Automatic measurement of river water-level using image-based computer vision

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ABSTRACT

Monitoring the water reservoir in hydroelectric plants is of fundamental importance for the management of energy production, flood warnings and planning of water resources. To that end, telemetric and electronic meters allow water levels to be automatically measured and monitored in the hydroelectric power plant. Such methods may have flaws or inaccuracies, necessitating a second measurement method. Video surveillance has come to be widely used for monitoring as a redundant system, but it is still subject to human errors in visually reading information. In this context, this work proposes a redundant automatic measurement method using computer vision. As a case study, images from conventional cameras from the Jirau Hydroelectric Power Plant, on the Madeira River, Brazil, were used. The results obtained show RMSE, MAE and R^2 errors of 0.045, 0.0328 and 0.9946 respectively. Such results show that the proposed model can collaborate as a redundant monitoring method.

1. Introduction

Monitoring water level has become an essential task for regulatory control of rivers in order to manager disaster risk assessment, flood warnings, water resources planning, public and industrial supply. In hydro-power energy production, it is essential to monitoring the rainfall, inflows and water level in order to maximize energy revenue, while taking into account dam safety risks [1, 2]. Different methods are used in redundancy in order to guarantee availability and accuracy of measurements. Automatic water-level gauges are used to monitoring water level by sensors that measure level of water (i.e. float-type, pressure-type, ultrasonic-type and radar-type gauge) [3, 4].

Moreover, video surveillance became widely used for monitoring and measure system at hydro-power stations as a redundant system [5]. The problem with this method is that human eyes are not reliable and subject to errors, which compromise the security of system. Therefore, defining an accurate and reliable method to monitor water level is a challenge for hydro-power system control. Floods are one of most frequent widespread and costly natural disasters in world. Floods result in highest number of casualties in comparison to any other disaster [6]. The purpose of flood management is reduce impact of flood events on local communities and infrastructure assets. Flood management include prevention, preparedness, response and recovery phases [7]. Flood risk management in hydroelectric plants is of great importance, especially if considered potential influence of climate change and reduction of natural river meadows caused by human activities [8]. Measurements realized by camera installed on river facilities, are used for precisely information about water-level estimations [9].

Automatic river water-level image-based measurement is a visual sensing technique that inspects reading of river water line using image processing instead of human eye. The image-based measurement process has to be characterized both systematic and random errors effects. Random errors must be estimated to qualify results obtained with uncertainty standard [10]. The characterization of image-based measurement processes are made of three main components: image acquisition, image processing, parameters measurement. Image acquisition provides a digital image of scene captured by a digital device. Image processing makes a suitable preprocessing of digital image as filtering, edge detection and segmentation. Parameters measurements extracts dimensional parameters or general features from the objects, measurement results [11].

Computer vision is an interdisciplinary scientific field that develop theory and technology for construction of artificial systems to gain high-level understanding from digital images or videos. It seeks to understand and automate tasks that human visual system can do [12]. Computer vision can help overcoming limitations of human visual in daily tasks. Vision-based measurements can be an alternative to measurement methods used traditionally in different areas [13].

Hasan et al. [14] develop a method for a continuous contactless water level measurement even under critical conditions like floods and hydraulic jumps by image processing,

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which is based on edge detection principle. Sakaino [15] proposed a methodology to detect the river level with a single image and a two-stage histogram model.

Lin et al. [16] presents an automatic approach for detecting the river level based on images from a single camera. They use digital image processing techniques to reduce noise, detect the water level in real time and, using the photogrammetric principle, track the camera's movements for better accuracy.

Pan et al. [17] propose a method to detect water level of a river or reservoir. Images of staff gauge, which is used to measure water level, are obtained from a camera installed on the bank. Based on property of images captured by the camera, problem of water level calculation is transformed in a problem of classifying each image into two classes of staff gauge and water.

Guo and collaborators [18] propose a water-level measurement method based on image processing and sparse representation. The method has a strong robustness to light variation, local disability, foreign matter occlusion.

Chen et al. [19] developed a method to water level staff gauge reading recognition based on image processing. The proposed method consists of three components: a multi-template matching algorithm to recognize characters on wherein water level staff gauge, a sequence verification algorithm to check and refine the recognized characters, and a projection height comparison method to achieve accurate reading even under the circumstance of incomplete characters.

