Remote Detection and Monitoring of a Water Level Using Narrow Band Channel

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Abstract: - To measure water levels from remote cites using a narrowband channel, this paper developed a difference image based JPEG communication scheme and a water level measurement scheme using the sparsely sampled images in time domain. In the slave system located in the field, the images are compressed using JPEG after changed to difference images, among which in a period of data collection those showing larger changes are sampled and transmitted. To measure the water level from the images received in the master system which may contain noises caused by various sources, the averaging scheme and Gaussian filter are used to reduce the noise effects and the Y axis profile of an edge image is used to read the water level. Considering the wild condition of the field, a simplified camera calibration scheme is also introduced. The implemented slave system was installed at a river and its performance has been tested with the data collected for a year.

Key-Words: - Water level measurement, Remote surveillance, Edge difference image, Edge-based JPEG, Image communication

1 Introduction

The importance of monitoring a water level of a river or a reservoir cannot be emphasized enough in agriculture, flood prevention, and fishing industry, etc. The schemes developed for measuring water level thus far can be categorized by four types based on the measuring features: pressure, supersonic waves, heat, and image.

The most popular methods used thus far are those of using pressure and supersonic wave. Since pressure which is force per unit area represented by a multiplication of mass and acceleration of gravity of water can show the quantity of water over unit area, it can be directly transformed to water level.[1] Although pressure sensor is easy to use, it has a weakness that it should be calibrated and replaced frequently due to possible breakdown by continuous water pressure. Supersonic wave sensor is free from water pressure since it measures the time of flight of supersonic wave pulse from emitter to receiver reflected by the water surface.[2] Since it does not contact water directly, its lifespan is semi-permanent. However, supersonic wave sensor has a shortcoming that it returns false values when temperature goes so high or low, there is a heavy rain or snow, and water fluctuates so rapidly.

The principle of using heat is to use the characteristic of a solid that if it contacts with fluid with lower temperature its temperature goes down too because of convection current. Since the amount of temperature drop of a solid is proportional to its contacting area with fluid, water in this case, the depth of a solid dropped in water can be calculated from the temperature change of the solid.[3] This type of measurement system has an advantage of having a semi-permanent lifespan, but it has as many disadvantages that it should be well insulated and the temperature of the solid should be controlled near the measurement area. Due to these problems, heat type sensors are used for restricted applications such as the measurement of cooling water level in nuclear plants.

Use of image sensor for measuring water level is the most recent approach. Differently from other types of sensors, it can provide the surrounding information around the sensor as well as the water level so that the measured data can be confirmed by eyes if needed. It also has an advantage that it is not affected by weather.[4] Although this type of sensor has most prominent features in measurement of water level and flood control, it has several disadvantages that its price is higher compared to other types, it needs a large and secured space to install, and data size to transmit is large. That is, a real-time data transmission is not guaranteed if a broadband communication channel is not reserved.[5] Another problem of this type of sensor is that the measurement accuracy is affected by lighting conditions and minimum light is required in night.

For utilizing the outstanding advantages of image sensor in measuring water level while minimizing the aforementioned disadvantages, this paper proposes an edge based water level detection scheme and an image transmission technique using the JPEG of difference image. The proposed system has been implemented and installed in the Nakdong River for the experiments. The measured data and image was received at a remote station using a 9600bps UHF modem, 3km apart from the field. Its outstanding performance has been proved by the experiments performed for one year, day and night as described in this paper.

2 System Configuration

The proposed system consists of two parts, as shown in Fig. 1.

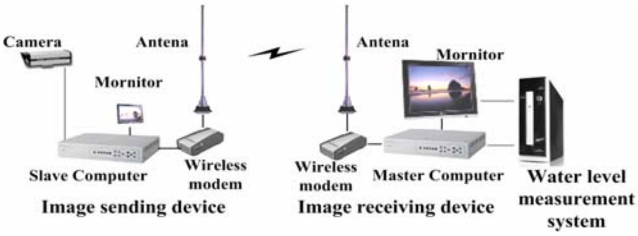


Fig.1.System configuration

One is the master system which receives images from the slave system(s) and measures the water level. It is connected with a slave system with a wireless modem and it can be connected with multiple slave systems to monitor at the same time. The other one is a slave system consisted of a camera system with a local memory and a wireless modem to communicate with the master system. Local memory is used to record the camera images for a purpose of recovering the lost data.

