Automated Runner Inspection by means of Computer Vision

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Abstract

In the present paper we will show you how Computer Vision can help powerplant operators to obtain better and more reliable runner inspection results and therefore can save maintenance costs.

Condition monitoring and predictive maintenance are trends that penetrate all of the industrial sector and consequently also the hydro business. This paper introduces a new approach of component monitoring by using Computer Vision to automate the inspection of Pelton runners.

For this reason, the presented concept[1] foresees to install an image acquisition unit with an industrial camera and two light sources in the turbine casing. The automated system then takes images of the buckets in regular intervals and does assessments and geometrical measurements on the images.

Early results of the pilot installation in the Swiss powerplant Mörel prove that the developed concept is viable and provides the expected results. Nevertheless, several technical hurdles had to be overcome and further improvement potentials were identified and can be implemented in the near future.

The gained experience from the pilot installation shows that such a system can be beneficial for electric utilities as the inspection results are more reliable and less dependent on the skills of the expert. This is very interesting for operators that act internationally as the needed know-how is not everywhere available. In addition, neither an outage of the unit is needed nor the opening of the casing is necessary. Thus, the unit remains available for the dispatcher at all the times. All in all, the system can contribute to significant cost savings for the operation and maintenance (O&M) of hydro units.

[1] Patent for concept and application pending

1. Introduction

Condition monitoring is today a frequent buzzword in the industry. In different sectors it is already a well-established tool for optimizing maintenance and thus increasing efficiency and profitability of the equipment.

In this regard hydropower is no exception and several electric utilities and equipment manufacturer started with the development of such expert systems [1], [4]. Most of the systems are based on sensor data already available on site that measure mechanical properties such as vibration intensity or they derive data from the available SCADA system such as power, net head or other values. However, with this information the condition of the equipment (e.g. a Pelton Runner) can only be assessed indirectly. In order to judge the hydraulic surfaces of a bucket profile a visual inspection is needed. This is often done by an expert from the O&M group who has a good know-how about hydraulics as well as mechanics or by an inspector from the equipment supplier. For this task the turbine casing needs to be opened and the scaffolding installed in order to grant a good access to the runner. The inspector does a visual examination of each bucket, marks and defines the size of irregularities and takes pictures for the reporting. Such a process is expensive, time consuming and the quality is very much dependent on the skills and experience level of the expert. The inspection result is thus not in any case reproduceable.

On the other hand, in recent years the developments in Computer Vision made big progress and concepts such as object recognition by means of neuronal networks are becoming state of the art. With this background it is a logical step to apply this new option in technology on the above-mentioned inspection task to improve the reliability and reduce costs.

This paper aims to present an automated system for Pelton runner inspection by means of Computer Vision, its benefits and some early results from a pilot installation in Switzerland.

2. Method

2.1 Concept

The concept of the present automated inspection system consists of two main steps. Firstly, the automated acquisition of images (see 3.2) of each bucket of the runner. In a second step the postprocessing and analysis (see 3.3) of these images. The two process steps are working independently but do exchange information via a central storage or database where the pictures are saved (Figure 1).

