Final report

1. Project details

Project title	**Offshore Wind Turbine Repair Robot**
File no.	**64018-0557**
Name of the funding scheme	**EUDP**
Project managing company / institution	**Rope Robotics**
CVR number (central business register)	DK37592021
Project partners	**Siemens Gamesa Renewable Energy (SGRE)**
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2. Summary

Summary English version

At Rope Robotics, we have developed a robot that conduct repairs of the leading-edge of the wind turbine blade. The Rope Robotics' solution minimizes the cost of wind turbine blade repair as it requires less staff and less standstill time of the wind turbine, and it certainly replaces hazardous work methods where rope access technicians are hanging in ropes from the top of the wind turbine used today.

The overall objective of this project was to demonstrate and document to the blade maintenance market that the robot meets the demand for safer and more efficient repairing processes.

We have proved this during field tests at different wind farms together with our project partner Siemens Gamesa renewable Energy (SGRE).

This project has made it possible for Rope Robotics to finalized and implement the optimizations of the robot and the repair solution to the stage ready for commercialisation. This includes the complete operational set-up to perform wind turbine blade repair.

Technology wise, Rope Robotics has upgraded the robot significantly during this project. The main achievement has been an essential change and the implementation of a dynamic move concept, as well as developing and implementing new tools being used for the complete process of sanding, cleaning and applying the leading-edge protection material. We also qualified a new leading-edge protection material, which also within this project has been thoroughly tested by SGRE.

Operational wise we now have a complete operational process in place with all support equipment well incorporated, clearly defined operational routines and a well working communication set-up.

It all makes the Rope Robotics repair solution complete. This project has not only made it possible to raise the quality but also made it possible to take several steps out of the original repair process. Specifically. it has meant a reduced repair time to approximately 7 hours per blade, which has a positive impact on wind energy in the future.

Summary Dansk version

Hos Rope Robotics har vi udviklet en robot, som kan reparere forkanter på vindmøllevinger. Vores robot løsning minimerer omkostninger ved vedligehold og reparation af vindmøllevinger, da den kræver mindre nedetid for møllerne, færre folk involveret og erstatter den farligt udførte nuværende mest anvendte arbejdsmetoder, hvor rebteknikkerer arbejder hængende i reb fra toppen af vindmøllen.

Det overordnede succeskriterie for dette projekt, var at demonstrere og bevise for vind industrien, at robotten lever op til deres krav om større sikkerhed og mere effektive reparations processer.

Det har vi bevist under vores tests i forskellige vindmølleparker i samarbejde med vores projekt partner Siemens Gamesa Renewable Energy (SGRE),

Projektet har gjort det muligt for Rope Robotics at færdigudvikle og implementere optimeringer af robotten og vores reparations metode til det stadie, som gør os klar til kommercialisering. Dette indebærer også et veludviklet, komplet og gennemtestet operationelt set-up.

På teknologisiden har Rope Robotics lavet væsentlige opgraderinger. Det mest revolutionerende vi har udviklet og implementeret, er ændringen til et dynamisk bevægelseskoncept og de robotværktøjer, der anvendes i vores reparation proces, som udgør slibning, rengøring og pålægning af forkantsbeskyttelsesmateriale. Et materiale vi har kvalificeret i løbet af dette projekt og som SGRE ydermere også har gennemtestet.

Operationelt har vi sikret, at vi nu har en komplet proces på plads med alt tilhørende support udstyr, veldefinerede operationelle rutiner og et yderst godt og funktionsdygtigt kommunikationsset-up.

Ovennævnte gør Rope Robotics' reparations løsning komplet. Dette projekt har ikke kun gjort det muligt at højne kvaliteten, men også gjort det muligt at fremtidssikre vores reparations proces ved at minimere flere processtep i den oprindelige proces. Helt konkret har projektet gjort det muligt at reducere vores reparationstid til syv timer per vinge til gavn for fremtidig vind energi.

3. Project objectives

The objective of this project is to demonstrate the functionality of the robot in real environment and to overcome the development and logistical challenges associated with offshore maintenance.

