A

Project Report

on

AN AUTOMATED SYSTEM FOR REAL TIME POTHOLE DETECTION

Submitted in partial fulfillment of the

requirement for the award of the

Degree of

BACHELOR OF TECHONOLOGY

in

COMPUTER SCIENCE ENGINEERING

by

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Under the Guidance of

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SCHOOL OF COMPUTER SCIENCE ENGINEERING

MAY, 2020

DECLARATION

I declare that the work presented in this report titled "**Pothole Detection system using MATLAB**", submitted to the Department of Computer Science Engineering, Galgotias University, Greater Noida, for the Bachelor of Technology in Computer Science Engineering is our original work. I have not plagiarized unless cited or the same report has not submitted anywhere for the award of any other degree. I understand that any violation of the above will be cause for disciplinary action by the university against us as per the University rule.

Place:

Date:

Signature of the Student

____

Arsalan Tabrez (1613102182)

GALGOTIAS UNIVERSITY

School of Computer Science Engineering

CERTIFICATE

This is to certify that the project titled **"Pothole Detection system using MATLAB''** is the bonafide work carried out by Arsalan Tabrez during the academic year 2019-20. We approve this project for submission in partial fulfilment of the requirements for the award of the degree of Bachelor of Technology in Computer Science Engineering, Galgotias University.

Mr. S. Poonmaniraj
Project Mentor

The Project is Satisfactory / Unsatisfactory.

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Internal Examiner (s) External Examiner

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ABSTRACT

Over the time, the roads around us age and their poor maintenance leads to the occurrence of potholes here and there. These potholes put the road safety on a risk and transportation efficiency is affected. Also they lead to majority of car accidents. Using a pothole database sophisticated road-maintenance strategies can be developed , which will require a specific pothole-detection system that can collect pothole information at low cost and over a wide area. Detecting and repairing potholes, has, for a long time required manual efforts. Some automatic detection methods developed for pothole detection were based on vibrations and laser scanning. However they were insufficient and infeasible as the vibration based methods lead to unstable detection of potholes and the laser based method, although is very accurate but is extremely expensive.

Thus, in our project, we used commercial black box camera to detect the potholes in our pothole detection system. It detects potholes over a large area and at an affordable cost. We have also presented the experimental results with our system, to show that the potholes can be detected accurately.

Keywords: Pothole detection, Matlab, Black box camera

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CHAPTER-1

Introduction

Potholes refer to any type of road surface distress on an asphalt pavement that is more than 150 mm in diameter .Potholes are induced by the combined presence of water in the asphalt soil structure and heavy traffic. Potholes are mostly generated in winter and spring, because water often penetrates the pavement during these seasons. In India potholes claimed about 3597 lives in 2017. Hence potholes have turned out to be a huge, menace which should be dealt with fast to prevent further accidents and loss of lives. For this we need to be able to detect potholes and then take suitable measures to remove it. Here detecting the potholes is a major task.

Manual methods to detect potholes require considerable time and expense. Recently, automatic pothole-detection systems have been proposed, including methods that detect potholes through vibrations, methods based on laser scanning, and vision-based methods . Vibration-based methods detect potholes at low cost and with simple algorithms. However with this system, the detection of potholes is not very accurate and only those potholes can be detected that are in the path of the wheels. Laser-scanning methods can collect extremely detailed road-surface information, but the cost of the required equipment remains significantly high.

To develop an efficient pothole maintenance system, rapid collection and detection of potholes over a wide area at low cost is extremely crucial. Existing manual methods, along with vibration-based and laser-scanning methods are insufficient.

The goal of our research is to develop a pothole detector using common devices that are used by many drivers over a wide area. Moreover, the devices should provide high detection accuracy at low cost. For this purpose we decided to use black box camera to capture the images. If our proposed pothole detection algorithm is installed on a commercial black-box camera, all the vehicles on roads will be a pothole detector. As a result, we can collect huge amounts of pothole data at high speeds over a wide area.

Vision-based pothole detection methods have the potential for application as a suitable pothole detection system. Video data can be obtained at low cost using commercial cameras. Moreover, cameras can scan the road’s surface, covering a wide area. Recently, the resolution of black-box cameras has become sufficiently high for capturing details of a road's surface.

In this paper, we propose a novel pothole-detection system using a commercial black-box camera. The pothole-detection algorithm can be installed on an embedded board in the black-box camera. This algorithm detects and collects information regarding the size of potholes and their location, captured by the black box camera and this information can then be send through the servers to a pothole database.

The proposed pothole-detection algorithm is uniquely designed in consideration of the embedded boards in black-box cameras. We tested our algorithm with a PC-based simulation software .Experimental results confirmed that our algorithm performs sufficiently well for pothole detection.