A slave system is connected with the master system with two channels. One is the control channel and the other one is the data channel. Through the control channel, it receives the control commands such as system on/off, camera test, send/stop, resend, etc. Once the system is on, it collects an image from the camera and extracts its difference image by subtracting it from the reference image acquired a priori to compress using JPEG encoder. Then the compressed difference image is transmitted to the master system where it is decoded and reconstructed to its original image by adding with the reference image, as shown in Fig. 2. The reference image is regularly updated by the request of the master system.

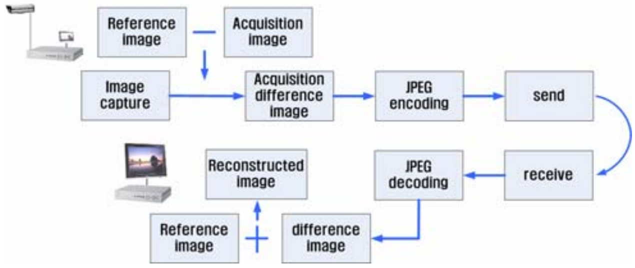


Fig.2. Block diagram of image compression and communication system

The master system monitors and controls the status of a slave system. Once the image is reconstructed, then its edge image is extracted from which the water level is derived by the water level measurement algorithm.

3 Slave System

A slave system is consisted of two subsystems. One is the image acquisition and storage system. 640x480 size images are collected by a camera and their difference images are stored in the local memory. The other one is the image encoding and transmission system. The difference is compressed by a JPEG encoder so that it can be transmitted through the narrow band UHF modem with the speed of 9600bps.

3.1 Camera Calibration

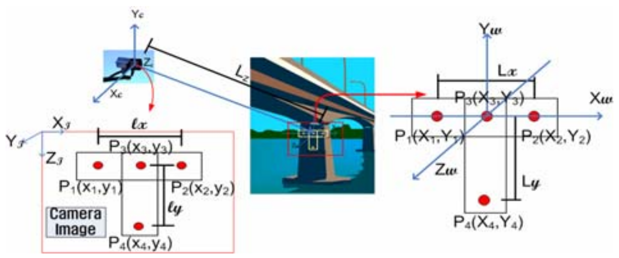
In installing a camera to measure a water level, it should be calibrated so that the reference level can be obtained without variation. Camera calibration is the process of defining the correspondence between the coordinates of a reference feature in the world frame and its coordinates in the image frame. However, it is very difficult to find this correspondence between the real world frame and the image frame in the open space. To solve this problem, a calibration pattern is used whose coordinates in the world frame are known. If the image of the calibration pattern is acquired in the image frame, their correspondences represented by the camera variables are calculated.[6]

In this work, camera is modeled as the pinhole camera which has the first axis lens distortion. It has total 11 variables, 6 external variables ($\theta_x, \theta_y, \theta_z, T_x, T_y, T_z$) and 5 internal variables (f, k, C_x, C_y, S_x) to be calibrated.

- f : the effective focal length
- k : the first axis lens distortion coefficient
- C_x, C_y : the coordinates of lens distortion along the lens axis
- S_x : the uncertainty coefficient of sampling in horizontal scan line of a frame grabber

- $\theta_x, \theta_y, \theta_z$: the orientation of a camera with reference to the world frame
- T_x, T_y, T_z : the position of the camera frame in the world frame

Among these variables, the internal variables can be decided before installing the camera in the field. To decide the external variables, the calibration pattern given in Fig. 3 is used where four points are marked at the known positions with reference to the coordinates of the calibration pattern.



(a) in the image frame (b) in the world frame

Fig. 3 Calibration pattern installed in the field

The calibration begins with aligning the X and Y axes of the camera coordinates with those of the calibration pattern, by controlling the pan/tilt of the camera. Once they are aligned, both θ_z and θ_y are set to zero and only θ_x remains to be determined.

To calculate θ_x, the reference points given in the reference pattern are used. The points X_i in the world frame are projected to x_i in the image frame. Thus the two distances, L_x and L_y, given in the reference pattern are also project to l_x and l_y, in the image frame. Then their relations can be expressed by the following Eq. (1) and (2).

$$X_2 - X_1 = \frac{1}{f}(x_2 - x_1)L_z \quad \Rightarrow \quad l_x = f\frac{L_x}{L_z} \qquad (1)$$

$$Y_4 - Y_3 = \frac{1}{f}(y_4 - y_3)L_z \quad \Rightarrow \quad l_y = f\frac{L_y}{L_z} \qquad (2)$$

From these two equations, the rotational angle about X axis, θ_x can be defined as Eq. (3).

$$\theta_x = \cos^{-1}\frac{L_y}{l_y} \qquad (3)$$

Using the orientation variables, the position variables (T_x, T_y, T_z) can be extracted simply. Since the centers of the image frame and the world frame are aligned, T_x is 0, and the other two variables are determined by the following Eq. (4) derived from Eq. (1) to (3).

$$T_z = Z_c \cos\theta_x \qquad (4)$$
$$T_y = Z_c \sin\theta_x$$

3.2 Difference image

To transmit a sequence of 640x480 size images using a modem with the speed of 9600 bps, their sizes should be minimized. For this purpose, a difference image is extracted and compressed using the lossless JPEG encoder, following the procedure given in Fig. 2. Once the camera is calibrated, then the background image to be used as the reference image is acquired and stored in the local memory, and also sent to the master system before the difference image transmission.

