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Water level detection for flood disaster management based on real-time color object detection

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Abstract

Currently, the water level monitoring system for a river uses instruments installed on the banks of the river and must be checked continuously and manually. This study proposes a real-time water level detection system based on a computer vision algorithm. In the proposed system, we use a color object tracking technique with a bar indicator as a reference level. We set three bar indicators to determine the status of the water level, namely NORMAL, ALERT, and DANGER. A camera was installed across the bar level indicators to capture the bar indicator and monitor the water level. In the simulation, the monitoring system was installed in 5-100 lux lighting conditions. For experimental purposes, we set various distances of the camera, which is set at 40-80 centimeters, and the camera angle is set at 30-60 degrees. The experiment results showed that this system has an accuracy of 94% at camera distance in the range of 50-80 centimeters and a camera angle is 60o. We compared the proposed method with ShuffleNet dan MobileNetV2. The results show that ShuffleNet and MobileNetV2 failed in detecting flood while the environment is low illumination. Based on these results, it can be concluded that this proposed system can determine the water level well in varying lighting conditions.

1. Introduction

A flood is a natural disaster that has the potential to damage, harm humans, and even claim lives. Floods usually occur in riverbanks and cities that are densely populated. The government has not appropriately handled flood disaster management until now. Mainly because it happens unexpectedly and without preparation, such as not during the rainy season, floods can come suddenly without anyone being able to predict [1]. Flood events occur due to various factors, such as overflowing river water that exceeds the river wall barrier because the water discharge is more significant than the river water flow capacity [2], [3], so the river water exceeds the wall height limit.

Flood disaster management aims to prevent the damage caused by the water bleeding into the community land. There are four stages to developing flood disaster management: (1) prevention, (2) preparedness, (3) response, and (4) recovery [7-9]. One of the methods to prevent flood disasters is an early warning system. Early warning systems require access to relevant, timely, and accurate data [9, 10]. Today's critical flood management tools include automated interpretation and remote data collection [7, 12-13].

One of the ways to prevent flooding and reduce damages/losses is to detect the river's water level [3]. Thus, the residents around the riverbank can take precautions to prevent flooding and decrease the number of victims. Until now, the water level detection system has been carried out by installing an instrument indicating the height of the river water level. The tool is set up on the river wall. However, monitoring must be done continuously and manually because the water level constantly changes. Such an approach is ineffective due to manual and continuous monitoring because this task is time-consuming [4]. In addition, there will be more spending on hiring people to do the task. Therefore, an automated system is needed that can provide real-time and accurate information.

Computer vision is a branch of computer science that aims to teach a computer to see and understand the content of a visual environment in the same way that humans do. In a computer vision-based system, a camera is used to capture and collect information from the environment. Several systems and techniques for preventing flood disasters have been proposed and developed, including flood assessment, flood monitoring, water velocity measurement, flood modeling, flood detection and management, and post-flood damage assessment. Despite the proposed technology, it's very important to design a simple and powerful system for flood disaster management that is easy to implement in several environments or regions.

Camera sensors have shown better performance compared to non-camera sensors such as ultrasonic sensors and proximity sensors. To get accurate results, ultrasonic or proximity sensors must be installed or placed close or in contact with the water surface. If the device is submerged or exposed to water, the sensor will be damaged and cannot work anymore [5]. A comprehensive review has shown that camera sensors are much better and more stable in detecting floods [6]. Several studies have been conducted to develop automatic water level detection systems using various approaches i.e. water surface, the water surface of velocity, and indicator level [4], [5]. The filtering approach is one of the more familiar methods for detecting water surfaces for flood detection [13–16]. In reference [13], water level detection was used with finite impulse response (FIR) filtering. The FIR filter works in the same way as the edge detection method. The author considered that changes between frames in a video refer to determining water level improvement [13]. Another approach is bandpass filtering, which was also proposed to detect water level improvement [14]. A frequency spectrum is used to underpin the proposed method. DCT was chosen to extract the details and significant information from the images. However, the filtering approach suffers from time consumption in processing the filter, especially if the proposed work is in frequency domains. Furthermore, the proposed techniques make it difficult to distinguish fluctuations in the water surface caused by the entry of an object from those due to the occurrence of a flood.

