Intelligent Water Metering System: An Image Processing Approach (MATLAB simulations)

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***Abstract*— The scarcity and misuse of fresh water pose a serious and growing threat to sustainable development. The population growth, severe droughts and uneven distribution of water resources are the reasons for water scarcity, and this scarcity will only continue to grow more severe. The technical sophistication of meters for measuring water flows has increased noticeably in recent decades in order to improve management of water. This paper proposes simple image processing approach for an intelligent metering system. The proposed system uses simple image processing algorithms and DSP processor, capable of executing MIPS; which makes whole system respond faster. As meter image is being captured from set distance, meter mask generation reduces the need of algorithms for detection and segmentation of meter reading. The proposed system improves the efficiency of drinking water management and reduces power consumption as image sensor is activated as per predefined billing cycle.**

***Key words* — Scarcity, sustainable development, water management, intelligent metering system.**

I. INTRODUCTION

Water is most precious natural resource. It is not only prime need of human beings but also a basic necessity of economic development. The water scarcity is a growing problem across the globe and is compounded by population growth, pollution, severe droughts, over exploitation of ground water, and uneven distribution of water resources. The uneven distribution and available fresh water resources across the globe is as shown in Fig (1). The uneven distribution of available freshwater is not limited to Sub-continents but the same is observed across the countries, states, districts, and villages. This results in community shifts to the nearby areas where water is available, which puts an additional burden on existing systems and may lead to fighting between communities and peoples. It is destroying social fabric of the country and become very dangerous problem in near future.

Water management is not a separate issue but it is directly or indirectly inter-related with the other important issues which must be considered very seriously. Economic development, health, effective governance, agriculture and industry growth, environment etc., are inter-related with water management. As per present scenario if such a huge revenue loss is avoided due to non-revenue water, the same revenue can be utilized for other developments which lead to economic development.

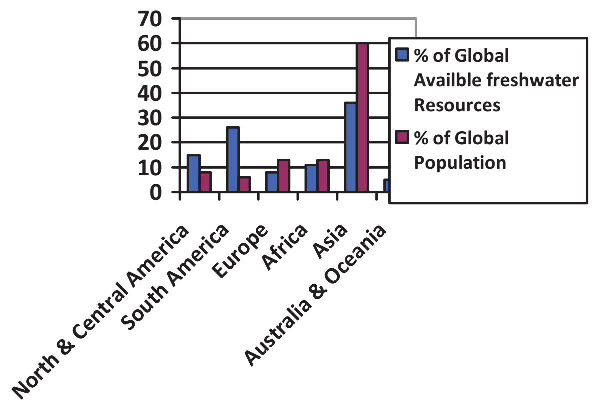

Fig.(1) Global population distribution and available freshwater resources.

This paper proposes simple image processing approach for an intelligent metering system. This involves conventional mechanical water meter, image sensor, DSP processor and GSM modem. The proposed device works like conventional mechanical meter for recording water usage. The power will be activated as per the billing cycle period for capturing image of water meter reading, and processing it to extract meter reading. The extracted meter reading is sent to the central server for analysis and billing. The power is automatically suspended after sending extracted meter reading to the central server, thereby reduces power consumption. This proposed system is able to detect water leakage through real time water monitoring.

The remainder of the paper is organized as follows. The review of metering systems is given in section II. The proposed system of intelligent metering is described in section III. Image processing steps used for extracting meter reading are described in section IV. Communication and water leakage detection are described in section V. Section VI provides the experimental results. Conclusions are outlined in section VII.

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II. REVIEW OF METERING SYSTEMS

The terms "intelligent" or "smart" metering are often used with reference to combination of technology that is superior to conventional metering. There is overabundance of technologies which are used for intelligent metering. It may refer to any "new systems employing the latest in communication capabilities and enhanced functionality" for monitoring water use. Intelligent metering systems can be further classified with reference to components employed: "meters that use new technology to capture water use data and communication systems that transmit water use data"

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A. Metering Technologies

There is large range of metering technologies, employing different principles to capture and record water use. These technologies are broadly classified into (i) Displacement meters; (ii) velocity meters; (iii) combination of displacement and velocity meters; and (iv) Electromagnetic meters. Water flow gets recorded as water displaces components within meter in displacement or mechanical meters. Velocity meters measures the flow through the meter with a known internal capacity, which is used to get the volumes of water utilized. Compound meters use the strength of displacement and velocity meters in single meter.). Electromagnetic flow meters harness the electromagnetic properties of water, which, as it flows, generates voltage as it crosses the force lines of a magnetic field.

