ROSA - Stoplog Monitoring and Inspection Robot ⋆

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Abstract: ROSA is a research project which endeavors to design and implement a robot for the monitoring and inspection tasks of the inserting and removing stoplogs process in a power plant. The proposed system is mounted on the lifting beam, which carries the stoplogs, and it is composed of different sensors: inclination, pressure, and inductive sensors for monitoring; and a profiling sonar with pan & tilt system for inspection. ROSA is innovative in its concept: provide eyes to what occurs underwater in stoplog operations, enabling operators to take informed decisions. The concept represents an improvement to the current industry practices and results in a financial and work security gain by reducing stoplog operation issues and intervention dives. In Jirau, over a period of 2 years, Stoplog operation issues resulted in a production availability loss of 37 days, enough power to supply a city of 160.000 habitants for over a month. Jirau is one out of 9 GDF Suez energy hydropower generation units in Brazil, therefore, the application of the ROSA system across the business is expected to result in a significant value return.

Keywords: field robotics; stoplog; embedded electronics; robotic software architecture; sonar;

1. INTRODUCTION

Hydropower is the most mature, reliable and cost-effective renewable power generation technology available (A. Brown and Dobrotková, 2011), accouting 16 percent of global electricity generation. The global hydropower use and capacity will increase about 3.1% each year for the next 25 years (Institute, 2012). The total investment for large-scale hydropower projects typically range from USD 1000/kW to around USD 3500/kW and, once commissioned, the annual operation and maintenance costs of hydropower plants are often quoted as 4% of the investment per kW per year (Ecofys and Young, 2011).

In the specific case of Brazil, the third biggest hydroelectric potential of the world, hydropower represents 84% of its electric power total production. Brazil is the second biggest country of installed hydropower capacity, 84 GW, and in the Amazon basin, in Madeira river, this number will be increased next years by the construction of Jirau (3300 MW) power plant, Figure 1 shows a photo from Jirau Barrage. The dependence on this renewable power source mobilizes private initiative investments on research centers and universities, and motivates the development systems with a high degree of automation based on advanced robotic systems (ANEEL, 2008).

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Fig. 1. The Jirau barrage

Stoplogs are modular physical barriers that are stacked to control the water level in a channel or to isolate and drain a particular dam section for maintenance. An operator installs and removes the stoplogs using a crane equipped with a stop-lifting beam. The beam is a self-engaging log-handling device for underwater retrieval and manual lanyard release of the log, purely mechanical. The stoplogs are inserted and remove at a special purpose slots in the barrage. However, problems may occur during the process: bad coupling between lifting beam and stoplog, bad stoplog stacking due to sediments, and etc. In the specific case of Jirau power plant, in Rondônia, Brazil, the

Madeira River tears out trees along the stretch, carrying more than 500 tons of sediments every day (Aranha, 2013). Figure 2 shows a photo from Jirau set of stoplogs.

Fig. 2. Jirau set of 8 stoplogs to seal turbine downstream side

Lewin (1995) studies stoplogs and lifting beam's physical and mechanical properties. The ideal stoplog, as mentioned in the book, has a mechanical contact sensor, and an hydrostatic pressure regulator valve, which solve most of the problems on stoplog operations. However, in Group (2006), England, a technical standard is proposed for manufacturing, do to cost and maintenance reasons without the sensing technology. In 2006, Hatch, an engineering and development consultancy, developed a system composed of a lifting beam with submersible proximity sensors and submersible electric servomotors to independently actuate the hook. In 2007, the system was installed at Ivanhoe Lake Dam greatly improving safety by reducing the amount of manual handling required in this hazardous environment (Hatch, 2009).

Similarly, the Atlas Polar log lifter automates the process of stoplog installation. The system is composed of an inductive sensor recessed in the compactor plate to sense contact with the log and a force sensor, stain gauge, which will indicate stoplog release or lifting (Polar, 2015).