In this article we propose a redundant method for monitoring water-level of Madeira River in facilities of Jirau Hydroelectric Power Plant. The measurement of water-level of river is obtained from processing a set of digital images obtained from conventional cameras installed at strategic points defined by plant's operating team of Jirau Plant.

2. Materials

This study uses data from Jirau Hydroelectric Power Plant installed on Madeira River in state of Rondônia in northern Brazil. The Madeira River is the biggest tributary of the Amazon river in South America. The river has a capacity for power generation of 3350 MW and its flows can reach 60,000 m^3/s, enough to supply approximately ten million homes. The Jirau Hydroelectric Power Plant is one of two power stations installed in Madeira River managed by The Jirau Energia consortium (Energia Sustentável do Brasil - ESBR). Figure 1 shows an overview of Madeira River and Jirau Hydroeletric Power Plant. Jirau Energia has provided images and measurements data set used to develop and evaluate proposed redundant method to monitoring water level.

The set of images used to develop redundant method for automatic water level measurement of Madeira River is converted from videos collected from Intelbras VIP 3215 SD IR cameras. The VIP 3215 SD IR is a security camera with 15 × optical zoom, 2 megapixel resolution and high definition images, suitable for IP video surveillance and surveillance systems [21]. The images were collected on 06.02.2020,

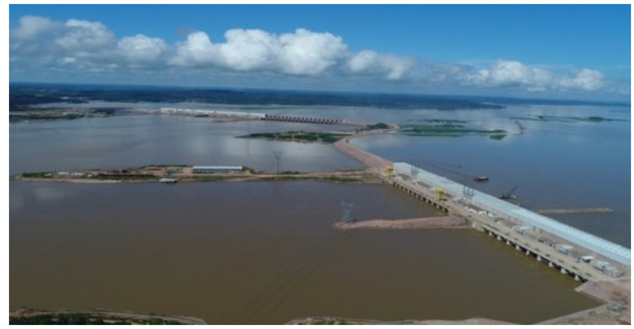

Figure 1: Madeira River and Jirau Hydroeletric Power Plant [20].

02.07.2020 e 06.01.2021 at different times, water levels and climatic conditions. The data set of images used to develop the automatic redundant method is formed by 43 images. Figure 2 shows an image converted from video of staff gauge used to measure water level of Madeira River at Jirau Hydroelectric Power Plant.

Figure 2: Original image obtained by videos from cameras and converted to image.

3. Methods

Image enhancement has an important task in image processing aiming to improve perception and interpretability of image adapting it to determinate task [22, 23]. The set of methods applied to noise reduction, image enhancement, definition region of interest (ROI) and ROI analysis is organized in a diagram depicted in Figure 3. The sequence of image processing techniques is applied in order to prepare the images for an accurate analysis.

In an image acquisition process, they are susceptible to presence of noises which are changes in image caused by modifications in pixels values. Considering image data set, there are too many noises harming analyses of staff gauge. These noises can be attenuated by smoothing images and keeping edges. The first technique to enhance images is *Noise Removal*. At this process, original images are converted to grey scale to standardize between images from day light and night and, then, it is applied median filter to smooth images. The media filter consists of creating a mask, such as

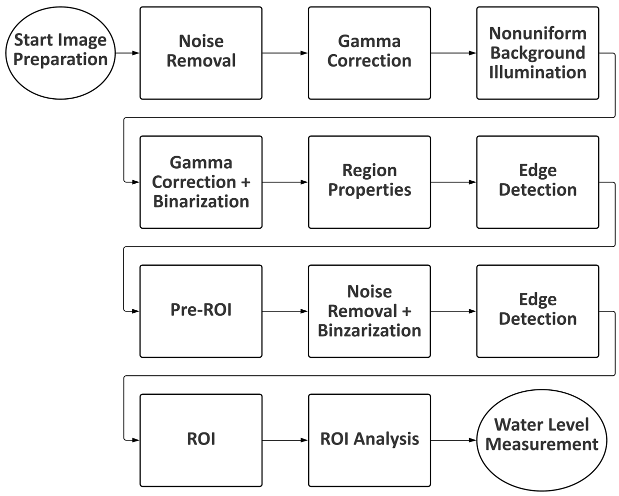

Figure 3: Image processing techniques to image enhancement and extraction of the region of interest.

a 3×3 rectangular window, which is applied to image pixel by pixel. Average filtering calculates the average value for each pixel in image. The media filter is defined by Equation (1)

$$\mathbf{R} = \frac{1}{M * N} \sum_{i=0}^{M-1} \sum_{j=0}^{N-1} (z_{i,j}), \tag{1}$$

where $\mathbf{R}$ is a square matrix of image, M and N is filter size (3×3), $\mathbf{z}$ is the sub-matrix of $\mathbf{R}$ where filter mask was applied. The filtering process is applied to entire matrix $\mathbf{R}$. [24, 25].