The remainder of this paper is organized as follows: in the next section, we review the related literature on pothole detection. In Section 3 we explain the proposed pothole-detection algorithm, , and, in Section 4, we write the Matlab Program for the same. Finally, our conclusions and future work regarding this study are discussed in Section 5.

1.1 Image Processing

Image processing is a method to perform some operations on an image, in order to get an enhanced image or to extract some useful information from it. It is a type of signal processing in which input is an image and output may be image or characteristics/features associated with that image. Nowadays, image processing is among rapidly growing technologies. It forms core research area within engineering and computer science disciplines too.
Image processing basically includes the following three steps:

1.Importing the image via image acquisition tools;

2.Analysing and manipulating the image;

3.Output in which result can be altered image or report that is based on image analysis.

There are two types of methods used for image processing namely, analogue and digital image processing. Analogue image processing can be used for the hard copies like printouts and photographs. Image analysts use various fundamentals of interpretation while using these visual techniques. Digital image processing techniques help in manipulation of the digital images by using computers. The three general phases that all types of data have to undergo while using digital technique are pre-processing, enhancement, and display, information extraction.

1.2 Analog Image Processing

Analog image processing is done on analog signals. It includes processing on two dimensional analog signals. In this type of processing, the images are manipulated by electrical means by varying the electrical signal. The common example include is the television image.

Digital image processing has dominated over analog image processing with the passage of time due its wider range of applications.

1.3 Digital Image Processing

The digital image processing deals with developing a digital system that performs operations on an digital image.

1.4 Image

An image is defined as a two-dimensional function,**F(x,y)**, where x and y are spatial coordinates, and the amplitude of **F** at any pair of coordinates (x,y) is called the **intensity** of that image at that point. When x,y, and amplitude values of **F** are finite, we call it a **digital image**. In other words, an image can be defined by a two-dimensional array specifically arranged in rows and columns.

Digital Image is composed of a finite number of elements, each of which elements have a particular value at a particular location. These elements are referred to as picture elements ,image elements , and pixels .A *Pixel* is most widely used to denote the elements of a Digital Image.

1.4.1 Pixel:

In a digital image, all the coordinates on 2-d function and the corresponding values are finite. Each value available in every location is considered as a pixel. In other words, a pixel is the smallest part of an image. So a digital image can be thought as 2-d array of pixels.

1.4.2 Gray Level:

Each pixel has some intensity value which is called Gray level or Gray value. These values are usually represented in 8-bit int. So the range of values from 0 to 255 . The values near to 0 indicates darker regions and the values near 255 represent brighter regions.

1.5 Types Of Images

1.5.1 Binary Image: A binary image has only two possible gray values or intensities 0 and 255, there are no intermediate values. Binary images are used as masks for indicating the pixels of interest in many image processing tasks. Below is the example of binary image.

FIGURE 1.1 .Binary Image (only 0 and 255)

1.5.2 Grayscale Image: Grayscale image has range of values from 0 to 255 i.e, each pixel location can have any value between 0 and 255. If you watch old films around the 1950s, you are watching grayscale images (films are nothing but videos which are collection of individual images in proper sequence). Here is the example below

FIGURE 1.2.Grayscale Image (0–255 range)

1.5.3 Color Image: Both binary image and grayscale image are 2-dimensional arrays, where at every location , you have one value to represent the pixel. Remember to represent a color image, we need more than one value for each pixel. Typically you need 3 values for each pixel to represent any color. This came from the idea that any color can be formed by combining 3 basic colors Red, Blue and Green. Ex: you get yellow by mixing red and green, violet can be formed by combining red and blue etc., This is actually called RGB color space. There are many other ways to create color images which we will discuss in future discussions. Below is an example of a color image.

FIGURE 1.3. Color Image

Colored images are further divided into :

1. **8 Bit Color Format**– It is the most famous image format.It has 256 different shades of colors in it and commonly known as Grayscale Image. In this format, 0 stands for Black, and 255 stands for white, and 127 stands for gray.

2. **16 Bit Color Format**– It is a color image format. It has 65,536 different colors in it.It is also known as High Color Format. In this format the distribution of color is not as same as Grayscale image. A 16 bit format is actually divided into three further formats which are Red, Green and Blue. That famous RGB format.

CHAPTER 2

Literature survey

Existing proposals can be categorized into :

2.1Vibration-based methods

Vibration-based methods generally use gradient variation from accelerometer data. Accelerometers have been employed for pothole detection, owing to their low cost and relatively simple detection algorithms. However, the accuracy of detection is lower than that achieved with other sensors such as cameras and lasers, because potholes are detected only when a vehicle's wheels traverse a pothole. Moreover, false detections can occur.

