Development of a Ship Mooring Inspection Winch Tool with Extended Reality

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Abstract: Over the years, the interactivity between the real world and the virtual world has been increasing, making it attractive for engineers to increasingly seek new tools for application in industrial areas Practices that reconcile the safety of people and assets, adds strength to investments. The focus here is a solution for working with winches for ship mooring systems. The mooring system used to moor ships at a pier is made up of methods characterized using combinations of hooks, bollards, and winches. Through the instrumentation on board this equipment, information is obtained to analyze the stabilization of the mooring. The main parts of the winch system consist of the sensing and measuring system, cable tension measurement system, electrical and the mechanical system. This work proposes the development of an extended reality application for training maintenance teams. The application will enable the trained team to interact with the equipment's functionalities and information in a virtual and safe way, thus ensuring they have access to the operation, fault diagnosis with simulations of problem solutions in a virtual reality environment. Is still expected to be added, in future developments, a of virtual interfaces for remote equipment operations increasing the speed of fault identification.

1 INTRODUCTION

The mooring system is complex, made up of equipment that guarantees the stability of the ship during its mooring period. These in turn consist entirely of winches and land hooks, responsible for the safety of mooring ships. At TMPM (Terminal Marítimo da Ponta da Madeira) in Vale São Luís, Brazil, there is four piers where ships are moored.

The piers I and II are protected from tidal variations due to their physical characteristics. However, pier IV, due to its characteristics and location in the open sea is directly affected by variations in sea currents and tide.

The complexity of pier IV is driven by the responsibility of the shore winch. In turn, the analysis and operability of this functionality is the responsibility of the ground operations team, which analyzes the data received throughout the loading and tide variation process and directs the operator to interact with the equipment, whether local or remote interaction, to apply the appropriate safety operational tension to the ship's mooring cable.

The load cell is the main monitoring instrument of the mooring system, responsible for ensuring accurate information to the operator about the mooring tension. However, the cable tension of the monitoring system is not the only functionality that must be taken into consideration. It must be considered that the winch depends on its entire operability so that when requested, it can act effectively to tension or loosen the cable.

The winch is exposed to marine weather and subjected to impacts during its operation, which tends to cause defects. Thus, it is subjected to regular maintenance stops which, in turn, can impact operational losses and even affect ship loading and security. Problems can occur whether the winches are at rest or when in operation. In this situation, the maintenance team is called and has to intervene in the maintenance

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of the equipment.

Currently, the maintenance team, when called, directs a technician to go to the location and diagnose the problem. This treats the problem by acting directly on the equipment, however, failure situations can occur between the electrical /mechanical/ hydraulic areas and the professional is not trained in all disciplines. When it comes to mooring ships, faulty equipment can even cause a catastrophe.

For example, a stray ship can collide with other moored ships or even with other piers, even so, there is no way to measure the losses of an accident of this magnitude because it involves large machines.

Electrical inspection of the winch in the field has some disadvantages such as: the exposure to risk related to SS&MA (Health and safety & Environment); exposure to the operational area, mainly in circumstances where the system may be operational; and travel time from the workshop to the pier area (1400m from the workshop to the bridge entrance plus 1800m from the bridge to the pier entrance plus 1000m to the Pier itself).

Therefore, the development of an inspection tool with extended reality becomes interesting. Through this tool, the maintenance team will be able to train virtually with the aim of an intervention focused on the likely point of equipment defect, increasing the effectiveness in solving the problem. It can also be highlighted that the use of a tool with extended reality will bring greater security to the professional's training, which can be carried out in a safe environment, not needing to be carried out directly on the equipment.

The main motivation for using this tool is that the user will be trained to inspect the equipment and, when there is a real need for a defect in the real equipment, they will gain agility in solving the problem. If the developed tool enables online connection with the equipment, the gains would be extraordinary, as the user could identify the defect remotely and go to the location with the defined solution significantly reducing the ship's mooring risks.

In summary, the application will allow the trained team to interact with the functionalities and information of the equipment in a virtual and safe way, thus ensuring access to the operation, diagnosis of failures with simulations of problem solutions in a virtual reality environment.

2 THEORETICAL AND SCIENTIFIC FRAMEWORK

2.1 Ship Mooring

The Mooring System is carried out as follows: when the ship is positioned on the pier by the tugs, the onboard cables begin to be launched, which in turn are hooked to the land hooks. This process takes approximately 1h30. Once completed, the laying of the earth cables begins. These, in turn, are the cables for the earth winches, the object of this project. The operator begins the process of releasing the cable to be hitched to the ship. Depending on the ship, the hitch may be on bollards or even ship hooks. Figure 1 depicts the land and ship equipment.

