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Evolution of automatic systems mooring sytems in commercial ports

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ABSTRACT

In the middle of the last century, some major changes began to take place in maritime transport, affecting both the regular lines and bulk transport. There were innovations in many areas of maritime activity, with the appearance of new means of traffic, new equipment and new methods. The main objective of these changes was to reduce the time of vessels in port, since this is considered unproductive. In this context, the traditional vessel mooring systems used in most of the world's commercial ports have evolved very slowly towards more sophisticated automatic systems.
The aim of this work is to identify and formalize the evolution of the technological innovations and technical modifications in automated mooring systems applied to merchant vessels. For this reason a qualitative analysis of the evolution of the different mooring devices developed throughout history until now has been carried out. For the first time, five generations of vacuum-based automated mooring technology are identified, coexisting with the traditional mooring system (since 1969 to nowdays). In all cases, the application of these mooring systems, in relation to the traditional system, does not imply any loss in the safety of the vessel moored during its stay in port.

1. Introduction.

Until the Second World War, the exploitation and organization of maritime traffic did not change substantially. The loading and unloading operations were slow and laborious. Thus, in the post-war era, with the expansion of the market and the rapid rise in labor costs, the system was subjected to an enormous stress. Congestion in ports increased and quick thinking was required to seek, through innovation in both technology and in processes, a response to these problems.

The maritime industry responded to the new challenges with two "revolutions" in the two subsectors of maritime transport: in non-scheduled traffic through the development of integrated transport systems (bulk carriers) and in regular lines (Pérez-Labajos et al., 2004) by grouping together the general cargo by means of the phenomenon of containerization, all of which led to profound changes being made in commercial seaports in order to respond to these challenges.

As a consequence of these revolutions, new innovations took place in the technological as well as the organizational sphere, with the appearance of new types of traffic, new equipment and new methods. The main objective of these revolutions was to reduce the time of the vessels in port since this was considered unproductive.

However, although innovation in the maritime sector has taken place in all areas, in the case of the mooring of vessels the changes tended to be less intense, since the traditional system is still used in most of the commercial ports of the world.

Currently, the traditional system coexists with the new mooring systems. There is an extensive bibliography on the traditional mooring system, most of the authors focusing their analysis on the different conventional mooring elements on board and on land, and on the factors that condition them from a technical point of view (Barbudo Escobar, 2004; Gaythwaite, 2004; Ji et al., 2011; Knight 1854-1927, 1930).

At present, these studies are focused on analyzing the reliability and risk of berthting, mooring and defense systems (Moyano Retamero and Losada Rodríguez, 2002), studying the behavior of mooring ropes using software programmes (Banfield and Flory, 2010) and the movement of moored vessels by means of simulation (Fang and Blanke, 2011); as well as port structures (Thoresen, 2014) and the environmental loads sup-

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ported by the mooring system (Fang et al., 2015).

Since 1914 the possibility of developing new mooring systems, with devices different from the traditional ones so far, started to be investigated. In order to differentiate such systems it seems appropriate to determine the concept of automated mooring system. In the present work AMS is meant to be every mooring system applied to moored vessels which adapts totally or partially to the weather conditions of the setting (tide, wind and current) without external assistance.

In this regard, the research carried out until now has led to an automated mooring system which is being implemented in many harbours all over the world (The USA, Canada, The UK, Denmark, Norway, Finland, Holland, Australia, New Zealand, South Africa and The Lebanon).

However, despite the research carried out and the consequent transfer of knowledge to society through the practical application of these systems, the results of this research have not been published in scientific journals. The information on these alternative systems is found in the patents registered for the different AMS which have been developed over the years.

In this context, several questions arise around the motives for installing these AMS in a commercial port. The need to find answers to this phenomenon, from the technical and commercial point of view, led to the undertaking of a doctorate thesis on innovation in the mooring systems of commercial ports. The work presented here is part of that research on the evolution of the AMS. In this sense, the aim of the present paper is to identify and formalize the technological changes which have defined and characterized the different generations of AMS, and the improvements made in each generation, by means of a analysis of the evolution of the different AMS developed up to the present.

2. Methodologyy.

The methodology used in the present work consists in the elaboration of three clearly differentiated parts: the initial bibliographic search, the construction of a database and finally the comparative analysis of the patents found.