Several approaches that use the water surface velocity measurement technique are proposed [17–20]. This method computes the direction and interchange in the direction of the river flow, as well as the surface shape of the imagery taken of the river flow. Such techniques require further review and require a high-resolution camera so that any changes in water flow can be captured with precision and detail [21-26]. Several methods or systems are proposed for specific cases, such as irrigation on lakes [16] or reservoirs [19]. These proposed methods or systems certainly cannot be directly reimplemented in other cases or environments, such as rivers. Furthermore, reference [27] detected water levels with digital image processing using the color tracking object method, where the selected color indicated the water level by showing normal limits and potential flood height limits. Reference [28] developed a water level tracking system based on color using blob detection with the background subtraction method to find objects in the image by subtracting the current image from the previous image. The drawbacks of research [27] and [28] are that they are not real-time and are affected by the conditions or environment of the camera placement. Furthermore, these researches also had drawbacks that are not tested in various environmental conditions, which makes it difficult to predict their accuracy in various conditions [2], [27], [28].

Based on the aforementioned drawback, we conducted a study to propose a real-time water level tracking system. This system was tested in various lighting conditions and camera positions to adapt to various conditions in a real environment. This system can replace the existing manual system because we implement a real-time computer vision algorithm. This proposed system focuses on detecting the indicator bar that has been installed. Therefore, the detection process of the bar indicator did not affect by the light conditions and the camera position in the environment. Hence, whenever a flood comes, the system can recognize the water level properly based on the indicator bar level.

2. Research Method

This section describes the method of the color object detection algorithm, system design and system simulation. The system is designed as a mini experiment by building a prototype of the actual detection system. Simulations are carried out to see the system's ability to detect water levels.

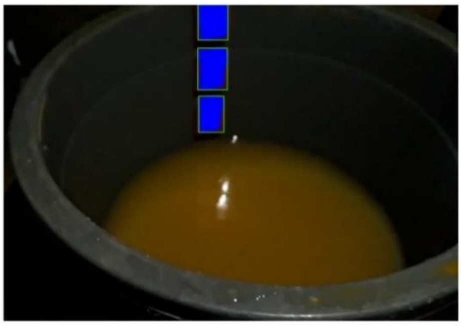
2.1 Color Object Detection

The indicator bar used a red object based on research recommendations [27]. The initial stage of color object tracking is to change the color space of the captured red image into the HSV color space (hue, saturation, and value). Then the process of separating indicator bars is carried out using the binarization technique. The binarization technique separates objects in an image from the background of the image. The technique used in this study is multi-thresholding. This method uses three threshold values for Hue, Saturation, and Value, respectively. This threshold value is used to separate the background and the object to be detected in the HSV image [29], [30]. Based on the results of repeated experiments, the best threshold value for this study was 140 for hue, 1 for saturation and 255 for value. After the threshold value is applied, every pixel below the threshold value will be black, while those above the threshold value will be changed to white. The results of the binarization can be seen in Figure 1a.

The following process is to detect the contours of the binary image. The contour detection process is carried out using the below function in python and OpenCV [31].

```
cv2.findContours(source_image,cv2.RETR_EXTERNAL, cv2.CHAIN_APPROX_SIMPLE)
```

This function searches for contours using a pixel value search starting from the top right pixel to the bottom left. The outermost white pixels that continue to form an object are considered the contours of the object. Next, for each detected contour, a bounding box is given. The bounding box can be set as a reference in calculating the number of detected indicator bars. Figure 1b shows an example of the results of adding a bounding box after the contour detection results have been successfully carried out.



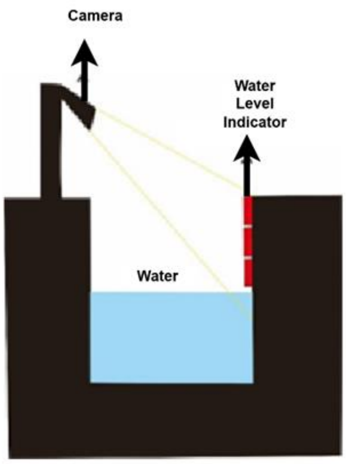
(a) (b)

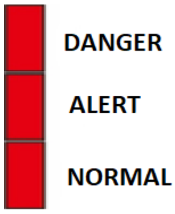
Figure 1. Color Object Detection Process, where (a) Result of Segmented the Bar Indicator Object, (b) Contour Detection Result with Bounding Box Marking

2.2 Design System

The design of this water level detection system uses the color object tracking method, which is based on similar research. The design of this system uses one of the computer vision libraries, namely OpenCV version 4.5.4 [32]. The programming language used is Python version 3.9.8 to build the algorithms used in the proposed system. The design of the water level detection system using color object tracking can be seen in Figure 2a. Based on Figure 2a, a prototype water level detection system consists of the following:

1. A water level indicator bar was placed on one of the water walls.
2. Camera mounted on the opposite side of the indicator bar to take an image from the water level indicator bar or bar
3. A computer is connected to the camera to detect the water level.