B. Related work

Electronic water meters have recently been introduced to record digital data using electrical counters[1],[2] and transfer to remote server using RF, Bluetooth or ZigBee communication[1],[4] for small distance and through GSM, GPRS network for long distance transmission [1],[4], spanning tree algorithm is used in order to distribute loads of root nodes to achieve longer lifetime and long range data transfer[2]. Print wheel region and pointers location is identified using Fourier transform [3] from the meter image for automatic meter reading. AMR system with non-contact arrow sensor based on capacitive signal sensing [5], this involves embedding an electrical circuit into the body of a conventional mechanical water meter.

Most of the work using image processing is done for number plate recognition and is very less used in AMR systems. The recognition algorithms used in number plate recognition system comprises of several steps [6]-[11] such as: (i) extraction of the region of license plate; (ii) segmentation of the characters from the plate region; and (iii) recognition of each character. Techniques based on binary image processing, neural network [7] and Markov Random Field have been proposed for extraction of region of license plate. Techniques of histogram [6], neural network and fuzzy logic were used to segment characters after extraction of license plate region. A number of techniques have been proposed for recognition of characters from segmented characters. Optical character recognition [7]; template matching [8]; statistical approach [9]; and neural networks were used for character recognition.

There are several intrusive and non-intrusive techniques proposed for water leakage detection. Water leakage detection using thermal imaging (IR) is proposed in [11], captures the contrast between cold and hot water areas. Acoustic sensors [12]; thermography, tracer gas, ground penetrating radars techniques are proposed for water leakage detection. In [13], Transmit time ultrasonic flow meters and Doppler flow meter were proposed for leakage detection.

III. PROPOSED SYSTEM

The proposed intelligent water metering system is as depicted in Fig. 2.

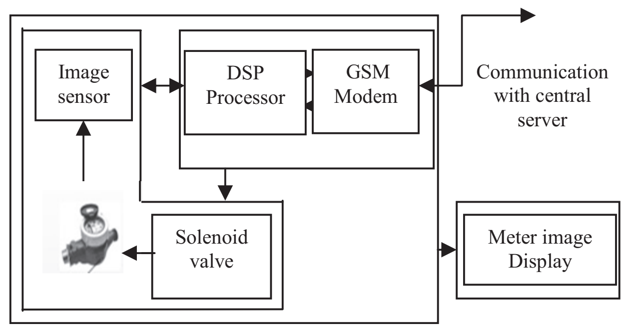

Fig. 2. Block diagram of proposed intelligent water metering system

The Fig. 3 shows the proposed intelligent water metering process. The system first checks for meter activation or deactivation signal from the central server and activate/deactivate water supply accordingly. Then system checks for meter image display activation signal, if it is true it will display the recent image captured on the display. At last system will check whether camera is activated or not. Camera is activated by the processor as per billing cycle (monthly, quarterly etc.) or on the signal received from the central server for real time water auditing. The captured image is processed by the DSP processor to locate meter reading area and extract/identify meter reading. Then extracted meter reading is send to the central server using GSM network. The received data is stored in database at central server. The meter reading data is processed by software installed on server machine to calculate water utility billing, leakage detection through zone wise water utility data analysis, to get idea about water demand in each zone by analysis of water utility data etc.

IV. METER READING DETECTION AND RECOGNITION

Before going to actual meter reading detection and recognition, we have developed the meter mask and 0-9 digit templates using the acquired meter images. As we have prepared setup to hold camera just above the meter at fixed distance, every time image captured is remains of same dimension and gives same view of meter. Once we prepare meter mask for meter reading area, it eliminated the need of use of extensive image processing algorithm every time to locate and segment the meter reading area from its background image. As we have generated 0-9 digit templates from acquired images itself, which are of same size, it will eliminate the need of normalization process before using matching algorithm. The detailed description of meter mask generation, 0-9 digit templates generation and meter reading detection and recognition is given in sub-sequent paragraphs.