The overall success criterion is to demonstrate to the market that the robot meets any demand set by wind turbine owners and manufacturers, and to document its performance and thereby become accepted as the new industry standard for wind turbine blade repair.

Our robot invention makes it possible to improve the productivity of wind energy. The wind turbine blades get eroded due to harsh weather, which means less productivity. The repair done by our robot rebuild the aerodynamic shape of the blade and thereby regain its the productivity.

Figure 1 Robot in action in field test in DK

4. Project implementation

The project went from being finetuning and maturation of existing development to which we should add the offshore ancillary equipment, to a complete rethinking of the existing repair process.

Halfway through the first project year we realised we had to make some extensive updates to the repair process to achieve the target speed of the repair process. This was based on the knowledge gained during the first field test in Bassens, Germany during the summer 2019. Several process steps did not show the expected speed and performance. We got a project extension approved and initiated the necessary and pervasive upgrade of the robot and the repair processes. The “extended upgrade” had started.

The extended upgrade meant validating and selection of a new Leading Edge Protection (LEP) material. Until now we had applied both filler and spray paint which required sanding and cleaning in several steps both before and after, and both applications cured slowly. Steps which in total made a long process and made the standstill time of the wind turbine very long. Standstill time means lost energy production and more expensive energy to the consumer.

We validated and chose “Teknoblade 9000” which in a simple way can be described as a combined material of filler and paint. To replace earlier methods with the use of Teknoblade 9000 we could cut several of the existing processes down, spend less time and cut down costs as well. But it required a new navigation and move system.

We upgraded the robot to be able to move while working on the blade. Earlier it worked in sections on the blade and the robot was stationary on the blade while working. Now it should apply the LEP while moving on the blade in one long go while applying LEP on the leading edge. This transformation required new tools for sanding, cleaning, one LEP tool for the application on leading edge and a specific TIP tool for application on the TIP of the blade.

We spend most of 2^{nd} project year to develop and assembly the first versions of above-mentioned tools in combination of tests in our workshop/test facilities. Parallel to the extended upgrade we made sure to optimize the communication module and to design and develop the ancillary equipment needed while running operations using the first robot version. We also performed a dedicated and successful simulated offshore test.

3^{rd} project year was mostly production and implementation of the extended upgrade. We ran several stabilizing tests in real environment to prepare and to be ready for the nearshore demonstration in Denmark, which we successfully executed together one of our partners in the autumn.

Figure 2 The robot running processes on the near shore demonstration

Siemens Gamesa Renewable Energy (SGRE) has been our important partner within this project. They have ensured we had access to several of the wind farms where we have been running the simulated offshore test and several of the stabilizing tests. Further have SGRE been valuable sparing for the development of our repair specifications. Parallel to our validation of the LEP material "Teknoblade 9000" has SGRE also tested the product thoroughly in real environment and have qualified it as well. This means that one of the biggest wind turbine manufacturers and very important players in the market has approved using the "Teknoblade 9000" on their blades, which without doubt play an important factor for our future business.

Both during the 2^{nd} and 3^{rd} project year, did the restrictions due to the COVID-19 make many of our activities difficult and delayed a few of our deliverables.

The last 6 months of the project has been used to secure the final maturation of the latest robot version and to ensure all repair processes are thoroughly tested and errors corrected. The robot is ready to be commercialised.

We have faced several risks within the project that have caused some challenges but with mitigating measures we have manged the project successfully.

The COVID-19 situation has made it difficult. Due to lockdowns and travel restrictions, we have had to interrupt an important field test in South Afrika, for month we were missing test capacity as we could not get access to sites. This delayed our field tests, and the travelling became more costly.

We have also faced financial challenges due to above mention delay, the planned market entry came later that expected which had a negative impact on turnover. This was solved with new investors.

The extended upgrade was the absolute correct decision but its implementation meant also a longer maturation time of the robot and even we have the ancillary equipment for offshore operations ready, it was not before at the end of the project we were succeeded with a successful offshore/nearshore demonstration.

We reached all milestones with only a few delays on a couple of them.

On serious unforeseen challenges within the project, we must mention COVID-19, which indeed challenged the project in many ways.