(a) (b)

Figure 2. The Proposed System of Flood Monitoring: where (a) Design of Simulation for Water Level Detection System, (b) Water Level Indicator Bar

The water level indicator bar is designed in red. Based on [33], the red color bar is the most effective color in the color detection process. Figure 2b shows the shape of the indicator bar designed for this water level detection system. Based on Figure 2b, the designation scale will be placed on one of the prototype walls of the river. When water is filled into a water reservoir prototype, the system detects a red object showing 3 bars; the water level condition is NORMAL. If the red object has been covered with 1 part so that two parts are visible, then the water level condition changes to status ALERT. Finally, if the red object has been covered in 2 parts so that 1 part is visible, then the water level condition changes to status DANGER. However, a re-checking process will be carried out if the red object is not detected.

2.3 Simulation System

The simulation is performed to replace the real environment nearby the river. However, the simulation condition is assumed as the real environment. During simulation the water are set improved so that the flood condition was represented. The flow chart of the water level detection system can be seen in Figure 3.

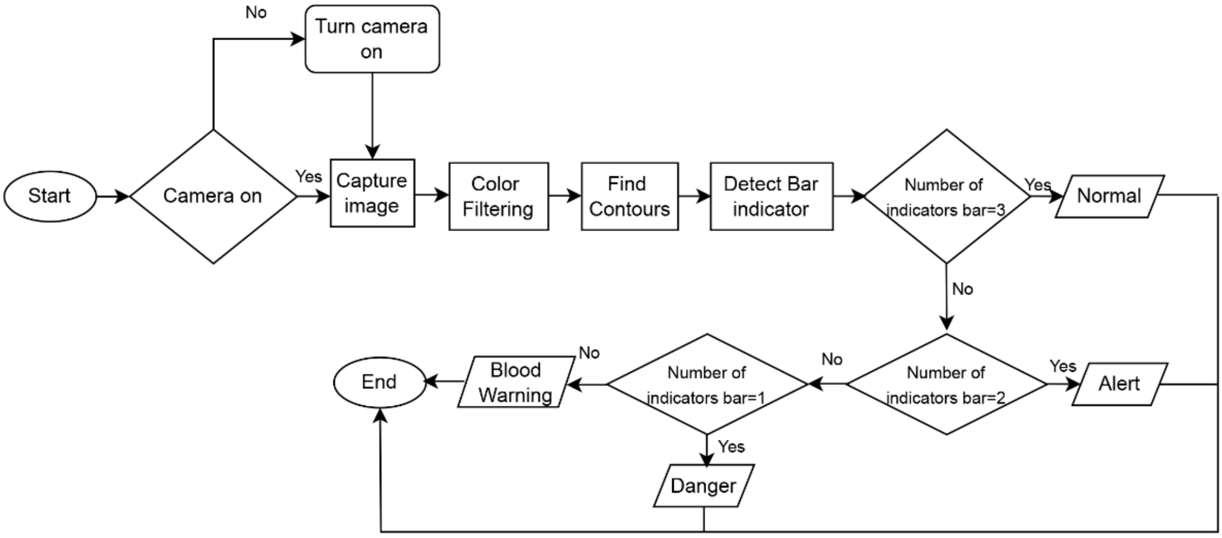


Figure 3. Flowchart of Water Level Detection System

While the system is running, the system will ensure that the camera is on and then capture the image containing the object. After the object is captured, the color filtering process is carried out on the object's color as required in the HSV color space. Then the process of finding contours will be carried out or find the outermost part that surrounds the colored object of the captured object. Then, the number of objects is detected through a bounding box process which is applied with a size that will change according to the contours of the object caught by the camera. If the bar indicator shows that there are still three bars, the system displays the water in a NORMAL state. If only two indicator bars are read, the system displays that the water status is ALERT. If the bar indicator reads only one bar, the system displays that the water status is DANGER. If no bar indicator is identified, the system will notify that the river has overflowed and a flood has occurred. Table 1 showed the parameters setting in simulation process to obtain the parameters in real implementation.

Table 1. Parameters setting during simulation

Parameters	Values						
Angle (degree)	30	45	60	-	-	-	-
Distance (cm)	40	50	60	70	80	90	100

3. Results and Discussion

The testing of the proposed method is carried out into several categories, namely testing the camera angle and distance to find out the best configuration of the distance and camera angle. The next step is to evaluate varying lighting conditions to determine the system's ability to handle lighting conditions. Furthermore, testing at different camera distances to see the system's ability to handle the quality of objects in the image.