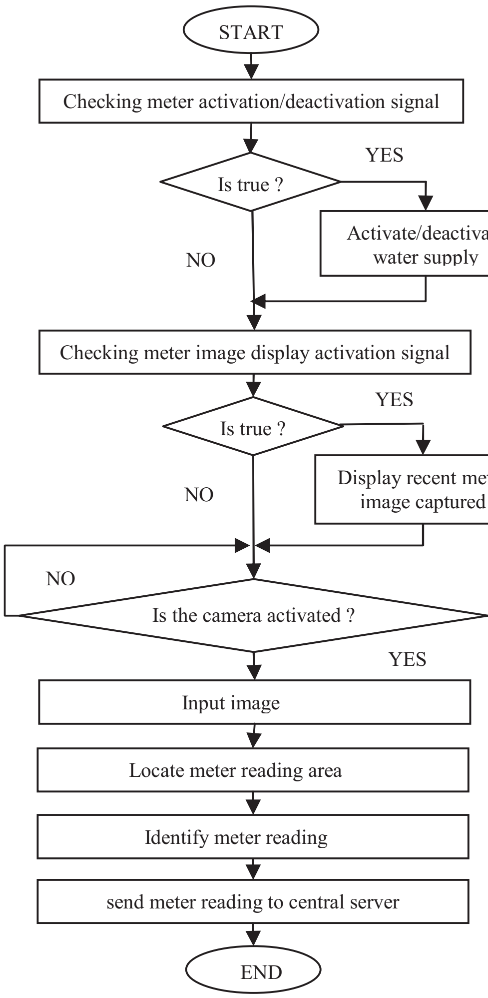

Fig. 3. Intelligent water metering system process.

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A. Meter mask generation

Fig. 4 shows the flowchart for meter mask generation. Pre-processing such as resizing image to fixed size and color to black & white conversion are applied to the acquired image. ROI in pre-processed meter image is selected using an interactive MATLAB function to get the location and aspect ratio of meter reading area. The ROI selected image and pre-processed image is used to generate meter mask; black & white image of same size as input image with ROI as 1's and 0's elsewhere.

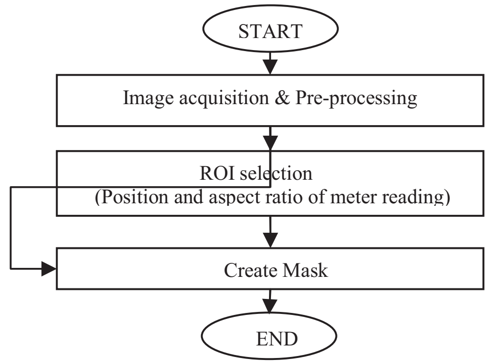

Fig. 4 Flowchart for meter mask generation

The acquired image and meter mask generated from that image are shown in Fig. 5

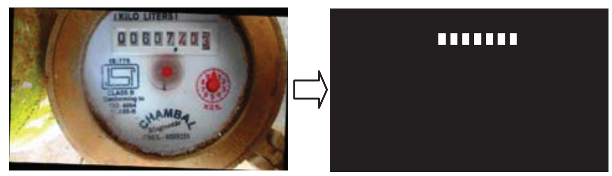

Fig. 5. Acquired image and generated meter mask.

B. 0-9 Digit templates generation

Fig. 6 shows flowchart for digit templates generation. Digit templates are generated from acquired images itself as numbers used on meter are of specific font and style. It is more important as we have used template matching algorithm in meter reading recognition, which is very sensitive to noise and it does not have adaptability for font style of the digits. The same pre-processing steps are used to finally get black & white image from acquired image. This binary image is masked with previously generated meter mask using simple logical AND operator. This separates meter reading area from its background image. The resultant image is segmented using the prior knowledge about the spacing between two digits of meter reading. Small objects present in the segmented images are removed using the area property of the connected components in that segmented image. At last each digit is labeled and stored in database.

C. Meter reading recognition

Fig. 8 shows flowchart for meter reading recognition and Fig. 9 shows the output images at every stage of recognition process. The steps used in recognition of meter reading are described in detail in sub-sequent paragraphs.