The second technique used to improve image is *Gamma Correction*. As a result of smoothing image, number marks on staff gauge has no good contrast and need a better outline. To that end, it is applied image gamma correction at smoothed images in order to improve contrast and provide a better visualization. The constant of gamma correction is defined by

$$s = c\tau^{\gamma}, \tag{2}$$

where c is a constant, τ is the pixel value of image and γ is exponent of power equation [25, 26].

After *Gamma Correction*, illumination correction is performed in order to prevent missing some details caused by nonuniform illumination that can lead to misinterpretations of image [27]. Since illumination from background is different from the center of image, it is applied *Nonuniform Background Illumination*. This process consists of removing foreground (staff gauge area) using morphological opening method and dilation process to correct illumination. Thereafter, background is removed by subtracting this corrected image, pixel by pixel, from resulted image after *Gamma Correction*.

The morphological opening process is a method of erosion followed by dilation in order to clean image. Erosion aims fine-tune or shrink pixels. It can be used as filtering operation in witch pixels smaller than structural elements are filtered. The erosion process eliminates foreground structure by decreasing it from original image.

Considering a structural element B translated by d belongs to set A, an enlarged and filled binary image. Erosion can be defined as

$$A \ominus B = \left[d \,|\, B_d \cap A^c \right] = \emptyset \tag{3}$$

where $\ominus$ is symbol for erosion, A^c is complement of A and $\emptyset$ represents empty set [25, 28].

The dilation process, through structural elements, adds foreground structures allowing it to increase foreground area as compared to erosion process. Considering G is reflection of the structural element B around the origin, dilation is set of all displaced elements d so image A and structural element reflected G overlap by at least one element. The dilation operation is given by

$$A \oplus B = \left[d \,|(G_d \cap A) \right] \subseteq A \tag{4}$$

where $\oplus$ is symbol for dilation [25, 28].

After *Nonuniform Background Illumination*, there are still unconnected pixels that will interfere on edge detection. In order to remove these unconnected pixels, its necessary to apply *Region Proprieties* process. First, *Binarization* process is performed by Otsu algorithm [29]. This method uses histogram of quadratic matrix R and finds global optimum value determined as ψ, in order to segment the background and object of interest in image [25]. In *Binarization* process, for each pixel on R, values greater than ψ receive 1, while values less than or equal to ψ receive 0. Relation (5) describes this process [25].

$$R = \begin{cases} 1, & \text{If } R > \psi \\ 0, & \text{If } R \leq \psi \end{cases} \tag{5}$$

Region proprieties process consists of extracting propriety of an image as a shape feature (i.e. circles). To that end, it is necessary to calculate centroid for each connected component and for longest and shortest axes. Through this information it is possible to obtain radius of each circumference for each identified pixel [30]. Therefore, it is possible to identify the biggest circumference as staff gauge. After that all the unconnected pixels with small circumferences are set to 0, removing them from images.

The *Region Proprieties* creates a mask that expresses only location of staff gauge in image. This position is found through *Edge Detection*, in which images are traversed pixel by pixel by the mask, aiming to find pixels different from zero value. This process detects top, left and right edges of staff gauge delimiting its coordinates. Therefore, it is possible to highlight staff gauge with part of river, cropping it from original images. The cropped image is defined as *previously region of interest* (PRE-ROI) [31].

To calculate water level, it is important to remove part of river that appears in PRE-ROI images and maintain only staff gauge, object of interest. To that end, it is applied again *Noise Removal* and *Binarization*. After that, *Edge Detection* process is applied at image, from bottom-up, in order to delimit bottom edges of staff gauge. Therefore, it is possible to crop from PRE-ROI images only staff gauge, which is defined as *Region Of Interest (ROI)*. As a result, lower bound of ROI images represents water line of river.

The Madeira river level at Jirau Hydroelectric Power Plant ranges from 82 meters to 91 meters, according to sea level. There are 9 staff gauges aligned that measures water level. They are formed by numerical counters in square window that marks every 10 centimeters (ranging from 10 to 90). Moreover, there are dashes marks, aside numbers marks, that represents 1 centimeter, in order to give more precision at water level measurement. At the beginning of each staff gauge level (in meters) is presented by a number mark with a different color (red) (Figure 2).