3.1 The Impact of Camera Distance and Angle on The Indicator Bar

The distance and camera angle testing are carried out to identify the camera's ability to capture objects in the form of a water level indicator bar. The tested distance ranges from 0 to 100 cm, and the tested angles are 30, 45, and 60. Table 2 shows the results of testing the camera's ability to capture the water level indicator bar with varying distances and camera angles.

Table 2. The detection result based on camera distance and Angle

Angle (degree)	distance (cm) 40	50	60	70	80	90	100
30	v	x	x	x	x	x	x
45	v	v	v	x	x	x	x
60	x	v	v	v	v	x	x

X = unidentified,
V = identified

Based on Table 2, the 30° angle only succeeded in detecting the bar indicator object at a distance of 40 cm, while it did not work at other distances. The 45° camera angle successfully detects the camera at a maximum distance of 60 cm. The camera angle of 60° detected the bar indicator object at a maximum distance of 80 cm. This result is due to the higher the angle between the camera and the location of the bar indicator, the wider the camera catches and the clearer the visual system produced for the object.

(a)

(b)

Figure 4. Successfully Detected image, where: (a) Angle is 30º and the distance is 40cm, (b) Angle is 60º and the distance is 60cm

Figure 4 shows the successfully detected water level by the system for status NORMAL, ALERT, and DANGER. Figure 4a is the result of detection using an angle of 30 and a distance of 40cm. It can be seen that the system detects all three parts of the red Styrofoam that are on the wall of the bucket by displaying them through a green rectangle called BBOX (bounding box) as an indicator. The three sections define the status of the water level, namely NORMAL, for the water level below the three red Styrofoam and can be considered acceptable. Furthermore, the system can also detect the two parts of the red Styrofoam after the water is slowly filled into the bucket, so it covers one part of the red cork and shows the two halves displayed through the bounding box. The two sections define the ALERT water level status. Likewise, when water is continuously filled into the bucket so that it covers two parts of the red Styrofoam and shows one part shown in the bounding box. The system can detect one part of the red Styrofoam. One section defines the status of the water level, namely DANGER. Similarly, for an angle of 60 and a distance of 60cm, the system also successfully detects the water level correctly, as shown in Figure 4b.

Figure 5 shows that the system failed to detect the water level at a distance of 80 cm and the camera height was 80 cm. The designation scale cannot be applied to the bounding box because the contours are not detected effectively at a distance of 80 cm by the system. Placement of the camera far from the bar indicator resulted in the gap that separates the bar indicator boxes became smaller. So that it becomes increasingly difficult for the system to separate each bar indicator box. This is also influenced by the thresholding value used. If the pixels between the gaps become very similar, then the system cannot segment between the bars correctly. Therefore, for the system, it recommended to locate camera near to the bar, it should smaller than 80 cm.

Figure 5. Examples of Image that Not Detected Successfully with Camera Distance is 80 cm

Compared with [21], the proposed system is simpler because the camera focused on bar indicator not to the water surface. Changing in the water level are more difficult to detect and potentially more likely to fail than focusing on bar indicator. Therefore, the proposed more focus to detect bar indicator. Using the bar indicator also improved the stability of the system. If the camera gets interference from outside or being disturbed, the system still worked, because the camera had wide angle scope.

3.2 Impact of Camera Height and Light Intensity on Indicator Bar Environment

The camera height test against light intensity is carried out to see the system's ability to recognize objects in certain lighting conditions. This situation is very likely to occur in the natural environment. The camera height from the ground is set from 40 cm to 100 cm. The light intensity given is 0 to 200 Lux. Table II shows the evaluation results for the camera height and light intensity experiment.

Based on Table 3, the proposed system can work at light intensities of 5 to 100 Lux. The maximum camera height that can be reached is 80 cm from the indicator bar. The very high intensity causes the image to have a very high saturation value or the resulting image to be very white, so binarization cannot separate the indicator bar from the background. The same happens if the lighting intensity is 0 Lux, meaning the resulting image is very dark. The too-dark image makes it difficult for the binarization method to separate the background image from the bar indicator image.

Table 3. Effect of Camera Height and Light Intensity on Air Level Detection System

Height (cm)	Light Intensity (Lux)						
	0	5	30	50	100	150	200
40	x	v	v	v	v	x	x
50	x	v	v	v	v	x	x
60	x	v	v	v	v	x	x
70	x	v	v	v	v	x	x
80	x	v	v	v	v	x	x
90	x	x	x	x	x	x	x
100	x	x	x	x	x	x	x

X = unidentified V = identified

(a)

(b)

Figure 6. Image with Light Intensity of 5-100 Lux Successfully Detected, where: (a) Distance Camera from 50 cm, (b) Distance Camera from 70 cm

An example of the detection results using a light intensity of 5-100 Lux is shown in Figure 6. The system has successfully detected the water level correctly at 50 cm and 70 cm. While at 80 cm, the system cannot detect the water level correctly, as shown in Figure 7. The further camera from the level bar indicator the lower accuracy in detecting the bar indicator. It was caused by the space between the bar indicators became smaller. Therefore, while the image of the bar indicator was captured, the space that separates the bar indicator becomes invisible. This condition can make two bars considered as one bar indicator because the gap between the bars becomes empty or non-existent.