Image acquisition & Pre-processing: Once image of meter is captured by camera, it is processed by DSP processor. It is resized to same as that of meter mask image. Then resized color image is converted into grayscale image using Eq. 1,

$$I_{gray} = 0.299R+0.587G+0.114B \quad \text{- - - - - - - - - - - - - -} \quad (1)$$

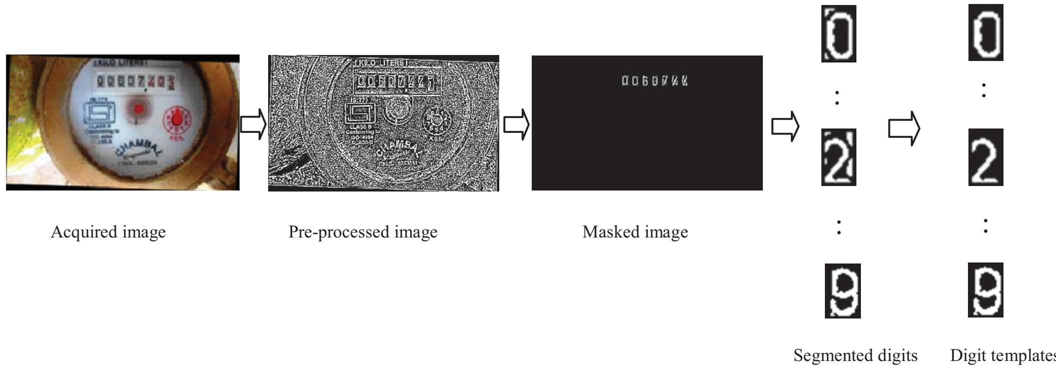

Fig. 7. Digit templates generation process

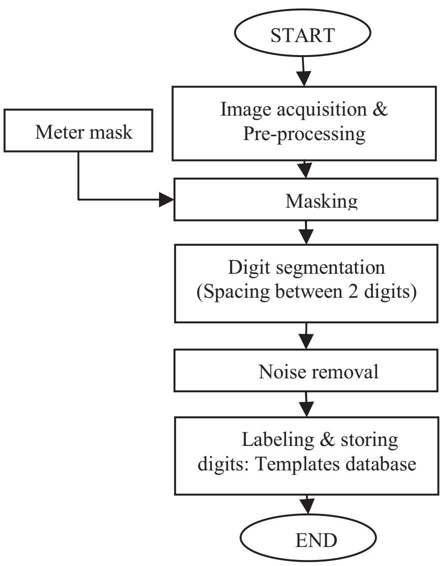

Fig.6 Flowchart for digit templates generation

The gray scale image is filtered using smoothing and sharpening filters for noise removal and enhancing details in an image that are blurred either due to error or a natural effect of particular method of image acquisition. Filtering is done by moving the filter mask over each pixel in the image. Response at each pixel is given by a sum of products of filter coefficients and the corresponding image pixel values in the area spanned by the filter mask; mathematically represented as given in Eq. 2,

$$g(x,y) = \sum_{s=-a}^{a}\sum_{t=-b}^{b} w(s,t) * f(x+s, y+t) \quad \text{- - - - - (2)}$$

where w(s,t) – mask coefficients, a=(m-1)/2, b=(n-1)/2, mask size = m × n.