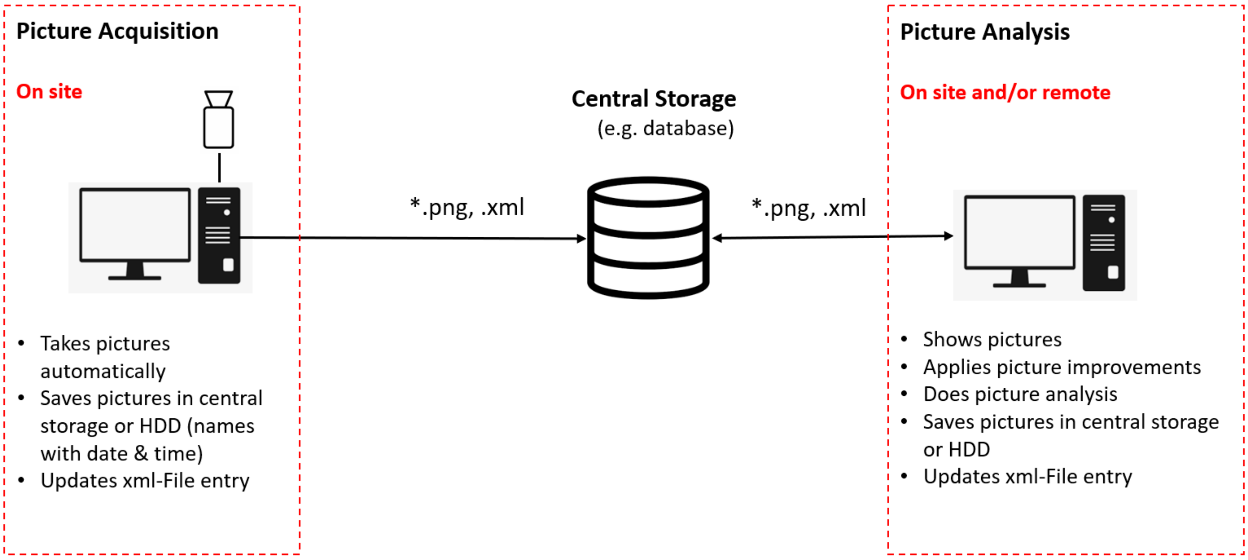

Figure 1: Concept and data flow of the Inspection system

2.2 Image Acquisition

It is part of the concept that the acquisition of the images is done with the runner in rotation. Either the runner is at nominal speed or he is ramping down after closing of the injectors and disconnection of the generator from the grid. This boundary condition makes it necessary that the industrial camera has good dynamic properties and allows a time controlled and external triggered exposure.
In Figure 2 the concept for the image acquisition is shown in detail. The industrial camera (3) is located in radial direction to the outer diameter of the runner. This allows a good view into the buckets of the runner (1). On each side of the camera two light sources (8) are located. The intensity of the light is adapted to the very low exposure time that is required due to the dynamics of the scene. The whole image acquisition process is managed by a controller (4). This controller measures via impulses from a proximity probe (7) the rotational speed and gets the actual circumferential position. With these values the delay period of the trigger is calculated in order to get an image of the selected bucket.

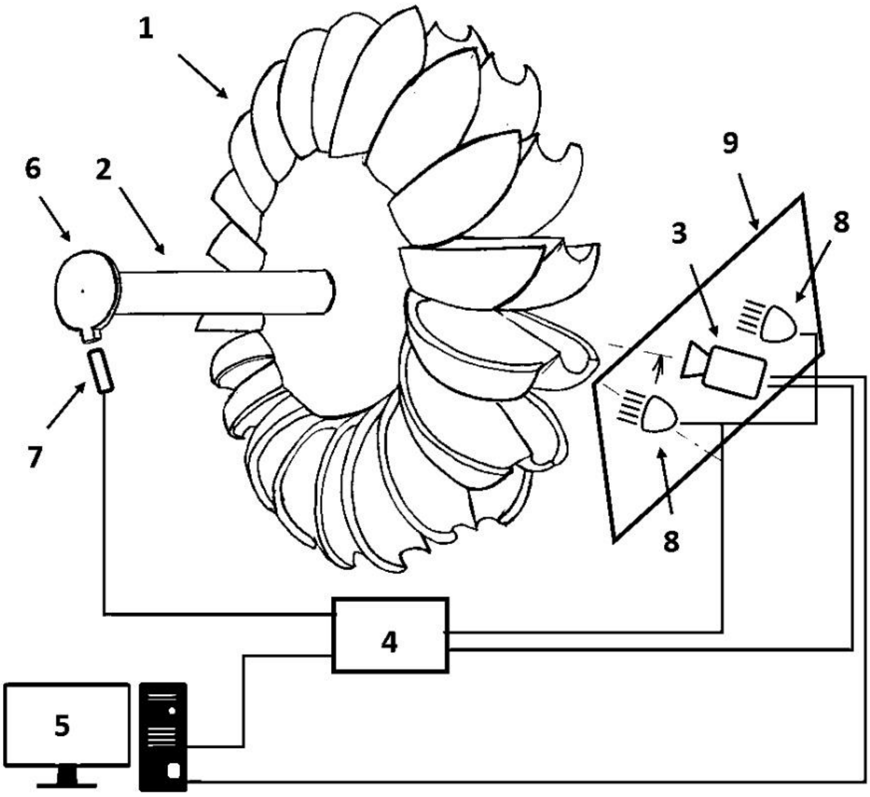

Figure 2: Schematic drawing of the image acquisition device

2.3 Image Analysis

The analysis of the images is done either on the computer in the powerhouse or remotely in an office. This is possible as the two process steps are not closely linked to each other and there is only an exchange of images and further information via a central storage that can be located somewhere in a network (see Figure 1).