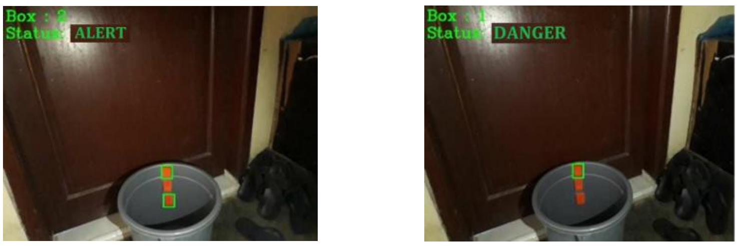


Figure 7. Image with Light Intensity of 5-100 Lux that was Not Detected Successfully at 80 cm

Compared with [18] and [33], the proposed system had the ability to detect under various lighting conditions. In [18]'s study, the bar used was an iron ruler which could reflect light so that the reflection of light greatly influenced the results of image processing. In the proposed system, the bar indicator was created from styrofoam which does not reflect light. So that it does not affect the image capture results. In [33], the frame from the video always normalized. This process increased the computational process, because the system always checks the light intensity in every second.

3.3 The Water Level Evaluation

The water level evaluation is an investigation to test the entire system with different lighting conditions and camera heights. The comprehensive tests carried out were 100 times with different light intensity settings and camera heights. In this test, the condition of the water is also set with a different bar indicator. In addition, tests were also carried out with clear water and cloudy water. The test results show that the accuracy of the system is 94%. Figure 8 shows a water level detection test using clean water. The test ensures whether or not the system can be applied in various water conditions. The test result shows that the system cannot detect the water levels properly in clean water.

Figure 8. Image that was not Detected Successfully in Clean Water

The system can detect the color of each indication scale even if every part of the scale is covered by water. It is because the clean water makes the visualization transparent between the water thresholds so that the system cannot distinguish the water level. Actually, the flood never bring water in clear conditions, but it has been mixed with soil and other water contaminants, so that there are no floods with clean water. Therefore, the drawbacks of the proposed system in the clean water will not affect the field later.

3.4 Comparison with Deep Learning method

In this study, we compared the proposed method with the classification method using deep learning. We utilized ShuffleNet and MobileNetv2 architectures for this comparison because they are lightweight and can be applied to mobile-based applications. Figure 9 displays the classification results using ShuffleNet and MobileNetv2. The model was trained with a learning rate of 10^{-3}, 100 epochs, and the SGDM optimizer.

Based on Figure 9, the deep learning method can recognize the water level conditions well if each bar indicator is well-separated and the lighting is bright, as shown in Figures 9b and 9c. However, if the bar indicators are not well-separated and the lighting is insufficient, then ShuffleNet and MobileNetv2 cannot recognize the water level conditions well. In Figures 9e and 9f, the conditions that should be ALERT are indicated as DANGER by ShuffleNet and MobileNetV2.

NORMAL Proposed Method (a)	NORMAL ShuffleNet (b)	NORMAL MobileNetV2 (c)

ALERT
Proposed Method
(d)

DANGER
ShuffleNet
(e)

DANGER
MobileNetV2
(f)

Figure 9. Comparison Result of the Proposed Method with Deep Learning Classification, where: (a), (b), and (c) are the Result of the Good Quality Image; and (d), (e), and (f) are the Result of Bad Quality Image

4. Conclusion

In this study, we proposed a system that detects water levels using color object tracking techniques for flood monitoring. The system works in real-time, which means that the status of the water level is monitored continuously. This study uses an environmental simulation to test the color object detection method. The result of the simulation showed that we obtained an accuracy rate of 94% for bar indicator detection. Based on the simulation in varying condition, the system would difficult to distinguish each bar indicator, if the camera far from the bar indicator or the angle is outside 30º-60º or very low light condition, because it resulted a small gap between indicator bar. Future research can be done by utilizing a system that can work the dark condition to use the system in late night situation. Furthermore, the experiment will be done in a real flood condition that the water consists of several materials such as rubbish.

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