1	1	1
1	1	1
1	1	1

Smoothing filter mask

1	1	1
1	-8	1
1	1	1

Sharpening filter mask

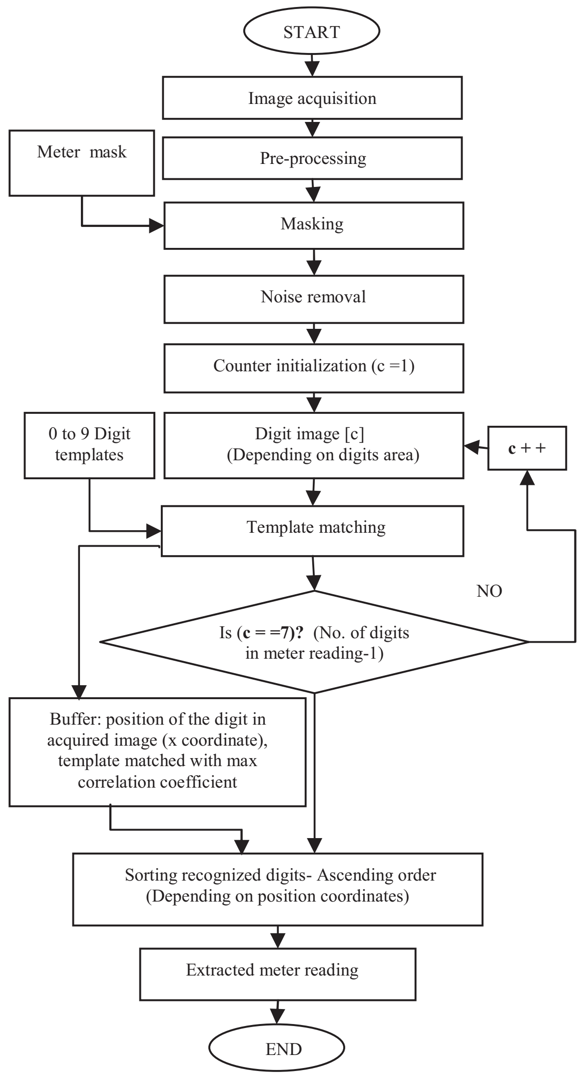

Fig. 8 Flowchart for meter reading recognition

This filtered image is then converted into binary image. The output binary image replaces all pixels in input image with

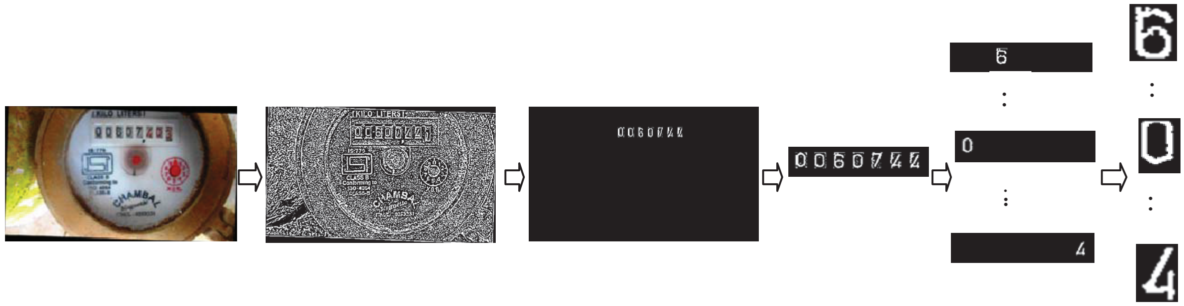

Fig. 9. Meter reading detection and recognition process

gray levels greater than threshold value with the value 1(white) and all other pixels with value 0 (black).

The obtained binary image after pre-processing is masked with previously generated binary meter mask using simple logical (AND) operator.

Connected component analysis of the ROI image obtained is carried out to get information of number of connected components present in the ROI image and their area i.e. pixel count of each connected component. The number of connected components is obviously much greater than number of digits in the meter reading. The excessive connected components are unwanted noise components and those must be removed before using matching by correlation algorithm. The approach used here is keeping 1st maximum area component and removing all other components; and using matching by correlation algorithm to get best template matched and position of that connected component in the ROI image. The same procedure is repeated for the 2nd , 3rd… upto 7th maximum area components to get best template matched and position of the connected component in ROI image

Template matching: Template matching is a process where template is a sub-image that contains a shape or character we are trying to find. The template matching process is as simple as moving centre of the template over each pixel in the source image. It gives the numerical index that indicates how well the template matches the image in that position. But as correlation function has disadvantage being sensitive to changes in amplitude of template and source image. Therefore an approach frequently used to overcome this difficulty is to perform matching by correlation coefficient given by Eq. 3. It gives the normalized correlation coefficient in the range -1 to 1.

$$\gamma(x,y) = \frac{\sum_s \sum_t [f(s,t) - \bar{f}(s,t)][w(x+s,y+t) - \bar{w}]}{\left\{ \sum_s \sum_t [f(s,t) - \bar{f}(s,t)]^2 \sum_s \sum_t [w(x+s,y+t) - \bar{w}]^2 \right\}^{\frac{1}{2}}} \quad \ldots(3)$$

Where, f- source image, w- template image, $\bar{w}$- mean of the template image, $\bar{f}$- mean of the source image in the region under template.