5. Project results

The original objective of the project was not fully obtained as we had to downsize the complete offshore demonstration to a nearshore demonstration. We realized this on an early stage in the project as we were forced to add the extended upgrade to the project which we knew would make it really hard to get a robot setup fully matured for offshore use.
However, we managed to get extraordinary results and have the onshore commercial set-up we aimed for. We have all procedures, manuals and documents, and equipment ready to commercialize our operation on-shore and we are well prepared to the much more demanding offshore operation.
We have obtained impressively many technological results during this project.

Robot and repair process
During this project we have built two robots which also have been fully upgraded to be the final model 1 robot version ready for production. When this project started and we built the robots, they were built to execute what we today call the spray paint repair process. The spray paint repair process consisted of the following steps:

Sanding > Cleaning > Filler application > Shape filler > Spray paint application

Total time consumed: approx. 30 hours. To this add the curing time both of filler and spray paint and a manual tip repair.

New process after implementing the extended upgrade:

Sanding > Cleaning > Coating application > TIP repair

Total time consumed: 7 hours

This impressive time consumption reduction in the repair process, was obtained due to the decision of developing and implementing the extended upgrade.

Extended upgrade
The extended upgrade consisted of a new navigation system, validation of a different type of coating and tools to be used within the new process.

We validated the Leading-edge protection (LEP) material “Teknoblade 9000” from Teknos. This coating could replace both the filler and spray paint. It has a very short curing time but needs to be applied in one process. Therefore, we changed the navigation system completely to be able to move the robot while applying LEP.

We use vacuum to stabilise the robot on the blade. We went from suction cups to a foam covering the complete backplate of the robot cabinet. It is very important that the vacuum through the foam is stable and uniform. To manage the vacuum, we have divided the foam area into sections. This gives high flexibility. We can control these sections, so if the robot needs to move quicker on the blade, then we can turn off the vacuum in a section. We have installed pressure sensors that monitor the vacuum in all sections.

To support the friction management, the ability to slide on the blade and to control the move process, we have developed a suspension system. The role of the wheels is to keep the robot in the right position but also to support the correct level of vacuum under the foam.

We have also developed the following tools:

The brush sander
When the robot is hoisted and placed on the blade, we start to sand. The sander is completely redesigned and consist of a cylinder that is placed on the leading edge and correct angled to ensure it sands the leading edge on both sides of the blade while the robot is moving. The brush sander also consists of a motor that drives the cylinder.

The clean tool
The clean tool is built the same way as the sand tool. However, the brushes are without sandpaper. The brushes are also a bit longer than the brushes used for sanding, to ensure the area cleaned is a bit bigger than the sanded area. The clean tool works the same way as the sand tool. The cylinder of the tool is placed on the leading edge and correct angled to ensure it cleans the leading edge on both sides of the blade.

The clean process includes adding isopropyl alcohol (IPA) on the surface while cleaning. The tool has a built-in container to the isopropyl alcohol (IPA). A nozzle dispenses the IPA in flat jets to ensure the complete cleaning area is reached.

We have aligned the designs of the sand tool and the clean tool such as a big part of the construction is the same, and they are smaller than earlier versions, which reduce production cost and make it easier to upscale production wise. We have also developed the software used, so both tools are controlled by the same base software.

LEP application tools
To do a successful LEP application we have to take the following factors into consideration:

- The temperature of the LEP material when applying, influences the viscosity.
- The mixing needs to be correct to obtain the correct adhesion and thereby the quality and durability.
- To ensure the correct and sufficient amount LEP available out of the cannisters when applying.

We have developed specific tools for the LEP application. There is a huge difference applying on the overall leading edge versus the tip of a blade and therefore we have two different tools.

Both Tools consist of a main construction which shall carry the canisters with the LEP. The LEP is available in big canisters for the blade LEP and small canister for the TIP LEP. Both tools consist of a pressure mechanism that presses the LEP out of the canisters. A second construction caries the squeegee and ensuring the finish of the LEP application.

For both tools it is important that they follow the edge, that the LEP has a certain thickness, and is spread out within a minimum area and leaving no edges in the transition to the blade and between the blade LEP and the TIP LEP. To secure that, the tools have each their specific constructed squeegee, which is the spattle used to allocate and smoothen the LEP.