Neither of the solutions presented by the literature were commercially viable to Jirau. The proposed solutions required the purchase of a new stop-lifting beam with integrated sensor payload, instead of an alteration of the existing infrastructure with add on sensor. No previous work was found with reference of applying Sonar for the inspection of the Stoplog rails and solace.

In this paper, we present a general overview of the ROSA robot, and a detailed description of the embedded electronics, power supply system and software architecture. The robot is designed to perform monitoring and inspection tasks of the stoplogs' stacking and retrieving process in a power plant. Carrying different sensors, the robot analyses sensor data *in loco* or stores it for a posterior analysis, interprets the results, and sends specific data to the operator. The sensors can identify the lifting beam actual operation (stack/retrieve), stoplog attachment/detachment, the lifting beam inclination, the system depth in water, and a profiling sonar for sediments inspection.

This text is organized as follows: an overview of the current procedure and its problem 2, detailed descriptions of the robot are taken in Section 3.

2. PROBLEMATIC

Stoplogs are modular physical barriers that are stacked underwater on top of each other at the turbine inlet and outlet at designed slots in the barrage, permitting the isolation and water drainage of the region for maintenance.

An operator using a crane and a special purpose tool, the lifting-beam, executes the handling of the stoplogs. The lifting beam is a purely mechanical tool. A manual key can be switched into catch or release mode and according to the key position 2 claws will hook or release the 2 stoplog lugs, located on top of each stoplog. Figure 4 is a photo from Jirau crane with a lifting beam attached.

Fig. 3. Crane with attached lifting beam

The mechanism of the lifting beam is robust in its simplicity, but do to the necessary mechanical clearance and unknown environment conditions the operation may fail. These failures are usually not noticed by the operator in its initial occurrence, since the only information feedback is the crane cable tension, resulting in an aggravation of the incident. The following Stoplog issues were recorded at Jirau this past 2 years:

- the fishing beam only latched to one of the stoplogs lugs, February, 2013, resulting in 10 days production downtime do to structural damage to the slot rails and solace;

- same occurrence again in December 2013, 4 days downtime, the stoplog left the rail and had to be searched in the slot surrounding regions;
- crane cable tangling and consequential snapping, 7 days of production downtime to fix tangling and remove the stoplog plus 90 days for crane maintenance;
- stoplog did not provide a proper water seal do to debris at the solace, twice in October 2014 and twice September 2014. Each occurrence resulted in a 4 days production downtime. After October 2014, every turbine maintenance stop has included a preemptive interventional dive; do to the high recurrence of debris.

Operations failures can only be resolved via interventional dives, Figure 4, a high-risk job, due to strong local currents and weight of the submerged equipment. In particular, in Jirau, the water has a high amount of suspended sediment, resulting in zero visibility underwater. So, the divers can only orientate themselves via touch.

In 2013, a interventional dive accident occurred in Jirau. A diver was dragged to an adjacent inlet, the security rope held him initially, but the water pressure was too high, making breathing and moving back impossible. He had to cut the rope and allow himself to be dragged through the system downriver. Luckily, the accident was not fatal.

Fig. 4. Divers accessing the intervention region

3. ROSA - ROBOT

The ROSA robot contains an inspection and monitoring payload of four inductive sensors, a profiling sonar, a Pan & Tilt unit (PTU), a pressure sensor (0-5 bar) and an inclination sensor . The robotic device and its sensors are mounted on the lifting beam of the stoplog. The robot monitoring capabilities guarantee online access to the embedded sensors, providing information of the surrounding environment and the robot operating conditions with real-time processing. Figure 5 is a photo of the complete assembled system. ROSA can be split into three subsystems: user interface, surface control unit, underwater control unit and robotics software.

