (two right angles with rounding) into the buffers (a, with flexible rubber covered, steel structures below with a 45 ° angle) and then press the "MOOR" button.
- **How long did the alternative way to berth take and how did it go?**
  Previously, we kept pushing with in the buffers. so that was faster because we do not have to wait for the Moor Master, but it cost fuel. Now we stop the screws if we are stuck to the Moor Masters. To attach the Moor Master, it takes about 15-20 seconds. To loosen 5-10 sec.
- **What has to be done manually and what does the system do?**
  Once the vessel is in reach of its berth an automatic GPS signal will notify the system to start a self-test. Once the test is complete and no problems occur, Mooring can take place. The captain will guide the ship into the buffers and then press the “MOOR” button. If it stays connected the captain will slowly halt the screws.
- **Why did you choose for vacuum and not for a magnetic solution?**
  Vacuum is already used by other ports and is known to function well. Magnetic mooring is not used as much. Besides that, we expect damage on the paint with magnets; the suction pads however have thick rubber edges that do not damage paint.

Disadvantage

- **What are the disadvantages of this system?**
  The only thing is that it must be lubricated frequently.

Consequences for crewmembers

- **Are there any consequences for crewmembers?**
  We never used lines to moor so for us nothing changed.

What if...

- **Who does the maintenance?**
Simple things as lubricating we can do ourselves. The machines are in connection with Cavotec New-Sealand and they keep watch over the logs, if something seems odd they will contact us. The pumps do not operate for long periods so they don’t have to be revised anytime soon.

- *How often does it fail to operate?*
Less than 10 out 5800 mooring operations
Appendix 3

Interview with Sjaak Sprong, pilot at the Dutch ‘loodswezen’, about pilotage and Shore-based pilotage.

- What is your opinion on the present-day way of pilotage?
  I think it is perfect.

- Can you name any pro’s or cons of the present-day pilotage?
  Where can none find the right balance? Both good and bad weather play a significant role. Let me formulate differently. I approximately board 300 vessels of which around 30 are important. Which of the 300 really matter, I can’t tell.

- When is shore based pilotage used?
  Usually when wind speeds of around 7-8 Bft are reached. The wave height makes it too dangerous for us get on board. When weather conditions aren’t safe, we will start with piloting vessels up to 175m in length in and out of the port. In both in- and outbound vessels, shore based pilotage is used. When dealing with bigger vessels, a helicopter is used to board the vessel.

- What is your opinion on shore based pilotage?
  I think it is a good system, but when SBP is applied, pilots will still come aboard when it is safe enough.

- In your opinion, which of the two works best?
  The conventional way. The shore-based pilotage is of course the second choice. Nevertheless, we prefer to pilot a vessel to its berth from the beginning, i.e. when entering the canal.

- What do you think of future pilotage in perspective of SBP²?
  I am pretty sure that in the future SBP will be applied more. Also, more vessel will get an exception of compulsory pilotage.

- Will eventually also be possible to apply SBP on vessels carrying dangerous goods, such as chemicals, oils?
  No, it will be harder for these types of vessels to get SBP, but smaller tankers do already make use of the SBP. In the future this will probably not change, as it brings many risks with it. Also, society will not be very pleased if this would be the case, as Rotterdam is quite a dense city.

- What is your opinion on the dangerous aspects of boarding a vessel with use of a pilot tender?
  I agree this is a safety issue.

- If you could change anything or improve something at the Loodswezen, what would you change?

- At which moment will the helicopter be used? And where is the boundary between using the helicopter and SBP?
  SBP² can be applied when the length of the vessel is less than 175m. When bigger, the helicopter will be used.
• **How long on average, would it take for a vessel to complete its track from entering the harbour and berthing alongside a quay?**

This of course depends on where one wants to go with the vessel. When using shore-based pilotage this may take half an hour more. The reason for this is that when SBP\(^2\) is used, it is not allowed to overtake other vessels. In Dutch this is called *slotvaren*.

• **On average, how long does the berthing proces take?**

This all depends on the size of the vessel. It may take half an hour or even one and a half hour.

• **When does preparing the mooring gear commence? When approaching the harbour or when the vessel is near its berth.**

This already commences at sea, before the pilot has boarded the vessel.

• **When harbours are more automated in the future, in your opinion, what will happen with present-day pilots?**

They will stay. The tasks that we will have on bored will become less, but we will always have an influence in one way or another on the shipping industry.
Interview Dronology
Wim van der Burgh, Dronology, Rotterdam, 9th July 2016

Drones and its surroundings
To what extend are professional drones depending on weather conditions and what influence does bad weather have on drones?

The current generation drones (DJI, Yuneec) can be flown up to wind force 5. Higher class drones, that are equipped with Global positioning can determine their own position and adjust accordingly. Most drones are not water resistance.

What weather conditions are too harsh for drones to fly in?
Gale force winds, wind force 6 and greater, hail, rain.

What kind of drones are most capable in bad weather conditions?
From personal experience I would suggest the DJI Inspire 1. This drone is very stable, also with strong winds. Besides being very stable, the Inspire 1 is also very manoeuvrable. We have flown the Inspire 1 during strong winds force 5-6 without any problems.

Drones in shipping industry
What kind of problems could occur when using drones near large vessels?

The current legislation: drones have to keep clear 50 meters from waterways and thus also keep clear from vessels. Exemptions can be requested by the government. Also, the stability and connection with the drone pilot could be risky; for the best communication between the drone and operator a clear line of view is necessary.

Drones could also be of advance to shipping industry. Drones can be equipped with camera’s and even thermal imaging. This combination would be perfect for inspections and similar things. A drone can be launched very fast.

Self-operating drones
Can drones in combination with the necessary tools plan and execute flight paths on its own?
Yes, this is possible and will also happen in the future. DHL is also doing research and trying to deliver parcel autonomously to its customers.

What systems are required to have drones fly autonomously?
All drones have to be connected and tuned to each other. They must also be adjusted to their airspace to avoid collisions with helicopters and aircraft. Drones have to anticipate and react to the surrounding airspace.
The future of drones
In what manner will drones change in the future?

Drones will become faster, smarter and capable of carrying more weight. The battery lifetime will increase as it currently only last 20 minutes on a full charge.

Legislation
How will legislation regarding to drones change in the future?

The legislation will become more strictly, nowadays everyone can buy a drone and let it fly 500meters above the ground. After July 1st a new law has been made for commercial drone operators to have a license, called RPAS-light.