Figure 1: Ship at berth. Source: VALE (2018).

2.2 Mooring Winches Automation System

The mooring winch system is integrated into a robust automation system, comprising control associated with PLCs (Programmable Logic Controllers) for equipment operation; remote monitoring and activation system through the system supervisory; and the PIMs system for operational and monitoring data, and statistics.

The supervisory system, well known as the human-machine interface, makes it possible for the operator to remotely interact with the equipment, having visual and operational control of the equipment. It is worth noting that for it to be operable, a remote release must be done on the equipment. Figure 2 illustrates the print taken from the winch supervisory system screen.

The equipment's automation control system is developed through a PLC application using specific software. The one used in the equipment was RSLogix, specifically for use in Rockwell PLCs.

The equipment's electrical panel has several control and drive components. This, in turn, is specific to

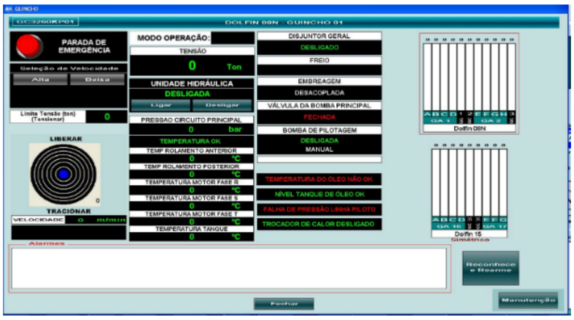

Figure 2: Winch supervisory system screen.

the operational electrical control of the equipment. In Figure 3, it is possible to check the winch electrical panel.

Figure 3: Power and Control Panel.

There is also the Rockwell distributed I/O panel, which is the connection point for all instrumentation on board the winch. Figure 4 illustrates this panel.

2.3 Extended Reality

This section highlights the evolution of augmented reality today and how it can be used in educational or training processes, including ship mooring training.

2.3.1 Virtual Reality Breaking Paradigms

It appears that technology has been accompanying the industry for around 50 years. This evolution is growing day by day. For some time now, technology added to the increasing reality has been applied in various segments, such as: training, maintenance support, operations (Engineering 4.0), among other segments. In the literature there are reports of the benefits related to maintenance in augmented reality, aiming to reduce

Figure 4: Distributed I/O Panel.

risk exposure and bringing benefits to users' health, as in the work of Justimiano et al. (2021).

A notable advance can be seen in the graphic quality of many digital games in recent times, without losing sight of the ease of use of consoles with much more exposed quality, displaying high-performance computing capacity, compared to the CAD programs known on virtual platforms (de Oliveira et al., 2017).

In a simplified way, virtual reality (VR) is an advanced interface technique between the user and the computer, which simulates a real environment in a virtual way, allowing the interaction, visualization and manipulation of three-dimensional synthetic environments generated by computers using certain types of multisensory channels. VR enables the user to have a high-performance experience of reality. From the virtual environment with new versions of interaction, using increasingly dynamic keyboards or controls, VR enables innovative experiences that lead to an increasingly detailed understanding of projects or activities of their implementation in a physical environment (de Oliveira et al., 2017).

VR allows navigation in the digital world using computer graphics, giving the user a three-dimensional view of the real world, which requires a hardware and software structure capable of recognizing six types of movements: front/back, up /down, left/right, right/left angle, up/down tilt, and clockwise/counterclockwise rotation. This dynamic of movements allows a simulation to the point of giving the user the sensation of touching objects, causing a change with the movements established in real-time (Valerio Netto et al., 2002).

2.3.2 Augmented Reality with Technological Advancement

Augmented reality differs from virtual reality due to its ability to generate new multimodal interfaces with high ease of manipulating objects in a given space, in which the user can use their hands to interact with a real environment. To make everything happen, the use of augmented reality techniques can place real elements, using optical tracking so that the scene has maximum realism, without the technological apparatus of much connectivity. Therefore, it is possible to create detailed and immersive environments, with interactive elements to allow several innovative applications, as they allow the reliable reproduction of real-life environments such as a house, bank, university, or even a city, guaranteeing the user interaction with each part of the environment and its proper purpose (Kirner and Tori, 2006).