A search of the existing patents on AMS up to January 1, 2015 was carried out in the following databases:

1. European Patent Office Registry (Office, 2014): Database that offers free access to information on inventions and technical developments from the nineteenth century to the present. Accessible to beginners and experts, it contains data from more than 90 million patent documents worldwide. The back-up information can help you understand if a patent has been granted and if it is still in effect.

This database is used to search and find patent publications, track the progress of emerging technologies, find solutions to technical problems and to investigate what the various competitors are developing.

2. Patentscope Patents Register (Patentscope., 2014) this website contains national and international patent collections, which has enabled us to carry out searches in 3 million patent documents, including published international patent applications.

3. IFI CLAIMS Patent Registration (Services, 2014): This database manages global patent information. It is fully accessible and contains more than 96 million patent registrations.

4. Google Patent Registration (Google, 2014): In 2006, Google launched this new tool in test mode that can be used to search among millions of patents registered in the United States. The search engine includes all inventions since 1790, except those that are still pending approval.

Then, a database was created in Excel with the patents found, a total of 334. After an exhaustive analysis of the same, it was found that there were numerous repetitions and that only in 20 of these were there any technological innovations or at least some technical improvement.

Finally, a qualitative analysis of the different patents selected was carried out, which provided us with the necessary information to formalize the different generations of AMS outlined in the following sections, analyzing the evolution and development of automated mooring systems.

3. Background: the first devices applied to vessels.

This group includes the patents that came before what is considered to be the first generation of AMS and it is worth establishing a clear distinction between the mooring devices applied to pleasure boats and vacuum cup fastening systems which are not actual mooring systems.

a) Buffering systems based on springs.

The first device to incorporate this system was designed by Steinhauer in 1914 (Steinhauer, 1914) (see table A_1 appendix A). Almost four decades later, in 1951, appeared the devices of Gorman and Smith (Gorman, 1951; Smith, 1951) (see table A_1 appendix A).

The Steinhauer device is a mooring system for pleasure boats made up of tubes, springs and rods that act as heads, breasts and springs lines. It is an electronic system that allows the boat to move with six degrees of freedom, once it is berthed. The system absorbs the shocks that occur when the boat moves as a result of the action of the waves against the dock.

The devices of Gorman and Smith (Gorman, 1951; Smith, 1951) are fast and simple to fasten and release. Their fastening mechanisms are also formed by springs, tubes, rods, chains and bars and allow the boat to move in the mooring with 6 degrees of freedom. These are economical systems to install and maintain.

b) Intertidal systems (1959-60).

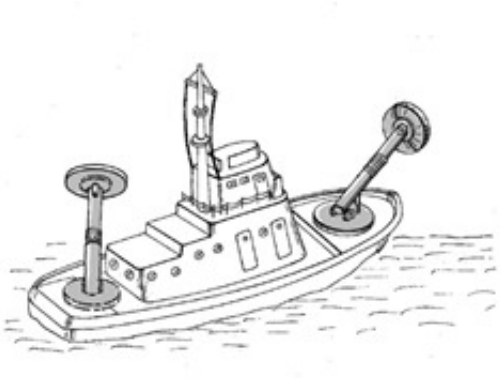
The first intertidal system for pleasure boats was designed by Gossen in 1959 (Gossen, 1959) (see table A_1 appendix A). The system is made up of chains and hooks and vertical rails on which the vessel slides in order to adapt to the changes in the tide. This is an economical system but it cannot be applied in docks where there is a lot of swell.

In 1960, the second intertidal device came out, developed by Kulick (Kulick, 1960) (see table A_1 appendix A). The system is made up of springs and a telescopic system that adapts to the different tide heights.

c) First system with vacuum cup fastening technology for a merchant vessel.

Standwick's patent of 1965 (Standwick, 1965) is not exactly a mooring device, since it is not installed in a dock. It is rather a fastening system by means of arms, with vacuum cups installed on a tug-boat in order to tug large vessels without using tug wires or ropes (see Figure 1).

Figure 1: Method and system for vessel maneuvering.



Source: Standwick Patent, (1965).

This is the first device that uses vacuum cup fastening technology and, although it is not in itself a mooring device, it is a basic reference for all the subsequent AMS that use vacuum-based automated mooring technology.

This device is quoted in most of the patents that use AMS with vacuum cups.