To control the factors mentioned earlier, we have developed and optimized the LEP tool and the TIP tool with specific designs and improvements.

Process testing and validation
A central part of developing a new LEP application method is extensive testing and validation. The consortium has worked with several testing and validation areas.

There have been constructed facilities to test the robot navigation on a 15m long blade section, this way it has been possible the test and tune all the control systems that ensures the robot navigates the blade correctly during the different repair processes.

A critical element in all coating application processes is the surface preparation. If the surface isn't prepared and cleaned proper the coating result will not get the desired quality. There have been done substantial testing and validation of the sanding and cleaning process to validated that the LEP coating applied will get the desired surface adhesion. The validation has been executed in close collaboration in the consortium and also with Teknos who supplies the Telnoblade 9000 LEP coating. The goal here has been to get an efficient sanding and cleaning process, but also ensuring the speed optimisation don't compromise the quality. Pull off test, pealing tests, crosscut tests, etc. have been performed for several parameter sets for the preparation process. This ensures an in dept understanding of the significant parameters. The process and parameters deployed in operation is thereby validated and approved by all parties including Teknos.

The application of the coating is the most critical process step, and an area were significant testing and validation have been executed. For this area test facilities have also been upgraded to support good facilities to test and evaluate the results. The test facilities include different blade types, as especially the blade tip varies a lot between the different blade types. Here we also have several parameters influencing the quality of the end result. We need to ensure proper mixing of the 2 component LEP, coating thickness, surface transitions, etc. A substantial study of the parameters influencing the quality of the application have been tested, like temperatures, dispensing and operational speeds, shapes of squeegee blades, etc. All parameters have been tested to ensure robustness in the operation. The results have been evaluated in the consortium and together with Teknos.

On top of all the testing in the R&D centre, the full process and setup have been validated on several onshore turbines. Here process speed and final quality have been validated. There have also been several lessons learned from all the field test and validation steps. All these learnings have been feedback in the system and used to improve the design and processes. This way we now here before project closure, have a stable process providing the expected end results.

Robot operator training and education
To ensure operation of the robot is executed correctly, and thereby ensuring proper safety and quality of the LEP application, we have developed an education program for Robot Operators.

The goal is to train and support robot operators to become fully capable and independent, being able to complete a robot blade repair operation, from start to finish.

Robot operators must have the ability to adapt and complete many different tasks, and most important of all have a systematic, persistent, and solution-orientated mindset. The education program has been divided in levels:

- RO1 is responsible for the physical onsite handling of the robot. The RO1 is also responsible for rigging the ropes and for preparing the wind turbine for blade service.

- RO2 is responsible for establishing the robot power supply and communication system and preparing the robot for operation. This includes pre- and post-use check of the robot, change and calibrate robot tools, controlling that all systems are ready for operating and loading of consumables materials. RO2 will have basic robot interface control skills.

- RO3 is responsible for performing the blade repair with the robot. RO3 must have a in depth knowledge on how to operate and control the robot and do blade repairs. How to perform troubleshooting, fill out blade reports and initiate software support and implement e.g., updates. Generally, the RO3 must have a good overview of the hole operation.

A higher operator level demands more responsibility and overview. The education of new operatora is a combination of classroom lessons, practical exercises with the robot on training blades, and practical training and experience in the field on real turbines together with experienced Robot Operators and instructors from Rope Robotics. New operators will not be certified before showing that they master all the disciplines, safely and within specification on real turbines.

Communication module

The communication and remote control of the robot is what enables the robot to perform work on the blade. We have created a communication setup, that is highly flexible yet easy to use. Operators can set up on site with minimal training because everything is labelled and intuitive. The setup has been tested on several locations and is continuously being updated based on experience gained. Process validation is an important part of the service and thus it is important to secure both data and images from the operation. Storing this data in the cloud ensures automatic backup and easy access from anywhere. These things combined result in a very well-suited setup for Rope Robotics' operations.