In order to measure water level by images, it is necessary to perform *ROI analysis*. To that end, it is necessary to define window size that contains water level marks which represent 10 centimeters in staff gauge. Next, defined window size traverse ROI images counting amount windows that fit in defined size. Considering that 91 meters is highest referenced measurement level, amount of window size detected, and detected water line, it is possible to determine water level of river by Equation (6)

$$l = 91 - \left(\omega + \frac{\delta}{\upsilon}\right) \times 0.1 \tag{6}$$

were l is *Water Level Measured*, ω represents amount of window size counted in ROI images and $\frac{\delta}{\upsilon}$ is fraction of last window size encountered at staff gauge considering water level line. Since each window size correspond to 10 centimeter, it is necessary to multiply Equation (6) by 0.1 to have correct measurement.

The proposed method is submitted to three different evaluation criteria compared to the the water level measurements dataset, provided by Jirau Hydroelectric Power Plant. The root mean square error (RMSE), expressed by Equation 7 mean absolute error (MAE) in Equation (8), and determination coefficient (r^2) in Equation (9).

$$RMSE = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(\hat{y}_i - y_i)^2} \tag{7}$$

$$MAE = \frac{1}{N}\sum_{i=1}^{N}|\hat{y}_i - y_i| \tag{8}$$

$$r^2 = 1 - \frac{\sum_{i=1}^{N}(y_i - \hat{y})^2}{\sum_{i=1}^{N}(y_i - \hat{y})^2} \tag{9}$$

where N represents dataset size, $\hat{y}$ is calculated measurements from proposed method, and y is the measurements from dataset provided by technical team from Jirau Hydroelectric Power Plant.

Mean absolute error (MAE) and root mean squared error (RMSE) are two of most common metrics used to measure differences between values measured by a model and the values observed. Both MAE and RMSE express average model prediction error in units of variable of interest. However, since in RMSE errors are squared before they are averaged, it gives a relatively high weight to large errors. The r^2 is a metric that provides a measure of how well observed outcomes are replicated by model, based on proportion of total variation of outcomes explained by model [32].

4. Results

The measurement of water-level of Madeira river is obtained from processing a set of digital images obtained from conventional cameras. The proposed digital image processing method is used to correct and improve image quality and for automatic detection of measurement of staff gauge. Moreover, detection results are compared to a dataset of measurements provided by technical team from Jirau Hydroelectric Power Plant. In this section, results of each correction and improvements of image is presented followed by performance of method compared to dataset.

4.1. Noise reduction and image enhancement

The *Noise Removal* process consist of applying median filter in order to smooth the images. This filter has function of arithmetic average values of a pixel and its neighbors, replacing it by this new value. This process is applied to all pixels of an image. The Figure 4 represents a smoothed image from 2 after median filter application.

Figure 4: smoothed image from Figure 2 by *Noise Removal* using median filter.

Next, *Gama Correction* is applied to improve the contrast of images as depicted in Figure 5. However, one can notice that there are illumination issues on image.

A nonuniform illumination may miss important elements and wrong details of images. Therefore, an illumination correction and background removal is applied in images through *Nonuniform Background Illumination* process. Figure 6 shows

Figure 5: Contrast enhancement of the imagem from Figure 4 by *Gamma Correction*.

the results of morphological opening and dilation process while Figure 7 present the result after background removal.

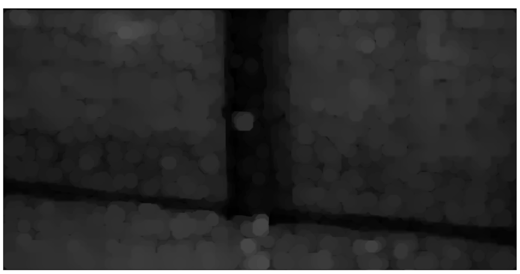

Figure 6: Application of morphological opening and dilation process to the image from Figure 5.

Figure 7: Background subtraction applied to Figure 6 as part of *Nonuniform Background Illumination* process.

As one can see, resulted image after *Nonuniform Background Illumination* process is dark for analyses. Therefore, contrast is improve by applying *Gamma Correction*, as depicted in Figure 8.

4.2. Region of Interest

To measure the water level it is necessary to identify staff gauge in image. By applying image enhancement and *Binarization* process, it is possible to highlight staff gauge at center of image, as shows in Figure 9.