4. Automated Mooring Systems.

The previous section outlines the background of the different AMS, but it was in 1969 when the first AMS using suction cups began to be developed, forming the base to make the generational evolution taking into account the technological innovations.

The analysis has been structured in different generations, considering a new generation to be a moment when there is a technological innovation in the system; any other significant change which does not imply innovation is considered as a technological improvement of the system. The different generations are the following:

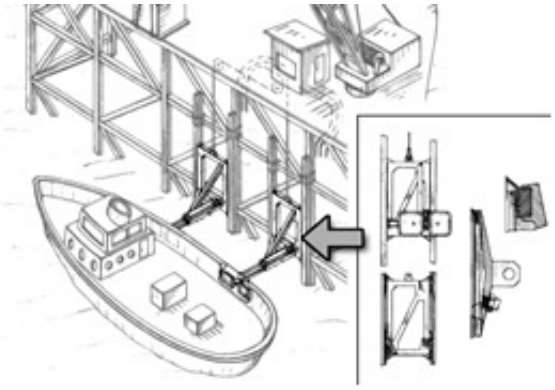
- First generation: arm system with suction cups.
- Second generation: automated system by direct suction cup on the hull.
- Third generation: Operator-controlled remote control system.
- Fourth generation: Total remote control system.
- Fifth generation: Remote control system with laser by telemetry.

4.1. First generation: arm system with suction cups.

The device of this generation (see Figure 2) was developed in 1969 with the Lovell patent (Lovell, 1969). It is a suction cup arm system, based on the Standwick vacuum suction cup device (Standwick, 1965).

The system is made up of an extensible arm that brings the vacuum devices to the vessel and, once placed in position on the hull, the vacuum is formed and the vessel is attached to the dock or platform. The vacuum device can be moved along the rails along with the vessel depending on the height of the tides and any other effect that produces vertical movement of the vessel.

Figure 2: Ship maneuvering procedure regarding their berth.



Source: Lowell Pat, (1969).

4.2. Second generation: automatic system by vacuum cup direct on the hull.

In the second generation, a technological innovation took place with the Apelstrand patent (Apelstrand, 1991) and three technological improvements in the shape of Hadcroft and Montgomery's devices (Hadcroft and Montgomery, 2001) and the Montgomery and Rositer (Montgomery and Rositer, 2003, 2002) systems respectively. All of these incorporate a vacuum cup AMS direct on the hull.

a) The Apelstrand patent of 1991 (Apelstrand, 1991).

This device constitutes an AMS which is both dynamic and innovative (see table A1 appendix A).

The system consists of two devices: one in the dock consisting of a mobile telescopic arm provided with a coupling mechanism; and another on the vessel formed by a mooring frame for reception and fixing of the coupling mechanism. It is influenced by the Lowell systems (Lovell, 1969) of the first generation and that of Lawlor (Lawlor, 1977).

b) The Hadcroft and Montgomery patent of 2001 (Hadcroft and Montgomery, 2001).

The system is made up of articulated mechanical arms, at the end of which there are bases to accommodate the vacuum suction cups.

The arms move vertically on rails to cushion the movement produced by the tides and waves. They also have the capacity

to withstand the transverse and horizontal movements that the vessel may be subjected to while it is moored.

The first prototype of this device was installed on the hull of the ship "Aratere" in 1998, years before registering the patent. On the dock, only a steel plate was needed to couple the vacuum cups.

This patent was influenced by that of Lovell (Lovell, 1969) and that of Michl (Michl, 1997).

c) The Montgomery and Rositer patent of 2002 (Montgomery and Rositer, 2002).

This system introduced a new term "coupling robot" or simply "robot" used to denominate each mooring element installed on land. The telescopic movement of the arms is activated by means of a hydraulic systems which, through a system of vacuum cups, leaves the vessel fixed to the dock quickly, safely and reliably (see Figure 3).

This system applies and introduces improvements of several types with respect to the previous systems mechanical, electrical, electronic and hydraulic. From this time on, the work of Montgomery begins to stand out from the rest through various patents for AMS by means of vacuum cups.

Figure 3: Mooring robot.

Source: Cavotec, (2015).

d) The Montgomery and Rositer patent of 2003 (Montgomery and Rositer, 2003).

This AMS is made up of several robots installed on vertical rails along which it slides in order to absorb the movements of the tides.