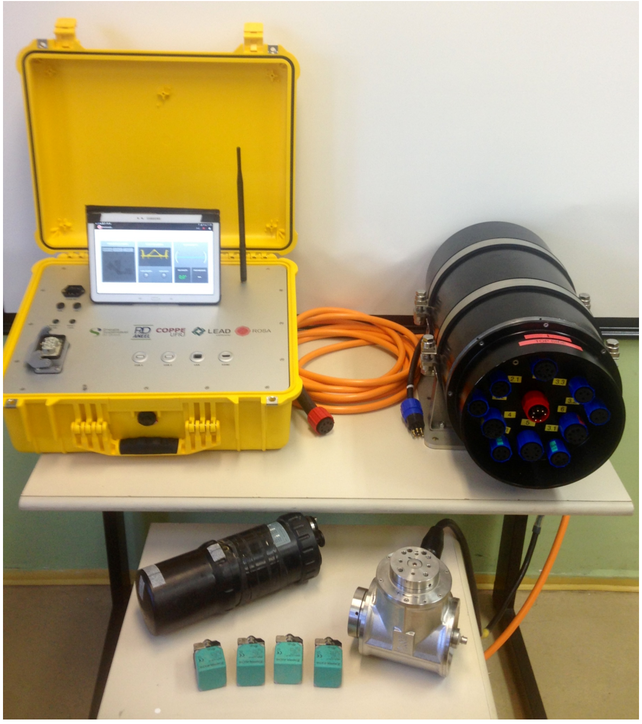

Fig. 5. ROSA - Robot

The user interface allows for remote online access to all robot data. The software can be installed in any android base tablet. The data access is given via Wi-Fi by connecting to the surface control unit.

The surface control unit electronic schematic is given by Figure 6. The electronics is encapsulated in a pelican case for easy transport and field deployment. All equipments are specified for operations in high temperatures and humidity, typical environmental from the Amazon rain forest where Jirau is located. The surface control unit is connected to the underwater control unit by a 60m long strain resistant data / power umbilical. The on board computer runs the sensor processing.

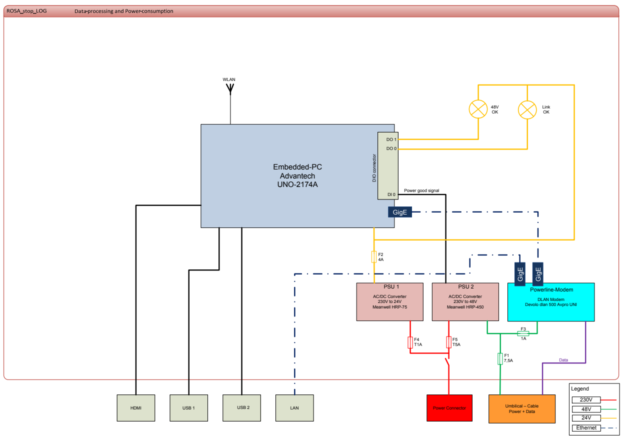

Fig. 6. Surface control unit embedded eletronic schematic

The underwater control unit is encapsulated in a pressure housing. The housing design is sealed against water and particles, it is submersible 100 meters, resistant to wide temperature range, protected from impact and vibration, and electrically shielded. The embedded electronic schematic is given by Figure 7. Underwater plugs provide connection for the umbilical and sensor payload. The on board computer is responsible for the low level communication with the sensor payload, data aggregation and transmission to the surface control unit.

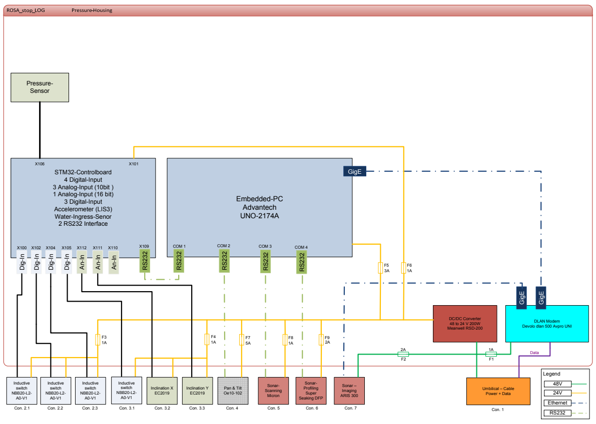

Fig. 7. Underwater control unit embedded electronic schematic

The robot software is based on a Linux OS and ROCK (Joyeux) as a robotic framework. Rock is a state of the art, component-based, robotic software framework published under an open-source license. It gave the project the flexibility required to quickly iterate on the hardware with minimal changes to the software. Its component-based nature allowed us to easily reuse open-source components that were relevant (map representation, device drivers, ...), thus allowing the researcher to focus on the project's innovations.