Once we get best matching template for each digit in the meter reading and their position in the ROI image of the meter, recognized digits are rearranged according to their position from left to right. It gives us the recognized meter reading from acquired meter image. TABLE. I gives the templates best matched and positions at which these templates are matched and TABLE II gives the recognized meter reading by rearranging digits as per their positions in meter image.

TABLE I. TEMPLATES MATCHED & POSITIONS

Template best matched	*6*	*0*	*0*	*0*	*4*	*4*	*7*
Position where template matched (x coordinate)	89	15	127	52	163	200	237

TABLE II. RECOGNIZED METER READING

Recognized meter reading	*0*	*0*	*6*	*0*	*4*	*4*	*7*
Position where template matched (x coordinate)	15	52	89	127	163	200	237

V. *LEAKAGE DETECTION SYSTEM*

The architecture for leakage detection system is as depicted in fig. 10. To detect leakage through pipeline, the water transmission pipeline network will be laid out as shown in fig 10. The geographical area will be divided into number of zones each having relay meters, indicating water transmitted from elevated reservoirs to each particular zone. Source meters indicating amount of water flow from elevated reservoirs. Customers/end water meters indicate the water consumption of individual customers. Water leakage will be zero if source meter reading and sum of end meter readings is same. Water leakage will be detected by real time water auditing. Meter readings will be transmitted using GSM communication network to the central server. The received meter readings will be analyzed at the server to indicate percentage water leakage using equation 4.

Water leakage = (Ms - ∑ Mn) × 100 / Ms . (4)

Where, Ms = source meter reading, Mn = n_{th} customer meter reading.

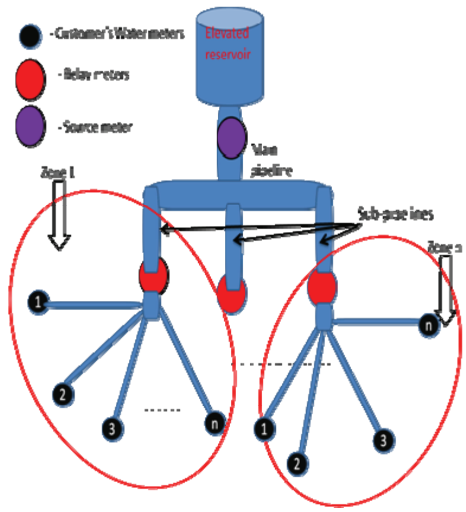

Fig. 10 Architecture for water leakage detection system

The leakage is detected in sub-pipelines if source meter reading and sum of relay meter readings is not same. The leakage in particular zone is detected if relay meter reading and sum of end meter readings in that zone is not same.

Early detection of pipeline leakage is useful for 24×7 water supply, to avoid wastage of precious water. This will avoid damage to building foundations, roads etc; health risk from contamination of water through leakage. It will minimize the non-revenue water.

VI. RESULTS

The experimental setup for proposed system is as shown in fig. 11. The 400 number of water meter images are acquired from set distance above the meter as shown in experimental setup. The simulation results for this proposed system are checked on MATLAB software. We achieved almost 96 % accuracy for proposed. The result analysis of the system is as given in TABLE III below;

TABLE III: Result analysis

No. of images acquired	No. of meter readings correctly recognized	Accuracy
400	382	96 %

VII. CONCLUSION

This paper presents image processing approach for intelligent metering system. The AMR meter components can be reused beyond lifetime of mechanical meters; by changing that meter only. The use of DSP processor speed up the execution time required for extensive image processing algorithms. Also the use of meter reading mask reduces the need of algorithms for meter reading detection and segmentation. This system has number of benefits such as: (i) Regular billing based on real consumption (ii) Automatic, accurate and transparent billing (iii) Reduced man-power requirement (iv) Operational time reduction (v) Reduces NRW through leakage detection.

Fig. 11 Experimental setup

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