Then the input images are subtracted from the reference image to produce the difference images. This operation is expressed for a color image case by equations given in Eq. (5).

$$R_d(x,y) = (R_r(x,y) - R_c(x,y) + 255)/2$$
$$G_d(x,y) = (G_r(x,y) - G_c(x,y) + 255)/2 \qquad (5)$$
$$B_d(x,y) = (B_r(x,y) - B_c(x,y) + 255)/2$$

In Eq. (5), the subscripts *d*, *r*, and *c* express difference image, reference image, and current image, respectively. Since an image cannot have a negative number, the subtraction operation is corrected by adding 255 and dividing by 2 so that a pixel value may take 125 to 130 if the difference is ignorable. An example of extracting the difference image is given in Fig. 4.

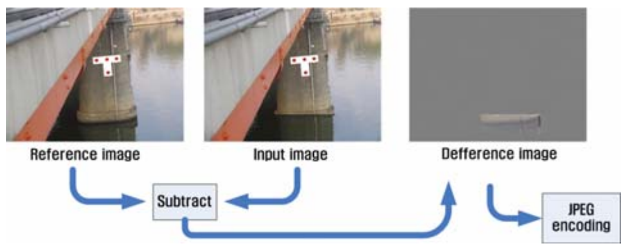


Fig.4. Difference image extraction

3.3 JPEG Encoding

Since difference image by itself cannot reduce the data size enough to transmit, it is compressed by a JPEG encoder which has an excellent compression rate about the image that has many pixels of the same value, as a difference image in this work does. JPEG encoder is consisted of the processes as shown in Fig. 5.

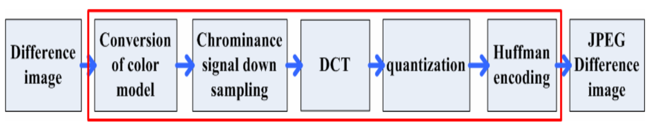


Fig.5. JPEG encoder

Encoder changes the input image from the RGB space to YC_bC_r space where the brightness component Y is emphasized by down sampling the chrominance components with the 4:1 ratio. Since the water level measurement does not use the chrominance information much, this operation is effective to reduce the data size. JPEG encoding operation is completed with Huffman encoding process which has an outstanding performance when more pixels have the same values. Using this process a difference image can be represented by 10kbits on average.

4 Master System

The master system can monitor and control multiple slave systems at the same time in real-time. It is connected with a slave system by two channels, one for control and one for data. Once the image is received, the JPEG decoder reconstructs the original image of the field from which the water level detector reads out the water level.

4.1 Field image reconstruction

When the master system is connected to a slave system, it receives the reference image first followed by difference JPEG images. The difference JPEG images are decompressed by the JPEG decoder which has the processes included in the JPEG encoder in the reverse order. A decoded difference image is added to the reference image to reconstruct the original field image, using the equation given in Eq. (6) where the subscripts *rc*, *r*, and *d* express reconstructed image, reference image, and difference image, respectively.

$$\begin{aligned} R_{rc}(x,y) &= R_r(x,y) - (R_d(x,y)\times 2 - 255) \\ G_{rc}(x,y) &= G_r(x,y) - (G_d(x,y)\times 2 - 255) \\ B_{rc}(x,y) &= B_r(x,y) - (B_d(x,y)\times 2 - 255) \end{aligned} \quad (6)$$

Figure 6 shows the reconstructed field image using the above process.

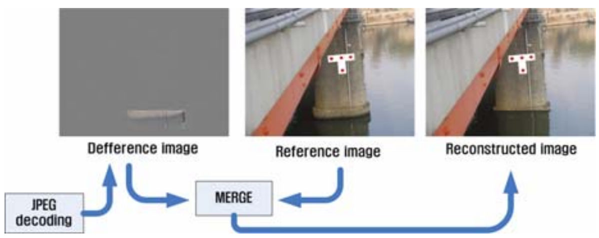


Fig.6. Field image reconstruction process

4.2 Water level measurement process

Fig. 7 illustrates the structure of the water level measurement algorithm. Since the water image tends to be contaminated by the noises due to light reflection and ripple on the water surface, the recovered field image passes through a low pass filter to remove such noise. Then the horizontal edge image is extracted and the water boundary points to tell the water level are detected from the Y axis profile of the horizontal edge image. The water level is decided by measuring the water height with reference to the reference indicator (an invariant feature in the image), based on the camera variables obtained in the calibration process.