The principle behind the inspection software is the methodology used to accumulate the volumetric data coming from the sonar. The approach developed use a probabilistic base volumetric accumulation to represent data coming from different point of views. This accumulation help disambiguate the data (sonar data is very ambiguous) since a false positive echo from a point of view probably disappear from another point of view, and that the sonar bins will overlap in non-regular ways allowing to achieve higher resolution than the original sonar resolution.

The principle behind the monitoring software is a decision table and rule induction knowledge that process the information coming from the sensors drivers, raising visual and sound alarms in case a fault is detected during the stoplog operation.

4. EXPERIMENTAL TESTS AND RESULTS

ROSA is still under development, currently in pilot unit testing and tuning phase. The available results are based on field trials in Jirau. During the field trials single components and full system tests were executed.

4.1 Monitoring

A full system test was executed for the stoplog monitoring capability. A ESBR operator inserted and removed 4 stoplogs into the designated slot, while visualizing the operation from a Tablet installed at the crane control cabin. All system worked as expected. The operator was after the experiment queried in terms of interface understanding and usability, 3 iterations were necessary to determine an optimal representation for the target user. The Figure 8 show the resulting user interface. During the monitoring test there was no occurrence of an operational failure. So, failures condition were forced on dry test, as in example, single lug catch. The monitoring system accused accordingly the operational faults occurred.

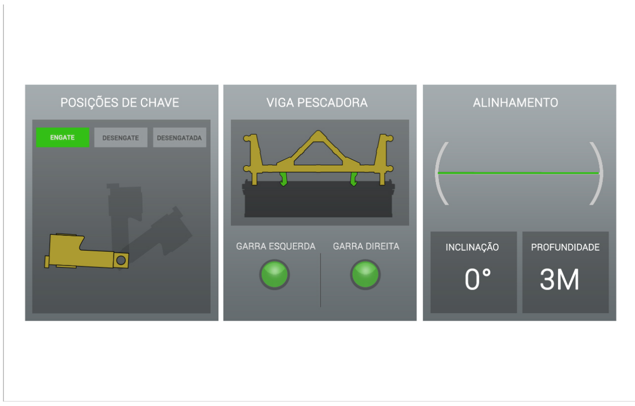

Fig. 8. Monitoring User Interface

4.2 Mapping

In Jirau, the inspection payload was mounted onto the lifting beam and submerged into the Stoplog rail region. The measurements were taken in 3 different depths and various pan & tilt angles to provide different point of view of the same region. Figure 9 show an illustration of the inspection proces. During the tests at Jirau, no debris bigger than 20cm was detected at the solace. No ground truth was available to confirm test result.

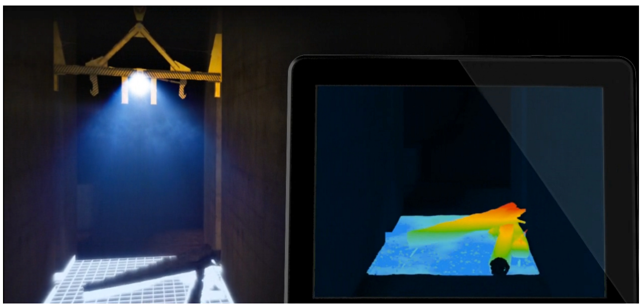

Fig. 9. Inspection process illustrative representation

5. CONCLUSIONS AND FUTURE WORK

The ROSA hardware presented the necessary rugosity to operate in the harsh environmental conditions of Jirau in surface and underwater.