For Kirner and Tori (2006), augmented reality can be defined as "the enrichment of real environment with virtual objects, using some technological device, working in real time". The mechanisms for making this combination between these realities stand out due to the user's sense of presence and the quality of the images, leaving them free in the environment without the application of as much technological equipment as happens in virtual reality. With augmented reality, the feeling of coexisting with the real world in the same space can combine and align real and virtual objects in real time.

2.3.3 Learning Methods

In recent years there has been a significant increase in the application of mobile devices in the field of education. The educational or training process constitutes a purposeful interaction with technology mediated by learning content between teachers and students where teaching materials seek to solve educational tasks in a systematized and updated way for the development of students. In this sense, the learning environment is virtually guided by information and communication technologies combined with traditional teaching technologies providing greater understanding with virtual environment tools (Zinonos et al., 2018).

With recent technological advances in the areas of cyber-physical systems, actuators and sensors, the flexibility of areas along value chains have demonstrated increasing digitalization in both society and industry. In this context, an ambitious technological trend is "Augmented Reality" (AR). Its use facilitates employees' work by providing data in specific situations, in real time and with targeted information. As a result, connecting data to machines results in work without the need for a fixed work environment. However, the inclusion of new technologies also implies a change in the way people work, leading to the restructuring of work processes, particularly in the manufacturing industry (Sorko and Brunnhofer, 2019).

Due to this factor, augmented reality offers several potentials for the industry, allowing, for example, digitize process, in real time, for parallel processes. In this regard, two types of processes can be mentioned: learning processes and industrial processes. If the focus is on industrial processes, it is possible to check which stage can be improved, the reduction of delivery times, and activities to be carried out, observing the step by step of a work process (Sorko and Brunnhofer, 2019).

Therefore, some industries already apply augmented reality in their processes, developing environment projects and activities inherent to the development of employees in the learning process. In the view of authors Makransky and Klingenberg, virtual reality improves safety training in industrial processes (Makransky and Klingenberg, 2022). The use of these resources can positively affect the results of safety training, since engaging training is three times more effective in promoting knowledge and skill acquisition, compared to non-engaging training.

AR-based simulations are more immersive as they promote high levels of psychological presence, offering the sensation of being at the scene of the activity, which are often difficult, expensive or dangerous to produce in real life (Makransky and Klingenberg, 2022).

2.3.4 Augmented Reality in Ship Mooring Training

Currently, some companies are already using augmented reality to carry out safety training. This is the case of OMS-VR, a Ukrainian company, which carries out various maritime safety training in VR in the same location, where it is developing its own software and hardware solution. In this case, VR training allows obtaining results on the professional's physical and psychological state in various stressful situations, without exposing them to the risks of such activities, including equipment for cargo handling, pump room for the fire detection and firefighting system on the Ship's deck and ship mooring winches, all on board.

What is desired in this current research project is the implementation and analysis of a methodology applicable to land winch mooring systems, where the principles for training are like those observed in a real world training, seeking acceptable principles for a better condition of safety levels for maintainers.

In navigation mooring cable protection training, the modules provide practical instructions signaling dangers and other associated risks, as well as identifying the return zone in compliance with the requirements of the STCW convention, Regulation 1/12.

2.4 Virtual Reality Development Feature

This section presents the tools used to develop the augmented reality application proposed in this work.

2.4.1 Software Unity

Unity is a set of diverse 3D modeling tools for creating interactive media optimized in simple geometries, enabling detailed editing and UV unfolding, as it has rapid prototyping. Unity is a widely used tool, as it guarantees support for independent developers, allowing the development of games and simulations in a more accessible way (Haas, 2014). This software is compatible with different platforms (PC, consoles, mobile, VR and AR) using a visual editor and programming through and scripting, offering users professional tools capable of meeting the requirements of any game.

The main idea is to bring the reality of the winch to a virtualized reality environment integrated with the real functionality of the equipment, providing the user with an interface with the equipment in a graphic image, making it possible to train the inspection.

Unity offers developers three ways to program applications attached to the IDE: Unity JavaScript (Commonly known as UnityScript), C#, and Boo. Regardless of the choice of which language to use, they all allow developers to implement the same content regardless of the established language (Haas, 2014).