In order to extract information from the images there is a post-processing needed which contains image improvement operations such as illumination corrections, histogram equalization or special colour filters. Based on the optimized images, geometrical data or other information can be derived. In the following, two examples of image analysis procedures are described. But many more are possible depending on the specific needs of the operator or maintenance team.

2.3.1 Splitter width measurement

The aim of this analysis is to measure the width of the splitter edge from an image. This allows to quantify the damage on a bucket due to erosion. Based on earlier measurement or model calculations the efficiency losses can be estimated.

The steps of this measurement operation are shown in Figure 3 below. From a given image (a) a region of interest (ROI) around the area of the splitter edge is extracted (b). In a next step the colour space of the image is mapped to gray values (c). With the application of a binary thresholding operation (d) the top of the splitter edge gets visible in white. In order to measure the splitter width, the width of the white band can be extracted at any position. Finally reference lines at the location of the initial width of the splitter edge can be added in order to visually support the erosion quantification (e, f).

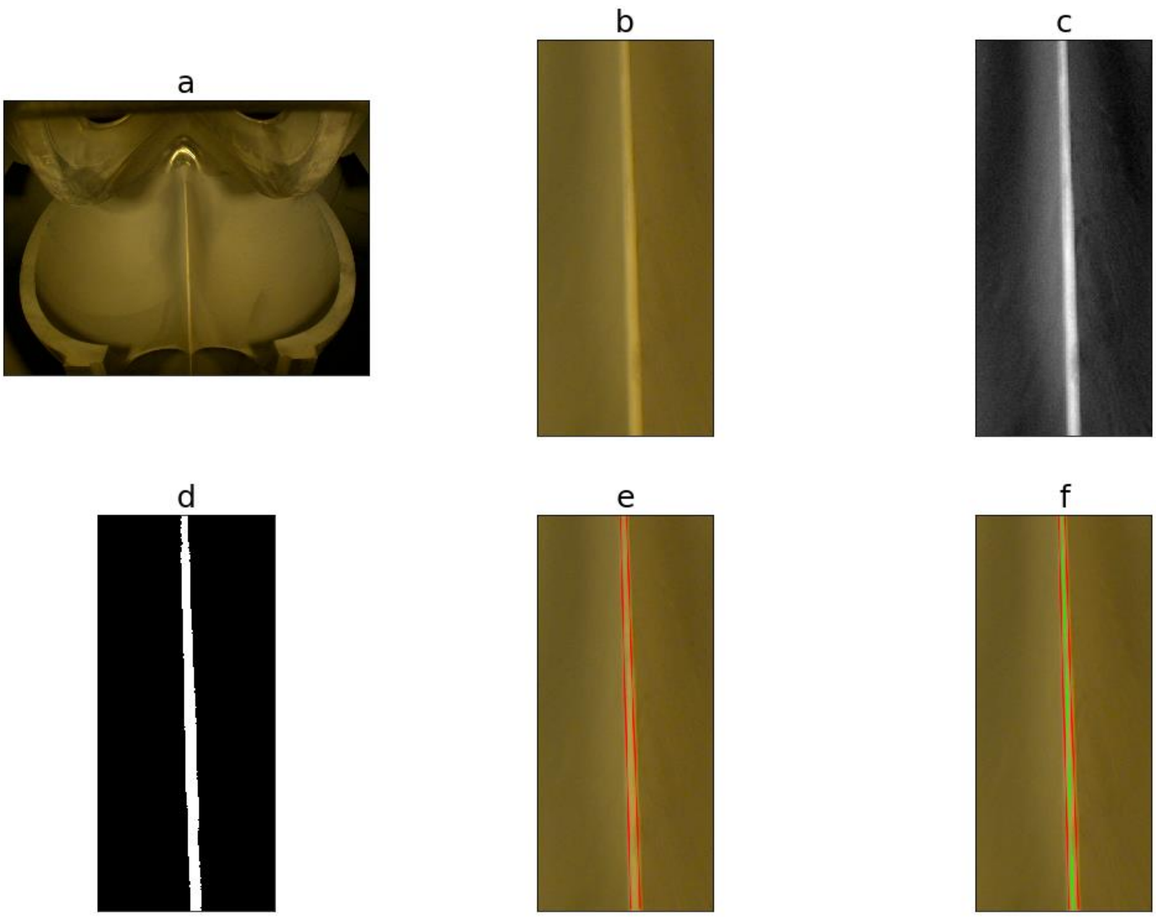

Figure 3: Process steps of the splitter width measurement

2.3.2 Pose Estimation

In Computer Vision the pose of an object refers to the relative position and orientation of the object to the camera [2], [3]. It can be changed by moving resp. rotating the camera or the object relative to each other. Pose estimation is an image operation that allows to correlate the 2D (planar) data of an image with the 3D information of a given real scene or object. The basic output of this operation is a rotation matrix R and a translation matrix t that describe the mathematical correlation of the 3D coordinates (World Coordinates) of a given object or Point (P) to the coordinate system of the camera resp. the image (See Figure 3).