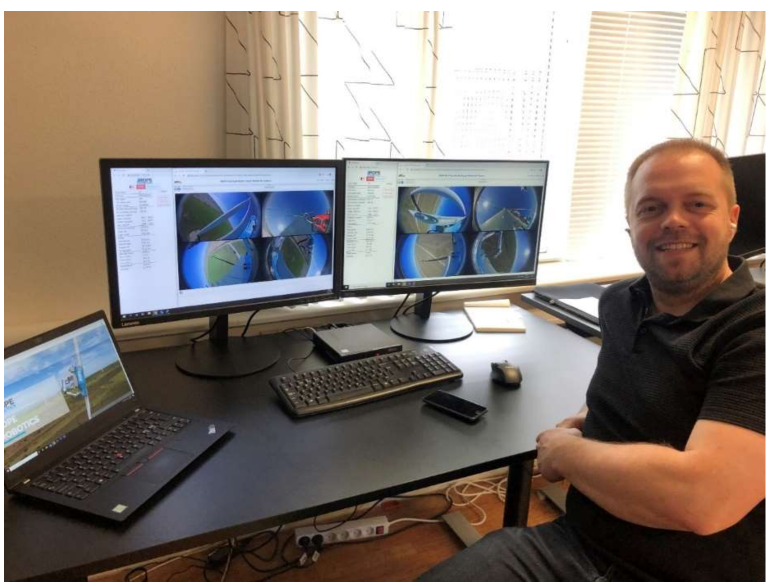

Figure 3 Martin is remote controlling the operation in Canada from Aarhus

To enable the communication with the robot, several steps are needed.

- Communication model
    - Setting up the different IP and VPN networks to allow communication with the robot from a PC and all the internal data traffic needed between different sub systems.
    - This is configured in the workshop before going to a work site and is mostly concerned with setting appropriate IP addresses and VLANs.
- Set up robot communication on site
    - Setting up communication on site to allow communication with the robot from a mobile robot control centre that might be on site or remote. This deliverable describes the training material used in the training of operators.

The backbone of the entire communication model is a carefully designed IP network. All access to devices is based on IP addresses configured to separate concerns in different virtual networks (VLANs). This lets an operator accesses robots on well-known fixed IP addresses, without having to worry about devices and routing. As an example, all robots are accessed through a fixed IP address. While setting up on site all relevant connectors are marked with their function to allow easy setup. The full communication model is comprised of several physical installations.

The ground box serves as a gateway to the robots. Besides providing communication to the robot, it also supplies power through one cable.

The ground box consists of:

- VDSL Modem for communication with the robot
- Switch, providing connectivity to all devices
- Wireless bridge, for connection to the control centre
- Groundbox computer, provides the web based user interface to the robot.
- Labelled connectors for easy setup (right image above)

VDSL modem, wireless bridge and switch are standard off-the-shelve components that are configured to use suitable IP addresses. The Groundbox computer is a small but powerful computer with Ubuntu Linux installed. It is fitted with two network interfaces, one for access to the communications network, one for access to the robot.

The Rope Robotics cloud setup is hosted in Microsoft Azure. It consists of storage for validation, backup, and process data. It can be accessed from anywhere through a VPN gateway. While in operation, the operator uploads a backup of all captured process data and validation imagery. Validation images are put in storage and will be provided to the customers as proof of the work done. Process data is unpacked and stored in a database where it is used to analyse and optimize the operation processes.

The data is stored for several reasons, for validation purposes, but also to keep historic performance data and to aid in solving problems seen in the field. The data is stored based on the actual job it links to. This makes it easy to find data from a given process on a given turbine blade, and to trace back if any errors are found afterwards.

Validation images are stored in the cloud storage according to the turbine/blade they describe. The images have embedded meta data with information about the current process, blade, and turbine.

Ancillary equipment
The ancillary equipment is the following

1. Trolley
2. Mobile Robot control Center (MRCC)
3. Pulley (Cable relaxer)
4. Cable Manager
5. Telescopic rod

Trolley
The trolley is the hand truck we use to handle and transport the robot when it is on the ground. Basically, it is a four-wheeled chart for moving heavy objects but upgraded to fit the load of our robot without damaging the backplate with the foam matrix covered with a polyurethane foil and with extra bigger wheels to ensure stability.