2.4.2 UnityScript

UnityScript is a language that resembles Javascript, and is the best choice for beginners. Generally used by most developers, it is easier to obtain assistance in the IRQ forum or the Unity forum. This language is simple to learn and quick to type. Javascript is a prototypical language, while UnityScript is a classical language, which grants it certain benefits. However, even though UnityScript has dynamic typing support, in certain cases it will be less efficient than the C# language, as the compiler must recognize that the object type can change (Haas, 2014).

2.4.3 Boo

The Boo language has a syntax similar to Python, and its structure is similar to UnityScript. However, it is little used by users, which makes it difficult to seek assistance (Haas, 2014).

2.4.4 Virtual Reality Glasses

Virtual reality glasses is a equipment that allows you to view images in a stereoscopic 3D effect. This can be connected to a PC and even smartphones. This allows the user to immerse themselves in a virtual 3D environment to practice inspecting the equipment. Since 2012, with the creation of the so-called Rift glasses, many possibilities have emerged with simulations of real environments, being designed with a degree closer to reality, in which high-performance projects are presented with a level of immersion in dynamic visualization spaces in their direct interaction with projects implemented based on the technological advancement of virtual reality (de Oliveira et al., 2017).

2.5 Use of Virtual Reality in Training

Nowadays, when it comes to economic issues, the job market and technological advances, organizations must adapt and look for effective and efficient ways to develop training programs, in order to educate, inspire and awaken knowledge in their employees, at the same time as they face the challenge of maintaining employee engagement and motivation in their training. Thus, while companies are challenged to maintain this engagement, comes the task of providing standardized training in a variety of geographic locations, with different groups of employees, which can result in high financial and energy costs, and expose the employee to various risks throughout the process (Makransky and Klingenberg, 2022).

Therefore, it was necessary to search for a way to overcome these challenges, creating flexible learning environments and incorporating technology to complement learning, and develop trained professionals in an effective and safe way. To verify such learning effectiveness in augmented reality training, a study was carried out by the Department of Psychology in Copenhagen, involving a training program at a maritime industry, on the islands of Kiribat, to investigate whether carrying out training based on augmented reality is more effective than standard safety training. It is detailed in the work of Makransky and Klingenberg (2022).

The main issue highlighted is that the combination of augmented reality associated with a generative learning strategy can allow students to reflect on the topics covered even after class, which increases learning results. Most training carried out in a standard way generally uses a single method to pass on content, without evaluating the needs of each student, or providing the opportunity for professionals to experience the relevance of their activity, without exposing themselves to risks (Makransky and Klingenberg, 2022).

In the study in question, a sample was used consisting of 86 students, both men and women, between 16 and 40 years old, all of them from the maritime education center in Denmark, Svendborg International Maritime Academy. The experiment was carried out as part of safety training on the topic of "Safety During a Mooring Operation" (Makransky and Klingenberg, 2022).

To obtain a comparative study on security training based on virtual reality, and standard training, the students in question were exposed to two different types of methodologies, one with a trainer and the other with VR, where the results were obtained. following results.

The results of this research demonstrate that the group included in the training with augmented reality significantly accepted and appreciated this training, obtaining significantly greater intrinsic motivations and changes in behavior. It was then discovered that professionals obtained higher levels of pleasure, motivation and learning, but the result in self-efficacy did not maintain many changes.

Therefore, the study in question points to several pieces of evidence suggesting that training with immersive simulations in augmented reality leads to significantly greater pleasure in learning, highlighting the potential that immersive technologies have with a wide range of users in the future.

3 MATERIALS AND METHODS

Pier 4 North was the largest project implemented at Vale, approved in 2008 by the board and it is located in São Luís do Maranhão at the Ponta da Madeira Maritime Terminal (TMPM). This project had as its fundamental principle the capacity for 130MTPA (Million tons per year), that is, an additional 30MTPA more than the 100MTPA (Million tons per year) that already had operational capacity. The project did not only involve increasing the port's unloading, storage and boarding capacity; it also generated many job and income opportunities for the entire region.

Ore shipment includes a long journey for the iron ore to be shipped. This process begins in Carajás-PA where the ore is extracted. After the entire process at the Carajás mine, it is transported by the Ramal Ferroviário Sudoeste do Pará to the TMPM-SL in Maranhão. In Figure 5, there is an aerial view of Pier IV South and North, where the ship moored can be seen in the North Berth, in its first test with cargo, and in Figure 6 it is possible to see the location of Pier IV on the map.