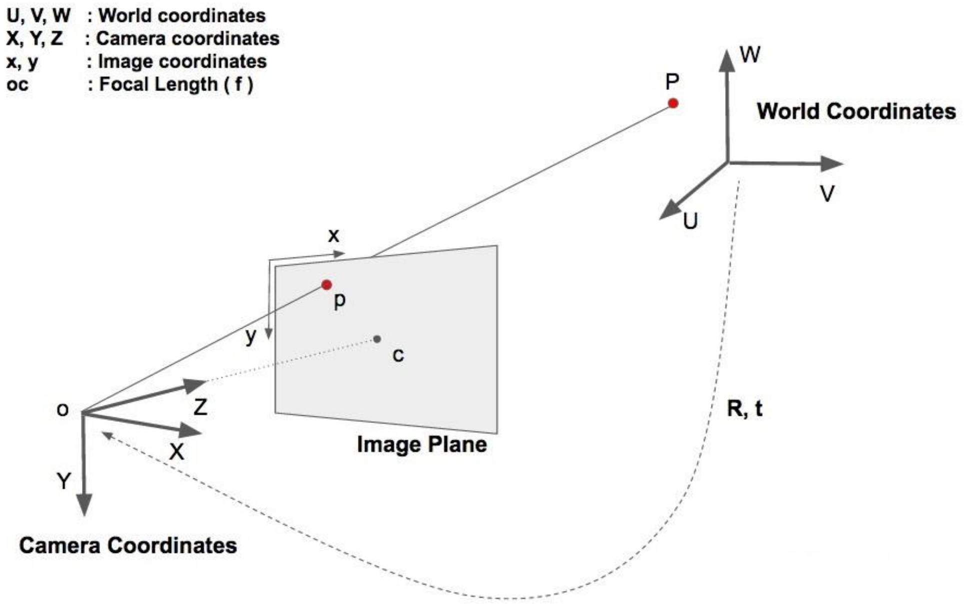

Figure 4: Concept of Pose Estimation as correlation between camera and real-world coordinate system [2]

In the present application, pose estimation is used to link features such as edges, curves or section cuts of a known 3D bucket profile (e.g. from CAD model) with the image of a bucket taken by the inspection system. This allows drawing of reference lines and other characteristic features into the images.
To calculate the two needed matrices R and t, at least a set of reference points is needed. In case of the Pelton bucket the template markings on the bucket top area are used. Thus, in a first step the recognition and separation of the markings is done by using colour filters. The identified set of points and the known coordinates of the corresponding points from 3D model are then used to calculate the position of the bucket in the images.