The number of robots and the distance between them will depend on the characteristics of the vessels and the meteorological conditions, such as the tides, currents and winds of the dock in which it is installed. This device can also be used to bring two or more vessels alongside each other; in this case it needs to be installed on the hull of the vessels.

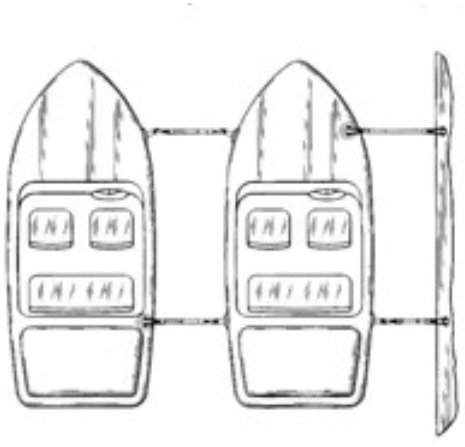
This system by Montgomery and Rositer (Montgomery and Rositer, 2003) is an improvement on the patent (Montgomery and Rositer, 2002) of the same authors from the previous year.

The patents that have been key influence in the development of this generation are those of Lawlor and Michl (Lawlor, 1977; Michl, 1997).

The Lawlor patent (Lawlor, 1977) (see table A1 appendix A) is a device that is composed of electric reduction motors with an electromechanical technique of translational gear or of sliding on a pivot. The device requires two vertical mooring points located on the dock at a certain distance from each other so that when the boat is being moored, one will be in a section of the bow of the vessel and the other will be in the stern. The mooring devices are coupled both on the dock and on the vessel.

The Michl patent (Michl, 1997) is an AMS for pleasure boats composed of two telescopic arms, one for the bow and one for the stern, both with rubber vacuum cups at their ends. The vacuum system is activated manually and the vessel is placed in a fixed position separated from the dock. (See Figure 4). It can also be used to moor two boats together.

Figure 4: Mooring by vacuum.



Source: Michl Patent.

4.3. Third generation: system of remote control by operator.

In this third generation only the Montgomery and Rositer patent of 2005 (Montgomery and Rositer, 2005) is included.

This patent develops a "robot" which, by means of an articulated arm with vacuum cups at its ends, is fixed to the hull of the ship. The device is capable of moving in the three directions, "vertical", "longitudinal" and "transversal".

Each mooring robot is attached to a structure on the vertical face or on the horizontal face of the dock, depending on the robot model and the obstructions found in the dock.

The technological innovation that the patent contributes is the incorporation of a technology of remote control by operator of the mooring robots, making them independent of each other.

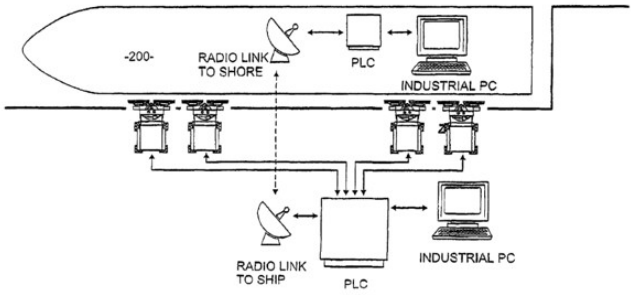
4.4. Fourth generation: total remote control system.

The fourth generation of vacuum cup AMS is made up of three devices which incorporate a total remote control system.

a) The Montgomery and Rossiter patent of 2007 (Montgomery and Rossiter, 2007).

This system incorporates an automatic control mechanism of the forces that the moored vessel exerts on each mooring robot controlled by a PLC (Power Line Communications), in order to be able to counteract them automatically (see Figure 5).

Figure 5: Automatic mooring system with remote control.



Source: Patent Montgomery & Rossiter, (2007).

This automatized mooring device can be installed on the hull of the vessel in order to moor it directly in a dock or to bring it alongside another vessel.

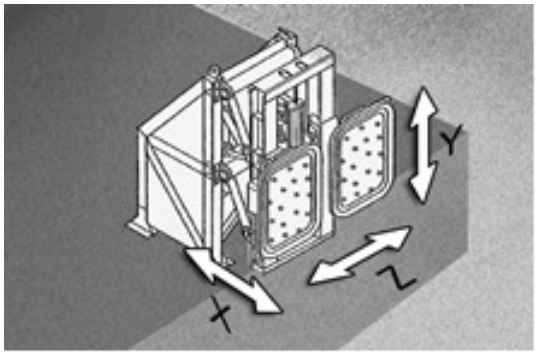
b) The Montgomery patent of 2009 (Montgomery, 2009).