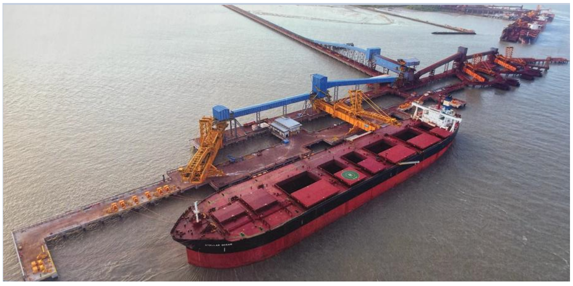

Figure 5: Offshore Project - First test with Pier IV North Load. Source: VALE (2018).

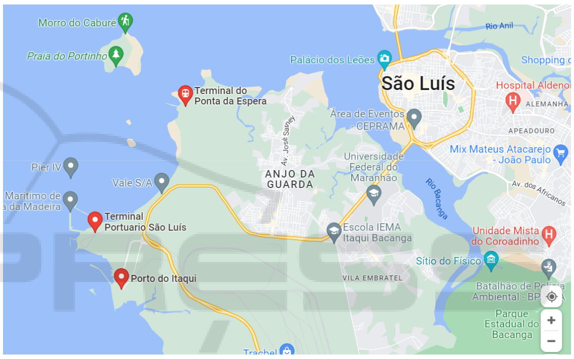

Figure 6: Geographic Location – TMPM. Source: GOOGLE MAPS, obtained in 2023.

The boarding area at Pier IV consists of 2 loading berths (South and North). The mooring system is carried out as follows: first, the onboard cables are launched, which will be fixed to the land hooks, after the onboard mooring is completed, the ground cables are launched, which, in turn, originate from the winches. of land. The effectiveness of earth winches is guaranteed through scheduled inspections to verify the state of integrity and functionality of the equipment. Based on these inspections, decisions are made regarding the actions of the areas responsible for preventive and corrective maintenance of the equipment. In Figure 7 it is possible to see a calibration procedure for the winch load cell.

3.1 Data

Equipment inspection is currently carried out visually through operational testing and must be carried out in person. All equipment history data is obtained through PIMs. With this record, reports of failures that occur during equipment operations can be ob-

Figure 7: Winch Calibration.

tained and statistics and trends can be generated for preventive maintenance and plans of reviews. In a graphical view, the process does not present any interaction with the equipment, just a database in which spreadsheets of registered events in the operational or idle state of the winch are processed.

All information is collected from the winch PLC via the ETH/IP communication network. The model developed in Unity will be used to link real and online data from the PLC application and supervisory system with the developed 3D model. This collected data will refer to status information in the actual operating situation of the equipment. It is expected to have inspection training in the model, which will provide a link between the real scenario and virtual reality.

3.2 Methodology

The development of the extended reality application takes place during the development of the project. In this phase, an extended reality tool is used so that the user, with the 3D equipment, has the ability to interact with the equipment virtually.

The entire project is developed with real information from the equipment, so that the user can, in a virtual system, obtain data that is as close to reality as possible.

The feasibility of obtaining virtualized images of the winch with an interface with reality will be studied. For the development of the tool, the Unity software is used and the Virtua VR Oculus Reality Glasses are used for visualization. In the testing phase, the application will be submitted to users. After completing the training, feedback will be requested through a questionnaire on the experience of carrying out the inspection using the tool. The main topic will be focused on results in terms of expectations with equipment.

3.2.1 Analysis Procedure

The suggested procedure is to take the tool to users (professionals involved in winch maintenance) so that they can give a feedback on the developed product and, through the results of their training on the tool, generate a spreadsheet and a technical report with information about their experience. A statistical analysis will be done on the quantitative and qualitative data collected.

3.2.2 Requirements for Winch Inspection

In this step, the necessary requirements are presented for the winch inspection to occur safely in a hydraulic mooring system, and which will be taken into account when preparing the proposed tool. Some procedures are adopted to control machinery and mechanical equipment. An interesting part to note is the hydraulic power unit that is attached to the base structure of the mooring winch. This unit has two power sources to ensure the necessary flow for the proper functioning of the winch. It consists of a 132kW power supply unit and another of unit of 4.8kW, which can all be delivered as a compact unit.

Another frequently used piece of equipment is the L46 pump, which is a fixed flow gear pilot pump that is used to activate the cylinder brake or change the engine displacement, with a composition of directional control valves of various shapes that are accompanied of solenoid valves and pressure filters to prevent excessive pressure from occurring.