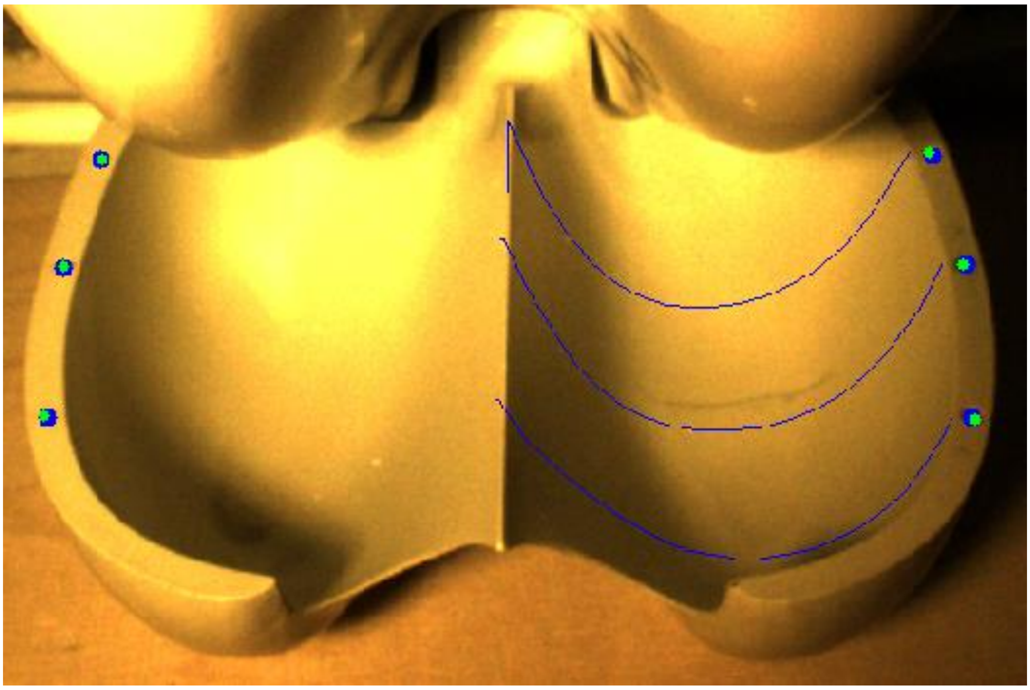

Figure 5: Pose Estimation with added template cross-section lines

In Figure 4 above the use of pose estimation is illustrated on a sample bucket. At the rim of the bucket the six blue markings are the positions of the profile templates that were used to calculate the alignment. Based on this information, the template cross section lines (blue) were added in the right bucket half. With these added references a damage in the bottom of the bucket can be better located.

3. Pilot Project

3.1 Installation

The pilot instrumentation of the automated inspection system has been done on Unit 3 of the Swiss powerplant Mörel. The selected unit is a single jet unit with a horizontal axis. The unit gets its water from a catchment area in the alps where a glacier is present. Therefore, the sediment load in summer is rather high and the runner sees some sand erosion over the time of operation.
In Figure 6 the image acquisition unit can be seen. The camera with a resolution of 2048x1536 pixels at the center plane of the runner and the two LED light sources on each side are mounted above the injector. With this position a good view into the bucket and thus to the hydraulic active surface is granted. In addition, with this installation location the equipment is well protected against the heavy forces of the splashing water during operation.

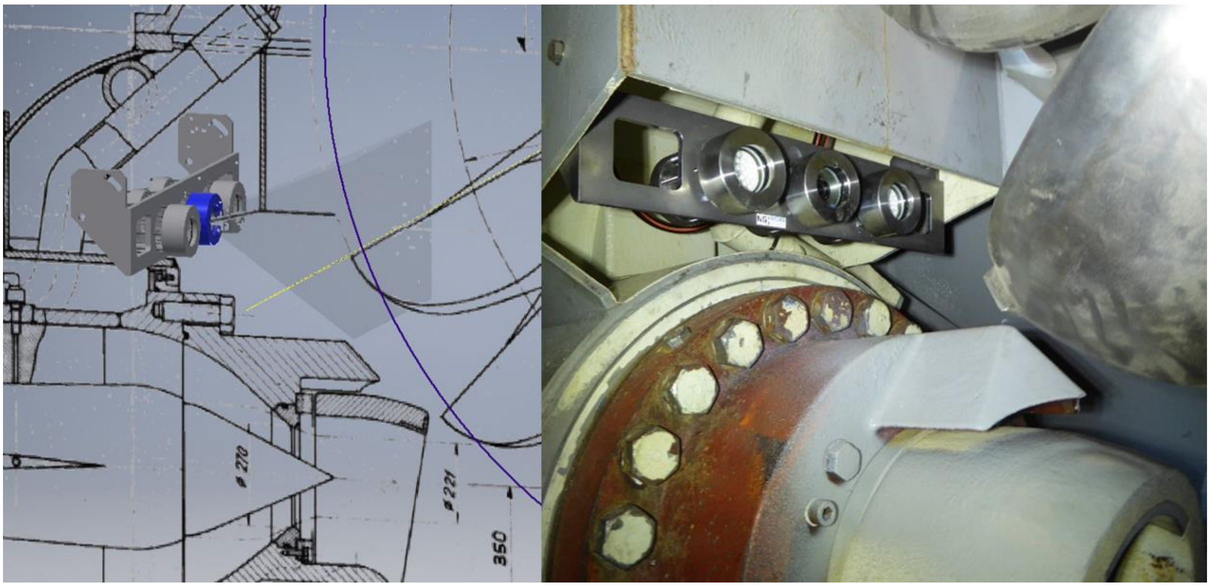

Figure 6: Image acquisition unit of the pilot project at Mörel 3 in CAD (left) and installed at site (right)

3.2 Results

The system has been in operation for a few months now and takes images independently. Since the unit is operated as a peak load supplier it is started once or twice daily and is then in operation for a few hours. The installed system configuration is set in a way that every time the unit is taken from the grid and the runner speed is ramping down a set of images is taken. A sample image of bucket 11 taken by the pilot system during commissioning is shown in Figure 7.