This device modifies the means used to connect the robot to the vessel (see table A1 appendix A), incorporating some elastic elements which absorb the impacts caused by the wind and the waves, buffering the movements of the vessel. With this system, the safety of the moored vessel is increased, softening the impacts.

c) The Montgomery and Rositer patent of 2012 (Montgomery and Rositer, 2012).

This patent introduces the monitoring of the forces that affect the vessel generated by the waves, the tides, the wind and the movements produced during the loading operations. These forces are absorbed by the AMS by means of the ”coupling robots” (see Figure 6).

Figure 6: Automatic mooring system with remote control.



Source: Cavotec.

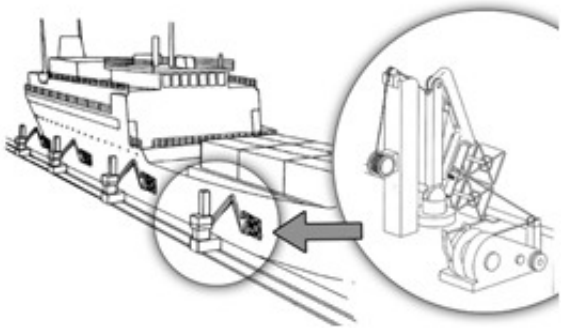
The program that reads the data includes alarms that jump when these forces rise above certain safety margins.

d) The Lee et al. patent of 2012 (Lee et al., 2012).

This is a system whose difference with respect to that designed by Montgomery and Rossiter (Montgomery, 2009), lies in the fact that the vacuum cup is placed at the end of an articulated arm installed in a structure on the dock. The articulated arm is moved by means of a davit with a winch with cable (see Ilustration 7).

The system is capable of minimizing the time and effort required to carry out the mooring maneuvers of the merchant vessels, keep the vessel moored safely and guarantee the minimum movement during loading and unloading operations.

Figure 7: Mooring system for ships, rail structures.



Source: Pat Lee and Han, (2012).

4.5. Fifth generation: remote control system with laser by telemetry.

This generation is made up of the devices of Montgomery developed in 2013 (Montgomery, 2013a, 2013b) which incorporate a remote control system with laser by telemetry.

a) The Montgomery patent of 2013a (Montgomery, 2013a).

This is a device that incorporates a telemetry system that allows simultaneous visualization of the data on board and on land and the transmission of the connection commands from the control station to the AMS.

b) The Montgomery patent of 2013b (Montgomery, 2013b).

This device improves and perfects the system of measurement of the parameters and includes a program so that the position of the vessel is maintained automatically. With this patent, each mooring robot can be controlled independently from the rest.

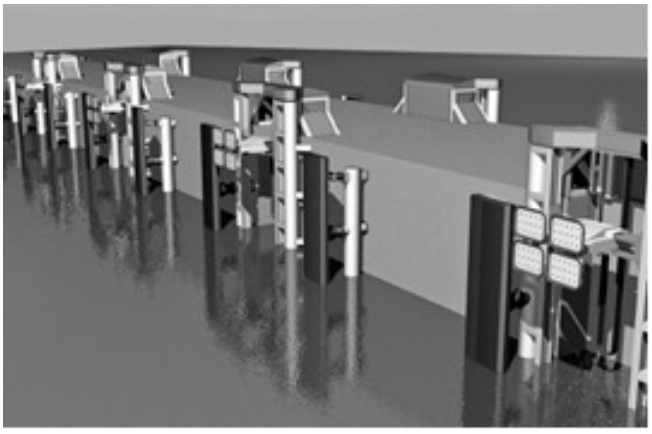
The data received by the processor through some sensors located in the robots are the following:

- the speed of the ship with respect to the terminal
- the acceleration or deceleration of the vessel
- the kinetic energy of the vessel
- the inertia of the vessel

It also receives another set of data from the on-board AIS and from the GPS.

This patent is the result of the combination of all the generations of vacuum cup AMS (see Figure 8) and consists of the following elements:

Figure 8: AMS.