The pilot pump operates in a controlled manner via the PLC in accordance with the signal from the pressure switch installed in the pilot line, and it is recommended to keep the selector in automatic mode. The pilot pump has a “Manual/Automatic” selector. The selector must always be in the“Automatic” position. The PLC controls the start/stop of the pilot pump via a pressure switch. With “Manual Selection”, the pilot pump starts when pressing the green ”Start pilot pump” button. Once the pump is running, the button remains lit. To stop the pump, press the red “Switch off pilot pump” button. With ”Automatic Selection”, the pilot pump is controlled via the PLC and pressure switch PS1.

The mooring winch is assembled with the hydraulic unit on the same base, where hydraulic and electrical power is supplied. This unit only needs power supply connection and communication connection with the remote-control room.

The mooring winch is operated from the control panel, so the site will always communicate with the remote-control room in “Local Run” mode. In this sense, the recommendation is to constantly provide information about alarms, pressure, load indication.

It is worth noting that the winch cannot be controlled remotely if this mode is selected. In “Operation in remote mode”, the mooring winch can be controlled from the remote-control room based on the hauling information. On the other hand, when it comes to emergency operation, the mooring winch is operated by the local control panel, noting that in this case, the system does not communicate with the remote-control room. Figure 8 represents the panel and the light indications on the winch selection modes.

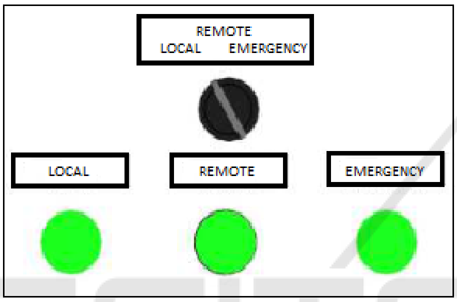

Figure 8: Winch Selection Modes. Source: VALE (2018).

For winch operation, the system must have the flow and pressure necessary to allow the hydraulic motor to operate. The hydraulic pump in operation enables smooth starting after 10 seconds of system operation via joystick control. It is not recommended to operate in joystick mode until startup is complete. The system is signaled by the green light on the control table. Figure 9 represent the control panel, joystick.

Figure 9: Hydraulic Pump Control Panel.

In this context, for the winch to function correctly, it is necessary that all controls and equipment comply with the characteristics presented above. Its operation must occur in “Local Control” mode, and its power lamp must be on, indicating that voltage is available. The pilot pump must be activated (being controlled through the PLC), together with the main pump, which provides the flow and pressure of the hydraulic motor, for the correct winch mooring. Its control, as previously mentioned, is carried out using the joystick, and the speed and rotation of the winch can be controlled. To perform the operation from the control room in remote operation, it is necessary to activate the “Remote” selection mode.

3.2.3 Elements Considered for Inspection

Following is the roadmap of the research project’s inspection plan:

1. Basic knowledge of winching
2. Electric
   - Electrical panel
   - Murr I/O Board
   - Local control panel
3. Hydraulic System
   - Hydraulic elements
   - Hydraulic plan
4. Mechanic
   - Lubrication
   - Reducer
   - Reel
   - Brake
   - Load cells
5. Fairlead
6. Technical assistance
7. Spares

In Figure 10, there is an image of the winch hydraulic system assembly.

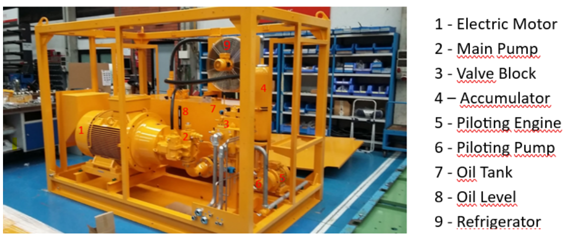

Figure 10: Hydraulic System.

3.2.4 Next Steps

This project is currently in the application development stage, where we are using the information collected about winch inspection, described in 3.2.2 and 3.2.3. Volunteers to participate in the experiment have already been contacted and, with the approval of the

University's research ethics committee, it will soon be possible to begin testing. All from applications that enable broader learning in handling equipment.

4 CONCLUSION

Currently, some companies are already using augmented reality to carry out safety training. VR training allows obtaining results on the professional's physical and psychological state in various stressful situations, without exposing them to the risks of such activities. The contributions generated can address engineering in more detail. With the development of graphic images and programming, it is possible to improve the interface between man and machine with greater precision and integrate extended reality with automation using data from PIMs and PLC database.

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