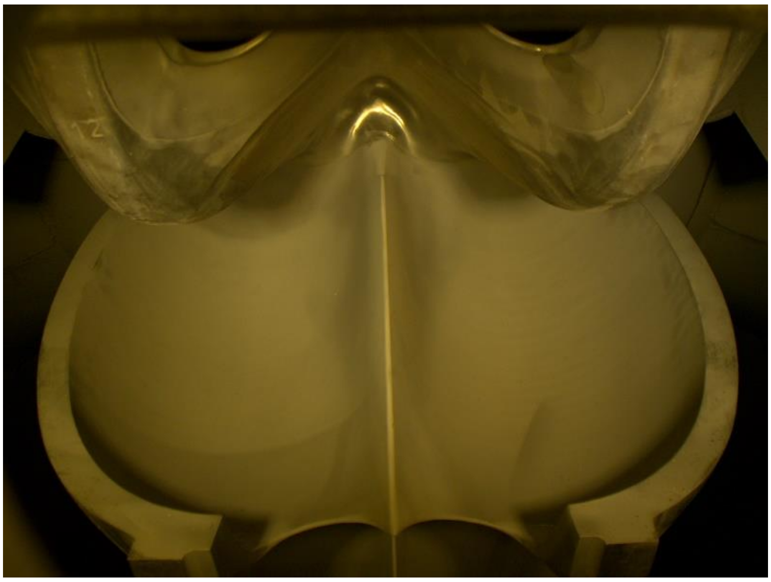

Figure 7: Sample image of bucket 11 taken with the pilot installation

The main outcome from the first weeks of operation is that all further analysis is strongly dependent on a good quality of the images. In order to get high quality images several points need to be taken into account.
Firstly, the lens needs to be clean and free of any droplets. This can be achieved by a cleaning process that applies oil-free pressurized air to the lens of the camera casing in order to blow away the drops. If the water contains a high amount of sediments and especially sediments with high hardness values (> Mohs 7) a chemical hardened glass or even a sapphire glass is strongly recommended to avoid visual disturbances due to fine scratches in the lens over time.
A second point is that motion blur due to the rotation of the bucket should be minimized. The selection of a sufficient low exposure time can tackle this problem. But by knowing the dependency between light sensitivity of the camera, exposure time and illumination of the scene one gets to the conclusion that this is only possible with the selection of a sufficiently strong light source.
For the further tasks of postprocessing and analysis of the images, the basic algorithms are implemented but will be further optimized with the increased amount of sample images that are available from the pilot installation.

4. Discussion

The results of the pilot installation of an automated inspections system proves that the presented concept is viable and can support the O&M divisions of turbine operators. The recent developments in Computer Vision and the availability of powerful Computer Vision libraries [3] made such a new approach for runner inspections possible.
It seems clear that with the concept at hand various external negative effects can be reduced and therefore quality is increased in numerous ways:

- The result is **independent on the skills and experience level of the expert** who is doing normally this inspection manually. The system is always applying the same clearly defined and given parameters.
- With a permanently installed light source the illumination is always the same. This **reduces misinterpretations** due to optical biases.
- In remote locations experts are not always available. Therefore, with such a system **travel costs of professionals at electric utilities that act worldwide can be reduced.**
- Due to its computerized assessment of the images **automated reports** can be generated that are **always up-to-date and available from any remote location** that has access to the network.
- As no dismantling of casing parts and installation of any scaffolding is needed, there are **no labour costs** for these tasks.
- The **availability of the unit is always given** as the system is permanently installed in the casing. Consequently, it is not needed to plan an outage for an inspection and the dispatcher can at any time decide to start the unit.

From the experience of the pilot installation it is clear that there is still a big potential for improvements and further developments. But the first results are very promising and prove the feasibility of the concept and its potential application in other hydropower plants.

5. Acknowledgement

The author thanks Ph. Ruffiner and B. In-Albon from EnAlpin, Switzerland and their team at site, for the support and for making the pilot installation at Mörel unit 3 possible.

6. References

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