Source: Cavotec.

- A certain number of mooring robots, with a coupling mechanism so that the vessel remains perfectly moored in its berth.
- A system that detects the movements of the vessel.
- A processor that calculates the movement required by the coupling mechanism of each mooring robot.
- A controller to control the movement of the mooring robots in response to the information received from the processor.

5. Discussion and synthesis analysis.

The United States is the leader in the publication of patents with AMS: of the 334 patents that were classified and analyzed to undertake this study, only 22 are from other countries such as New Zealand, Canada or Germany. The rest are all from the United States.

The authors who have had the greatest influence on the evolution of AMS by vacuum suction cups have been Montgomery and Rositer, but undoubtedly the one who was the precursor of it all and who introduced the concept of vacuum suction cups applied to the maritime world was Standwick in 1965 (Standwick, 1965).

There is no doubt that there is a relationship between the different patents. A correspondence has been established between authors, patents and the influences they have had on each other over the years in the different types of vessels, both merchant and recreational (see Figure 9).

The first patent of these AMS to be found is that of Steinhauer of 1914 (Steinhauer, 1914) which refers to recreational craft and those of Gorman and Smith both of 1951 (Gorman, 1951; Smith, 1951) are based on this one. These patents are very similar to each other: they include some improvement in the system, but mechanically they are similar.

The Gossen patent of 1959 (Gossen, 1959) and that of Kulick of 1960 (Kulick, 1960) are predecessors, with a visible influence on the subsequent generations.

The Standwick patent of 1965 (Standwick, 1965), is not in itself a mooring system but has had a clear influence on the subsequent generations of AMS (see Table 1).

Table 1: Patents cited in the Standwick patent of 1965.

YEAR	TITLE	AUTHOR
2001	MOORING DEVICE	HADCROFF J. / MONTGOMERY P. J
2002	MOORING ROBOT	
2003	DEVICE OF YARD OF BOATS	MONTGOMERY P.J./ ROSITER B.J.
2005	MOORING ROBOT	
2007	AUTOMATIC REMOTE CONTROL SYSTEM	
2009	MOORING SYSTEM AND RELATED MEDIA	MONTGOMERY P.J.
2012	AUTOMATIC REMOTE CONTROL SYSTEM	MONTGOMERY P.J./ ROSITER B.J.
2013	LASER SCAN FOR MOORING ROBOT	
2013	AUTOMATIC MOORING METHOD AND MOORING SYSTEM	MONTGOMERY P.J.

Source: Author.

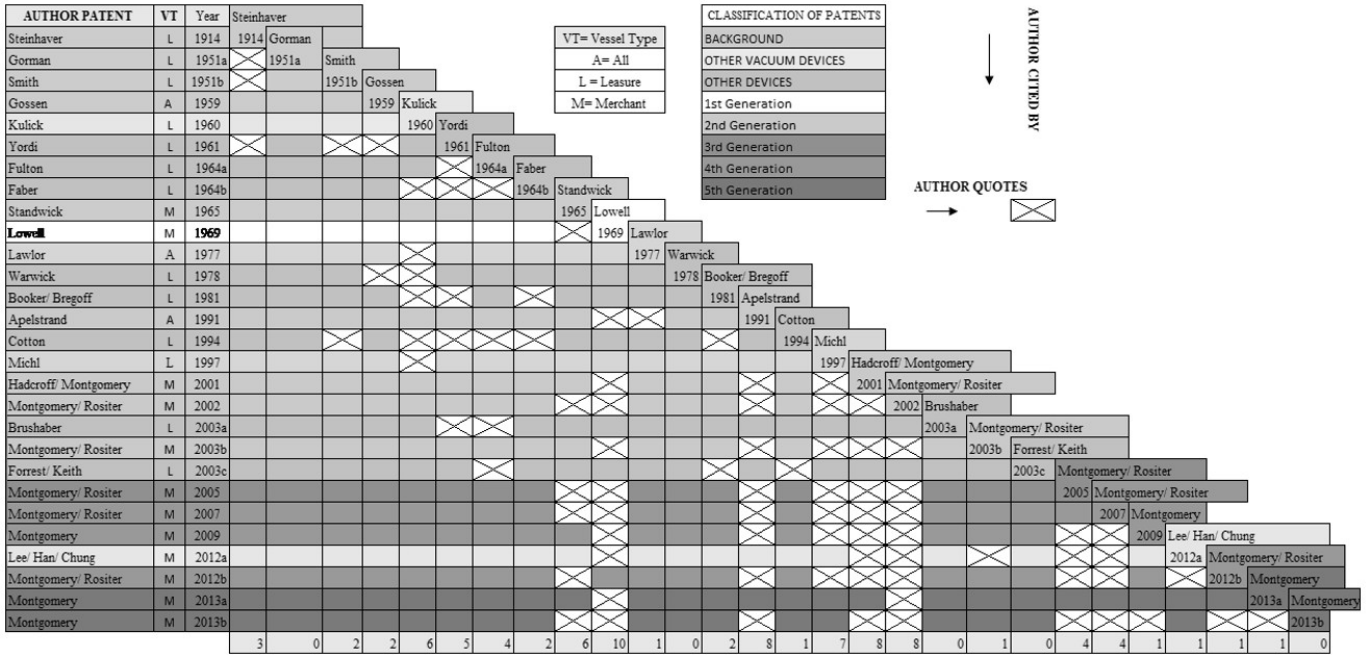
The 1969 Lovell patent (Lovell, 1969) is the first generation of AMS using vacuum suction cups, and together with the former are the starting points for the current system developed by Montgomery, which is being commercialized and implemented in many commercial ports around the world.