The trolley is a multi-functional chart with 3 different positions. It can be used as a two-wheeled hand truck but also as a four-wheeled chart in a horizontal position. We normally use it with four wheels but in a position of approx. 45 degrees. The different positions are managed by a safety mechanism, which is very easy to adjust but still locks the different positions. The trolley is produced in aluminium, which makes the chart strong but still light and easy to move around. It is important it can carry minimum 150kg.

Figure 4 The trolley used to transport the robot while on the ground.

MRCC
The Mobile Robot Control Centre (MRCC) is a Rope Robotics design and designed to fit our specific needs. The MRCC is a mobile workshop, warehouse and control centre for the robot operator, as well as transportation unit. We can pack all our operation gear, tools and robot(s) within the MRCC and transport it safely around.

We have made a few different solutions such as designed a van, a trailer used in EU and one in North America, and a 20” container. Equal to all of them is that that they consist of a set of minimum requirements, and they are all documented in the MRCC specifications.

Figure 5 MRCC – from inside the rebuilt container

Figure 6 Robots and operators in from of the MRCC in South Africa

Pulley (cable relaxer)
The pulley is the name of our patented cable relaxer used to manage our cable when operating on the blade. It ensures that the cable is not damaged being caught by the robot or by the jagged edges on the rotor blade. The pulley is a Rope Robotics development and is designed specifically to fit our operation.

Figure 7 The red rings mark the position of the pulley while in operation.

Cable manager
The cable manger is a necessity being offshore to avoid the cable ending in the water. It ensures the cable is coiled up systematically on the limited space on the transition piece around the offshore wind turbine.

Generally speaking, the cable manager is a big bucket that can contain the power/communication cable, with a mounted motor on top to manage the cable between the bucket and the robot. It is important that the cable is coiled gently.

Transportation gear
As mentioned earlier we use the MRCC to transport either on land or sea, but we have also designed flight cases to contain the robot, the tools and the gear used within the complete operation, which allow us to use air freight.

Manuals and procedures
We now have procedures in place which guarantee the correct documentation handling and the flow in where to find and how to use our specific instructions. Specifically, we have procedures and manuals ensuring we cover all steps before and while being in operation, from how to check if the operators have the certification needed to how to ensure all elements are taken into consideration doing the risk assessment. As mentioned earlier, we have a well-developed training set-up with material ensuring the operators to obtain their needed level of knowledge, manuals describing how to set up the communication model for the operation, and production and procurement procedures and specifications, just to mention some. Lots of our processes have been build up and documented during this project and all have been streamlined.

Figure 8 A complete leading edge repair done

Market in-sight

Commercial wise we have obtained very positive acknowledgement from all three target customer groups. They are ready to use the robotic solution as alternative to the manual process often used today, due to the higher level of efficiency, uniform quality and the significant advantages concerning health and safety.

Of not expecting results we have seen some asset owners changing or introducing a maintenance strategy. Some have until recently not really had a maintenance strategy of rebuilding the leading edge. They found it too costly and not advantageous enough. Seems this is changing. We have seen several examples of asset owners now consider repairing the leading edge with our robotic solution.

Target Customers

We operate with four main customer categories.

- Turbine OEMs who are the turbine manufacturers.
- WFOs who are the wind farm owners, who often is very big energy corporations with huge influence
- ISPs who are the independent service provides. They are often doing the blade repair today using rope access technicians.
- JVPs is the abbreviation of Joint-Venture Partner. The JVP can in principle be any kind of customer who would like to run a Rope Robotics unit outside of the head quarter.

We have tailored our ways of approaching the different customer groups by doing severe stakeholder analysis and mapped the buying behaviour mechanisms within the blade maintenance industry.

We approach the customers in alignment with our business models within which we are operating with three models:

The service model

So far, we have used the service model, where we perform the blade service job with our own robots and operators. We expect the service model only to be used in special cases. We are going to use it mainly for commercialized demonstration purposes and for smaller jobs. This model is too resource demanding on the long run and not sufficient scalable for the business acceleration.

The rental model

The rental model is the model where the customer rents the robots and supply their own people to handle all the manual tasks around preparing the robot, preparing the wind turbine, setting the robot up and taking it down again.