The monitoring system measured all operation parameters necessary to detect the expected faults. Intervention dives are still necessary to correct any operational error, but the aggravating conditions, as structural damaged, can be avoided, reducing production downtime and length of the dive. The monitoring system represents an innovation to the current standard practice of blind operations, as well as, an innovation with regard to the literature: quick mount to any lifting-beam, remote online access and automated operation analysis alarms.

The inspection software was capable of mapping the solace of the stoplog rail with a precision of 20cm. The high amount of floating sediments, particular to Jirau river, resulted in a higher than expected noise/singal ratio, limiting the sonar to lower frequencies, consequently reducing the possible measurement resolution. Further tests are necessary to verify if the current precision of 20cm is enough to avoid the need for preemptive intervention dives. The method represent an innovation to Sonar base 3D mapping, but no comparative test between the developed method for probabilistic accumulation of data and the standard industry practices were yet executed, so the advantage or disadvantage of the proposed method can not yet be determine. Improvements on the applied methodology may also result in further noise reduction and an increase in the achieve precision.

In conclusion, the ROSA concept represent a potential economical and work security gain to GDF Suez, with an applicability across all of GDF hydro power generation portfolio. The next steps are to extended system field trials by permanently deploying the system for use, component optimization to generate a pilot unit and development of more mature probabilistic volumetric accumulation technology.

6. TEAM

Breno B. Carvalho is graduated in Mechanical Engineering from the Universidade de Braslia (UnB), Brazil, in 2007. Currently, he is the Mechanical Maintenance Coordinator at HPP Jirau, Rndnia, Brazil. In ROSA Project, he is the manager.

Joao Ernani Alcantara Lopes has a technical formation in crane control e mechanical maintenance, with 17 years of experience in the area of crane operation. In ROSA, he is end user for the system, providing feedback and executing all field system testing.

Ramon R. Costa received D.Sc. degree in electrical engineering from the Federal University of Rio de Janeiro (UFRJ), Brazil, in 1990. Currently, he is an Associate Professor in the Department of Electrical Engineering of COPPE at the Federal University of Rio de Janeiro and the project coordinator. In ROSA, he is responsible for the coordination of the project within the university group.

Gabriel Alcantara Costa Silva holds a bachelor degree from the UFRJ and is currently a master student student at the Robotics, Department of Electrical Engineer from COPPE, Rio de Janeiro, Brazil. He is responsible for the inspection software in ROSA.

Renan Salles de Freitas, holds a bachelor degree in Automation and Control Engineer, UFRJ, Rio de Janeiro, Brazil, and is currently a master student student at the Robotics, Department of Electrical Engineer from COPPE, Rio de Janeiro, Brazil. In ROSA, he is responsible for electronic design and integration.

Eduardo Elael de Melo Soares holds a bachelor in Automation and Control Engineer from UFRJ and is amaster student of Robotics, on the Department of Electrical Engineer at COPPE. In ROSA he is responsible for the monitoring software of the system.

Julia Campana is an Interface Designer with focus in Usability; she has graduated at Illinois Institute of Technology and specialized in User Interface at Vancouver Films school. On the project ROSA she has elaborated the user interface that monitors the Stoplog operations. Joo Ernani Alcantara Lopes has a technical formation in crane control e mechanical maintenance, with 17 years of experience in the area of crane operation. In ROSA, he is end user for the system, providing feedback and executing all field system testing.

Dc. Sylvain Joyeux has been deep in the field of field robotics for 10 years. He graduated with a double degree in 2005 from Ecole Polytechnique as well as the french aeronautics engineering school, ISAE. He followed then with a masters and PhD in robotics at LAAS/CNRS in Toulouse, in the field of multi-robot architectures, PhD he obtained in 2007. Currently, he is the research director of CIR, Brasil and in ROSA, he was responsible for the technology concept, guidance and develpment.

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