Lawlor's patent of 1977 (Lawlor, 1977) is an improvement on the system developed by Kulick in 1960 (Kulick, 1960). Almost all the patents found in later years are based on the Apelstrand patent of 1991 (Apelstrand, 1991) and, in turn, this patent is based on the Kulick patent. The Michl patent of 1997 (Michl, 1997), which has been considered as a basic influence on generations of automatic mooring systems by vacuum suction cups is also based on Kulick's patent (Kulick, 1960). The system developed by Hadcroft and Montgomery in 2001 (Hadcroft and Montgomery, 2001), is the first robot vacuum AMS. It is a patent based on those of Lovell, Apelstrand and Michl (Apelstrand, 1991; Lovell, 1969; Michl, 1997).

Montgomery and Rositer developed different patents between 2002 and 2013, each one complementing the others. These patents enhanced and profiled the vacuum suction cup AMS. The system has been improved through innovation in the remote control systems and through sensors for controlling the movements suffered by ships when moored.

The Lee et al. patent of 2012 (Lee et al., 2012) is based on the patents of Lovell (Lovell, 1969), Hadcroft and Montgomery (Hadcroft and Montgomery, 2001), and Montgomery and Rositer (Montgomery and Rossiter, 2007). This is a system which is similar to that of Montgomery (Montgomery, 2013a, 2013b) In keeping with what is indicated both in the present discussion and in paragraph 4 on automated mooring systems using vacuum suction cups, Table 2 has been elaborated showing the AMS generations which have been applied in commercial seaports for merchant vessels.

Figure 9: Ratio patents quoted.



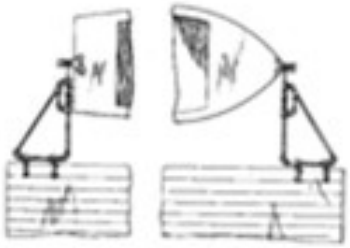
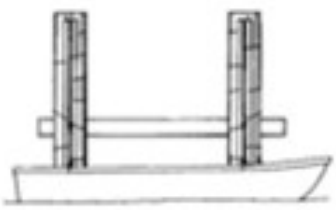
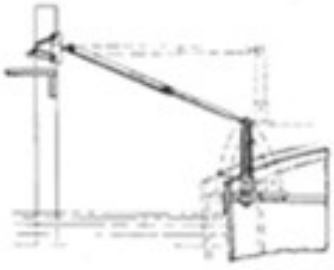
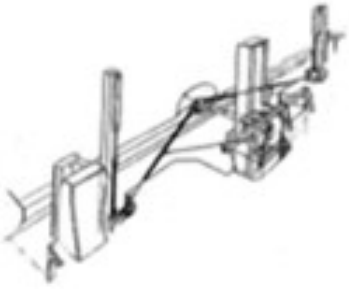
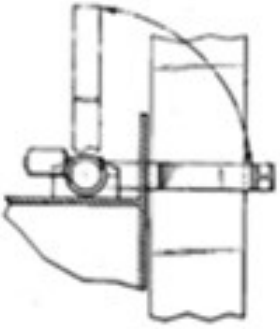
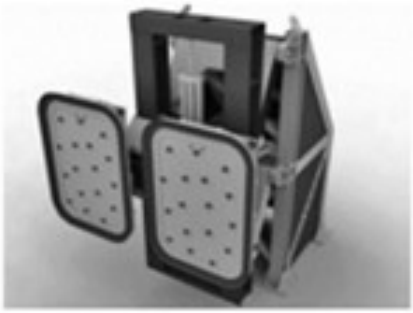
Source: Author.