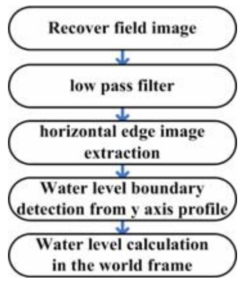


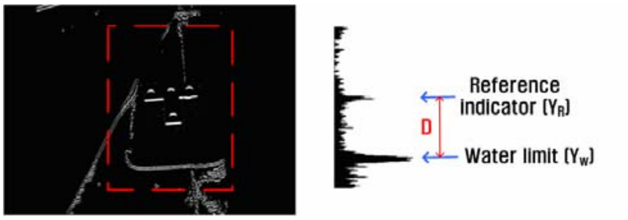
Fig.7. The process of determining the water level from field image

The accuracy of the water level measurement depends on the resolution of image near the reference indicator. Fig. 8 shows two examples of different resolution near the reference indicator. Figure 8(a) shows the global view of the field so that a user can monitor the surrounding information. In this case the image resolution near the reference indicator falls down to a tens centimeter order. Figure 8(b) shows the zoomed view of the reference indicator. In this case, the water level can be read in the order of centimeter order, although the surrounding information is excluded. The image resolution is selected by the user.

(a) with low resolution (b) with high resolution

Fig. 8 Image near the reference indicator

To measure the water level from the recovered image, the top of bridge leg is used as the reference indicator which is parallel to the water surface. Its horizontal line segment is marked in the reference image. The objects in a field image can be segmented in large by a bridge leg and water. Since the camera is installed so that its X axis is parallel to the water surface, the boundary of water appears the longest horizontal line in the bridge leg. Thus, the horizontal edge image is extracted using the Sobel operator and the position where the longest horizontal line in the bridge leg is located is found by projecting the edge image to Y axis, as shown in Fig. 9.



(a) horizontal edge image (b) y axis profile

Fig. 9 Y axis profile to detect the water limit

The water level is calculated by measuring the gap *D* between the reference indicator Y_R and the water limit Y_w. To minimize the noise effects, the position of water limit is decided as the average of the measured values in a moving window whose length is 10 in this case. The measured gap *D* in the image frame is translated into the one in the world frame using Eq. (7) derived from Eq. (1) and (2).

$$H = \frac{D}{f} L_z = \frac{(Y_R - Y_W)}{f} L_z \qquad (7)$$

5 Experiment

To test the performance of the proposed system, it has been implemented and installed at the Nakdong River and tested for a month, 24 hours a day. In the nights, the light has been used. The experimental results were compared with those acquired by a supersonic wave sensor. The specifications of the master and slave systems are given in Table 1, and the specifications of modem are given in Table 2.

TABLE 1 SPECIFICATION OF AN IMAGE END-RECEIVE SYSTEM

Camera	SCC-B2305 (Zoom: GL-A82210C)
Computer	Pentium 4 (1GHz) , Memory : 512 M HDD : 250Gbyes * 2, OS : Windows XP Pro SP2
Frame grabber	Matrox CronosPlus

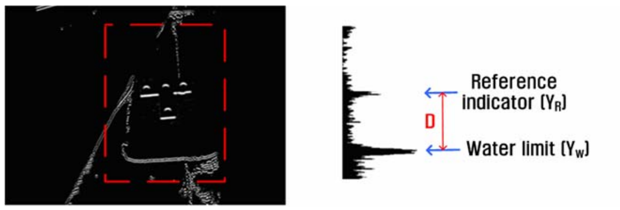
TABLE 2 SPECIFICATION OF A WIRELESS MODEM

Frequency Range	2.4GHz
Channel Spacing	4.096MHz
Modulation technique	GMSK
Communication distance	5km using external Antenna
Maximum data transfer rate	Full-duplex mode: 9.6Kbps

A size of difference image to be compressed by the JPEG encoder is about 8Kbytes. Depending on the image quality to achieve after reconstruction in the master system, the compression rate can be as high as 97% when the 70% image quality is required after reconstruction. This compression rate shows that an image sequence can be transmitted through a narrow-band channel having a 9600bps speed. In practice, the reference image is transmitted every 1 hour which can be changed by the user considering the field circumstances. To transmit a difference image, it takes about 7 seconds on average so that 8 frames can be transmitted in a minute. This transmission time changes in a large range. For example, if a difference image is of little change, then its size after compression becomes less then 8Kbytes. Instead, if the difference image contains a large change, then the compression effect becomes very little. However, since the water level does not change rapidly in general, the transmission speed is not a major issue in the water level measurement as long as the above speed is maintained.