The customer can as well be trained to pilot the robot themselves. As described earlier we have developed a training concept that takes the operator thoroughly through all aspects of the repair process.

This model is going to be used for the assignment with the ISPs

The Machinery Joint-Venture model

The Machinery Joint-Venture model can be described as a model with many similarities with an original franchise model. Research and development, and production is the core competences of Rope Robotics. Therefore, it could be beneficial to outsource services and leasing to a strategic business unit, which is still under our control.

This model sets the stage for a Joint-Venture Partner (JVP) to buy the robots. It could also be a shared investment with Rope Robotics. A new company is created by the Joint Venture Partner (JVP) and Rope Robotics' owns a part of the it. The set-up is flexible but Rope Robotics act as the corporate company from where the JVP can buy value added services.

The JVP could be an ISP but in principle it could be all types of customers, who would like to lease or in special cases buy robots and combine it with signing up with a partner (e.g., an ISP) to run the operation.

For dissemination we have mainly used the SoMe platforms with regular posts of our project progress and regularly uploaded videos on YouTube. We have used the dedicated project website http://windturrepro-bot.roperobotics.com/ and have had several articles via TechMedia, Fyns Stifttidende and Jysk Fynske Medier. We have participated in Podcasts and we have naturally been in close direct dialog with all relevant stakeholders.

In 2021 we had the chance to visit the HEI fair in Herning, but due to covid-19 we have mainly been participating in online events such as: the "International Symposium on leading Edge Erosion of Wind turbines Blades" both 1st, 2nd and 3rd, "the Future of Blade Performance and Maintenance", "CanRea", "Skyspecs and PowerCurve", Internship-day at the Technical University, and represented by Tekno at "Blade Global".

6. Utilisation of project results

The solution will be used within the wind industry by the partners needing and executing wind turbine blade maintenance. Our project results lead to a complete new robotic leading edge repair solution not seen before in the market. We are competitive on all parameters which means the complete wind turbine blade maintenance industry will gain from using our solution.

Our solution

- Is setting new standards for blade repair speed and efficiency
- Is setting new standards for documentation and surface diagnostic
- Is setting new standards for safe blade maintenance work
- opens for new business opportunities for the LEP suppliers
- opens for new job opportunities within the blade maintenance and service sector

What we also experience is a massive interest from other areas of the maintenance services. Our robot solution represents a highly innovative invention, and it seems the demand of more tasks for the robot to handle is growing. We have inquiries for specific sanding tasks, extended documentation tasks, ice coating tasks and different type of scanning tasks.

We have increased our turnover. The project results have made it possible for us to enter the market and to start the whole commercialisation process. We have been able to attract both new private investors and employees. The project partner does not expect a direct increase in turnover, but they do now have access to a very competitive leading edge repair solution for their leading-edge eroded blades, which can save them costs compared their traditional repair methods.

Traditional repair methods, which mainly are Rope Access Technicians (RATs) repairing blades while hanging in ropes from the nacelle or using platforms, constitute the main competitor for Rope Robotics.

To keep the optimal performance of the wind turbine, it is recommended to repair the blades every 5-7 years depending on the weather conditions and how harsh their environment is.

The RATs have naturally a smaller weather window than the robot, the industry suffers from shortage of RATs which also lead to a salary increase, which means higher maintenance costs. It is difficult to improve the quality of their work and documentation of the work done. In average it takes them days for one blade.

The service offered by the robot is done quicker, at higher quality as no human fatigue doing repetitive tasks has an impact on the result and the documentation is done by the robot regularly issuing images before and after each process, and with specific meta data incorporated in the images telling exactly where on the blade the image has been taken and what has been done. Finally, the robot is operated with less staff and its high efficiency means less standstill time of the wind turbine, which plays an important role in reducing the maintenance cost.

Robotic wise we also seen competitors on their way. So far, we have heard of a few other robotic solutions, whereas some are mainly doing inspections, and some are still in development.

Important to mention as well is that wind energy continues an upward trajectory worldwide with both the total number of turbines being installed as well as the total capacity increasing year by year, there is a growing demand for operation and maintenance solutions. The market potential is huge. Plus, the aging existing fleet of turbines also demand more attention to ensure they remain fully functional.