Through binarized image, it is possible to determinate

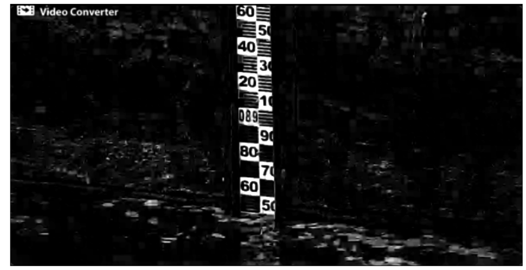

Figure 8: Contrast enhancement of the Figure 7 by *Gamma Correction*.

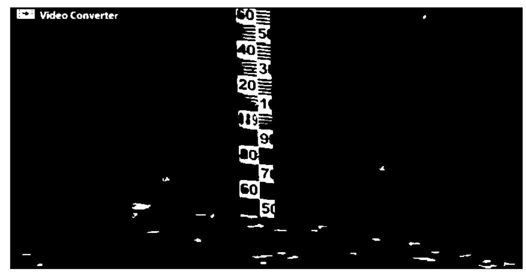

Figure 9: Binarized image from the Figure 8.

edges of staff gauge in order to extract the region of interest. However, there are still unconnected pixels surrounding the staff gauge. In order to remove those unconnected pixels, *Region Properties* process is applied. This process consists of extracting propriety of an image as a shape feature, as depicted in Figure 10.

Figure 10: Binarized Image from the Figure 9 with *Region Properties* highlighted by circles.

Once unconnected pixels are identified, it is calculated circumference of each circles and removed the unconnected pixels except the one with biggest circumference [30]. The remained unconnected pixel refers to staff gauge, Figure 11 depicts resulted image from *Region Properties* process.

The resulted image can be used as a mask that to be applied to original image in order to express the position of staff gauge, by applying *Edge Detection* process. Next, detected image is cropped from original image and defined as *PRE-ROI* image. Figure 12 shows resulted image where there is

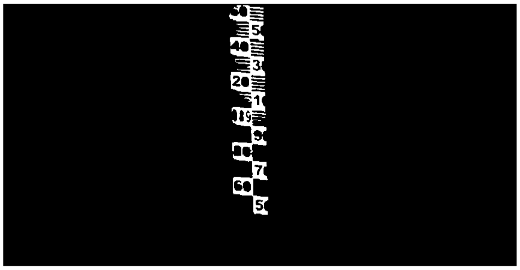

Figure 11: Region proprieties approach from Figure 10.

only staff gauge and a part of river.

In this way, original image can be transcribed to space determined by mask by extracting object as represented in Figure 12, where there is only staff gauge and a part of river. In sequence, river needs to be removed from image in order to analyse it and measure water level, according to Figure 13. As explained in methodology, staff gauge contains marks of meters and centimeters all over it. The water level, in meter, is signalized by red circle, centimeters are lines between windows and windows are represent by yellow square, as represented in Figure 14

Figure 12: Extraction of the pre-region of interest from Figure 4.

In *PRE-ROI* image remain part of river that is not necessary for water level measurement. To remove this part, it is applied *Noise Removal + Binarization* and *Edge Detection*. Therefore, it is possible to crop from *PRE-ROI* images only the staff gauge, which is defined as *ROI*. Figure 13 depicts resulted image.

Next, it is performed *ROI Analysis* where water level marks from staff gauge are detected and river measurement is calculated according to Equation (6). The resulted image is show in Figure 14, where red circle points out to the water level measured in meters (the beginning of one staff gauge) and yellow square represent where water level of river is marking.

Figure 13: river removing from 12 resulting in *ROI* image.

Figure 14: Staff gauge highlighting the measurement of river.

4.3. Evaluation Method

To evaluate method, all measurements detected from image dataset are compared to measurements dataset generated by automatic water-level gauges installed at Jirau Hydroelectric Power Plant. The automatic water-level gauges are composed by sensors that constantly monitor water level of Madeira River.

For the evaluation process, it was selected 43 images from recorded videos to compose image dataset at different dates, times, water levels and climatic conditions. For day 1 (06.02.2020) were collected 11 images, for day 2 (07.02.2020) were collected 20 images and for day 3 (06.01.2021) were collected 12 images. The proposed digital imaging process method were applied to image dataset and measurements results were compared to data from automatic water-level gauges from same period of date and time. Table 1 presents results from measurements for each date (**Day**) from auto-

Table 1
Water level measurement on Madeira River.