Fig. 10(a) shows the reconstructed field image in the master system using the JPEG decoder, which is transformed to the gray level image and the possible noises are eliminated by the Gaussian filter resulting in the image given in Fig. 10(b). Fig. 10(c) shows the horizontal edge image whose Y axis profile is given in Fig. 10(d) from which the water level is represented by *D*. Actual water level is calculated using Eq. (7).

(a) reconsturcted field image (b) gaussian filtered image



(d) horizontal edge image (d) y axis profile

Fig. 10 Images used in the experiments

Table 3 and Table 4 show the experimental results compared with those obtained by using ultrasonic sensors. Table 3 summarizes the hourly average measurement acquired for one day and Table 4 shows the monthly average measurement acquired for one year. The first column in the tables shows the water level read by eyes using the indication attached to the bridge leg.

Fig. 11 shows the screen image of the master system where four slave systems can be simultaneously connected. It may select one image among four and send command to the selected cite. The calculated water level is displayed on the image.

TABLE 3. WATER LEVEL MEASURED WITH NO RAIN

Time	Eyes (m)	Ultrasonic Sensor		Image Sensor	
		Measurement(m)	Error(%)	Measurement(m)	Error(%)
06:00	1.54	1.55	0.65	1.55	0.65
07:00	1.50	1.50	0.00	1.50	0.00
08:00	1.48	1.46	1.37	1.47	0.68
09:00	1.42	1.41	0.71	1.42	0.00
10:00	1.38	1.39	0.72	1.37	0.73
11:00	1.37	1.37	0.00	1.37	0.00
12:00	1.37	1.38	0.72	1.37	0.00
13:00	1.39	1.40	0.71	1.40	0.71
14:00	1.42	1.43	0.70	1.40	1.43
15:00	1.43	1.43	0.00	1.41	1.42
16:00	1.45	1.45	0.00	1.44	0.69
17:00	1.46	1.47	0.68	1.46	0.00
18:00	1.46	1.46	0.00	1.46	0.00
19:00	1.43	1.45	1.38	1.42	0.70
Avg.	1.436	1.439	0.55	1.431	0.50

TABLE 4 WATER LEVEL MEASURED IN 2006

Month	Eyes (m)	Ultrasonic Sensor		Image water level	
		Measurement(m)	Error(%)	Measurement(m)	Error(%)
1	1.482	1.484	0.13	1.483	0.07
2	1.496	1.498	0.13	1.497	0.07
3	1.481	1.482	0.07	1.480	0.07
4	1.537	1.538	0.07	1.537	0
5	1.508	1.509	0.07	1.507	0.07
6	1.520	1.521	0.07	1.522	0.13
7	2.343	2.346	0.13	2.349	0.26
8	1.613	1.614	0.06	1.615	0.12
9	1.602	1.604	0.12	1.603	0.06
10	1.561	1.560	0.06	1.560	0.06
11	1.504	1.503	0.07	1.505	0.07
Avg.	1.6043	1.6054	0.089	1.6053	0.088

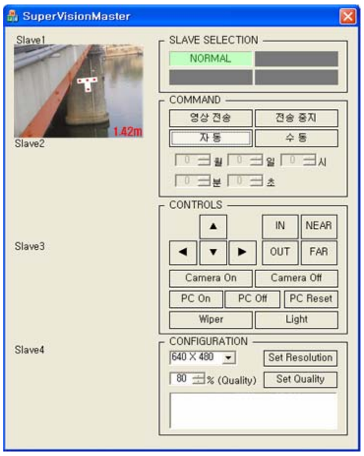


Fig. 11 Display of the master system

5 Conclusion

This paper deals with the problem of measuring and monitoring water level of a river. Since the conventional methods using ultrasonic, heat, laser sensors can measure only the water level itself, there is no way to confirm if the provided data is correct or not. It is also impossible to monitor the surrounding situation of the river. The proposed system solves this problem while it provides the more accurate measured data than the conventional sensors do. This prominent performance has been achieved by using the measurement scheme which correctly reads the water limit from the noisy and irregularly sampled field image. The experimental results have shown that the performance of the proposed system is not deteriorated by changes of weather condition.

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