Rope Robotics still have the important first mover advantage over competing robotic solutions and with a strong customer network and the extensive testing experience, we are confident that we have a very strong position on the market.

We offer a new and fairly unknown and for some customers controversial repair method. It breaks with the traditional repair methods, which for some can be seen as a threat and further to that we offer a LEP product:" Teknoblade 9000" which also is relatively new in the market.

The important step for us is to influence the customers to break with their traditional way of acting. Specially to choose the LEP material we offer and to choose our solution as application method.

We do the following to influence their buying process.

- Execute a lot of brand awareness activities.
    - Highlight the qualifications of the LEP
    - Focus on our efficient application method
- We offer demonstrations to proof the concept.
- We offer conditional agreements with step execution to proof the business as we go along. It makes it possible for the customer to renegotiate the agreement which minimize their risk of involving with a new supplier.

Our solution contributes to more competitive pricing on wind energy. We cut down on the operation and maintenance cost of the blades and offer a more efficient repair process that the one used today which means less standstill time of the wind turbine and regained energy production.

The GWEC Global Wind report 2021 presents that the wind energy capacity has increased with 59% to a total of 743GW. It is still crucial to maximize the economic and environmental benefits of the wind assets. We see more wind turbines but also bigger which means faster tip speed of the blades. As a result, wind turbine blades wear faster due to large tip speeds. Regular maintenance of WTBs is important to keep them operating with optimal performance.

Wind turbines are expected to run within a period 20-25 years. According to IHS Market report from 2017 is operation and maintenance (O&M) cost in average to be found between USD 42,000 – USD 48,000/MW during the first 10 years of operation. It is estimated that the US wind farm owners are expected to spend over USD 40 billion on O&M over the next 10 years. According to a report made in 2019 by Wood Mackenzie the global O&M for offshore alone is expected to grow by 17% annually to more than EUR 11 billion by 2028.

More and larger wind turbines mean more demand of repairs. More repairs have eventually led to a shortage of qualified staff (well trained technicians) in the wind service market. A shortage of 5000 was already noted back in 2012 and EWEA predict this shortage to raise to 28,000 by 2030.

In the latest EU Renewable Energy Directive issued on 14 July 2021, it is stated "Renewable energy plays a fundamental role in delivering the European Green Deal and for achieving climate neutrality by 2050.

7. Project conclusion and perspective

The combination of the wind energy playing an even more dominant role in the energy supply chain, the generally cost increase of electricity, the growing shortage of wind tubing blade maintenance staff, the demand to decrease the O&M cost and to find efficient maintenance and repair methods, have never earlier been so clear.

This project really made it possible to robotize the way of doing leading edge repair. We managed to lift the robot from a version that was mirroring the human tasks done with the limits that has, to a version that fully benefits from the application method possible being a robot. Which made it possible to lift the efficiency of the robotic repair solution with almost 75%.

We have managed to get the high complexity of doing the leading-edge repair in control in real environment and are now ready to commercialize the present version of the robot. We now meet the present standards set by the wind industry and we even offer a solution that require less staff being involved in the process and a solution that requires less standstill time of the wind turbine while being repaired. Elements that influence the price structure of wind energy downward.

With this project we have reached extraordinary results, but we aim for more. Next step is to do a successful commercialization. We are well prepared and ready to enter the market. We now have a strong focus on scalability and the involvement of strategic partners. To do this successfully, we aim for even higher efficiency. Therefore, we expect the next level of development to focus on lean processes, we would like to use machine learning to incorporate decision support to our operators and we wish to develop smart training, which shall make it easier and quicker for us to execute flexible training sessions to make our partners ready to run the operations.

Parallel to above we still aim to develop an even more efficient deployment set-up to go offshore. We are also going to investigate more areas within the blade maintenance services. We have inquiries to develop solutions within extended scanning solutions, repair of structural damages, application of ice coatings, etc.

The project results are surely going to have a huge impact on our future development. It has become clear to us that we have a very agile and a very high level of willingness to corporate between departments. It gives us a very short time to action.

8. Appendices

http://windturreprobot.roperobotics.com/