Day	AWG	DIP	Error	Day	AWG	DIP	Error
1	90.03	90.03	0.00	2	89.98	90.02	-0.04
1	90.04	90.03	0.01	2	90.03	90.02	0.01
1	90.06	90.02	0.04	2	90.01	90.03	-0.02
1	90.05	90.02	0.03	2	90.02	90.01	0.01
1	90.01	90.02	0.01	2	90.00	90.06	-0.06
1	89.98	90.04	-0.06	2	90.01	90.13	-0.12
1	89.98	90.03	-0.05	2	89.99	90.04	-0.05
1	90.00	90.03	-0.03	2	90.00	90.12	-0.12
1	89.98	90.02	-0.04	2	89.99	90.01	-0.02
1	90.00	90.02	-0.02	3	88.49	88.49	0.00
1	90.00	90.03	-0.03	3	88.51	88.49	-0.02
2	90.00	90.03	-0.03	3	88.50	88.48	0.02
2	89.99	90.03	-0.04	3	88.49	88.47	0.02
2	89.99	89.98	0.01	3	88.51	88.52	-0.01
2	90.01	90.03	-0.02	3	88.50	88.52	-0.02
2	89.98	90.02	-0.04	3	88.49	88.50	-0.01
2	89.98	90.02	-0.04	3	88.51	88.50	0.01
2	90.02	90.02	0.00	3	88.51	88.54	-0.03
2	90.00	90.02	-0.02	3	88.49	88.51	-0.02
2	89.99	90.00	-0.01	3	88.50	88.52	-0.02
2	90.00	90.01	-0.01	3	88.51	88.48	0.03
2	89.98	90.19	-0.23				

matic water-level gauges (**AWG**) compared to the proposed digital imaging process method (**DIP**). The column **Error** present the difference between **AWG** and **DIP**.

The methodology is evaluated through three different criteria, RMSE, MAE and r^2. The objective is to assess how close measured results are compared to data of automatic staff gauge. The RMSE and MAE measure magnitude of errors. A lower value for RMSE is better than a higher one. The MAE calculates the average between water level measuremnts from proposed model and water level measurements from automatic gauge. r^2 represents relationship between variance of measurements from proposed model and total variance of measurements from automatic staff gauge. The Table 4.3 presents the evaluation results.

Table 2
Results Evaluation

RMSE	MAE	r^2
0.0495	0.0328	0.9946

5. Conclusion

Monitoring water level is an important task to control in hydro-power energy production in order to maximize energy revenue, while taking into account dam safety risks. To guarantee accuracy, different methods are used in redundancy. In Jirau Hydroelectric Power Plant it is used automatic water-level gauges and video surveillance to monitor water-level of Madeira River. The problem of rely on video surveillance is that at human eyes are subject to errors. Moreover light conditions and camera position can compromise measurement precision.

This work proposes a methodology of computer vision to automatic calculate water level in Madeira River. The proposed method uses only digital image processing techniques in order to solve difficulties encountered due to bad light, camera position and weather constrains, in order to automate detection process. Through techniques such as noise removal, gamma correction, morphological processing and image properties, it is possible to eliminate noise and extract region of interest of images. Therefore, it is possible to perform detection of water level by detecting water line and counting counter marks of staff gauge. The measurement results obtained by proposed method presents are similar to measurements from data of automatic staff gauge approximate values to provided by technical team of Jirau Hydroelectric Power Plant.

To assess how close the measured results from proposed method are to data of automatic staff gauge, three different evaluation criteria were used: RMSE, MAE and r^2. The evaluation resulted in a lower value for RMSE and MAE (0.045 and 0.0328 respectively) and 0.9946 for r^2. Since RMSE and MAE are close to 0 and r^2 is close to 1 that would indicate a perfect fit of measurements from proposed model compared to data from automatic gauges.

Therefore, it can be concluded that digital image processing is a promising approach for water level detection of Madeira River at Jirau Hydroelectric Power Plant. It can collaborate as a redundant method for monitoring the water level contributing to safety, energy production as well as hydropower control and management.

However this model is not able to work at connected staff gauges without a human operation. To automate this process, an automated model that uses deep neural network to be able to predict water level. Therefore, precision of water-level detection by proposed model can provide a qualified dataset for training and test a convolutional neural network model that can estimate level of Madeira River at Jirau Hydroelectric Power Plant.

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