Table 2: Evolution of automatic mooring systems.

GENERATIONS	DENOMINATION	CLASSIFICATION (PATENTS)/AUTHOR (YEAR)
Background:	First devices	Springs-based systems (pleasure craft) / Steinhauer (1914); Gorman (1951); Smith (1951) Intertidal Systems / Gossen (1959); Kulick (1960) First system with technology of subjection by vacuum suction cups / Standwick (1965)
First Generation	Arm Vacuum System	Automatic clamping system by suction cups. / Lovell (1969)
Second Generation	Automatic Vacuum System for Direct on The Hull	Dynamic robotic mooring system. / Apelstrand (1991) Automatic tie-down system for vacuum cups. / Hadcroft, Montgomery (2001) Mooring robot / Montgomery, Rositer (2002) Docking robot / Montgomery, Rositer (2003) Influences / Lawlor (1977); Michl (1997)
Third Generation	Remote Control System by Operator	Mooring system consisting of several "Robots / Montgomery, Rositer (2005)
Fourth Generation	Total Remote-Control System	The System a PLC remote control. / Montgomery, Rossiter (2007) It incorporates elastic elements to absorb the vessel movements. / Montgomery (2009) Collection of data and in the sample of the same in a screen. / Montgomery, Rositer (2012) System suction cup is located at the end of an articulated arm. / Lee, Han et al. (2012)
Fifth Generation	Remote control System with Telemetry Laser	Use of laser telemetry and obtaining distances and variations of movements / Montgomery (2013)a It perfects the system of measurement of parameters / Montgomery (2013)b

Source: Author.

Figure 10: **Appendix A.** Evolution of automatic mooring systems.

Patent Author/ Year /number	Patent Author/ Year /number	Patent Author/ Year /number
[14] Steinhauer F. 1914 (US1094610 A).	[15] Gorman W. 1951 (US2552424A)	[16] Smith FA. 1951 (US2569783A).
		
[17] Gossen MJ. 1959 (US28733712A).	[18] Kulick EL 1960 (US2938492A).	[21] Apelstrand L. 1991 (WO 1991014615 A1).
		
[25] Lawlor J. 1977 (US4008678A).	[30] Montgomery PJ. 2009 (WO 2009048342A2).	[33] Montgomery PJ. 2013 (US8408153B2).
		

Source: Author.

Conclusion.

1. The analysis of the databases analyzed with the AMS patents from all over the world allows it to be stated that 93.4% of them are from the USA.
2. The recreational sailing sector has constituted a test bed for the AMS applied to merchant vessels, since the first devices were designed for pleasure boats.
3. The installation of the AMS, thanks to their great versatility, does not require any structural modifications in the docks in which they are mounted.
4. The application of these mooring systems does not imply any reduction in safety, in relation to the traditional system, since the movement of the ship is automatically minimized during its stay at berth.
5. Although the first AMS vacuum cup patent came out in 1969 with Lowell, the first to be applied and commercialized is the one developed by Hadcroft and Montgomery (2001) in 1998. This was a prototype of a direct suction cup on the hull installed on the ferry "Aratere" of 150 meters in length and 12,000 GT. This device was the precursor of all AMS by vacuum suction cups.
6. AMS are currently used in the following countries: The USA, Canada, The UK, Denmark, Norway, Finland, Holland, Australia, New Zealand, South Africa and Lebanon. These devices have been implemented in the ports of these countries at different times. Hence, there is a coexistence of 5 generations of AMS.
7. Currently, the Montgomery AMS (2013) belonging to the 5th generation, which incorporate a system of remote control with laser by telemetry, are being installed in commercial maritime ports.

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