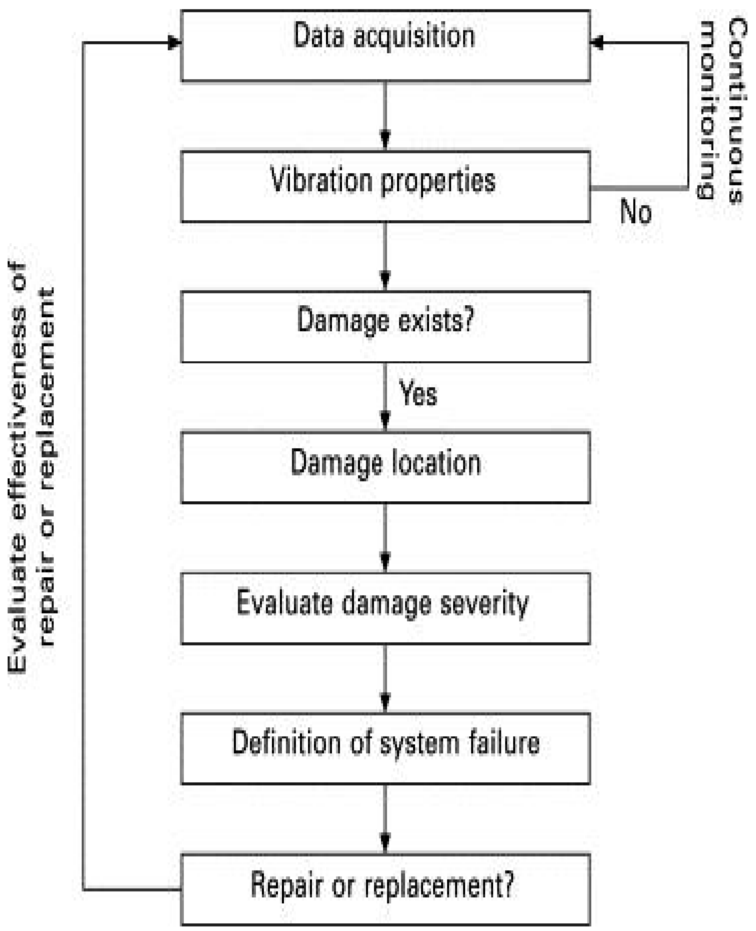

FIGURE 2.1. Flow chart of Vibration based method

2.2 Laser-scanning methods

Laser scanning offers outstanding detection performance, compared to other methods. This approach is able to collect extremely detailed road-surface information using a technique that employs reflected laser pulses to create precise digital models . Accurate 3D point clouds measure elevation in the surface, and this information is captured with the laser and then extracted by filtering the data for specific distress features by means of a grid-based processing approach. However, whereas laser scanning is highly precise, the equipment needed is expensive. Furthermore, this method cannot be applied over a wide area for fast pothole detection.

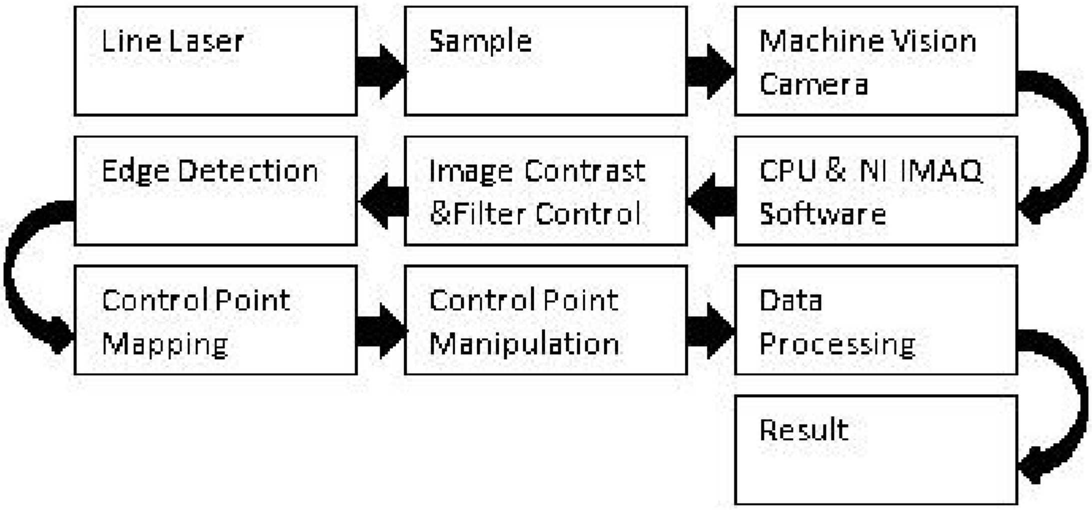

FIGURE 2.2 Laser-scanning methods

With the extensive use of laser equipment and weapons systems, such as laser range finder and laser guided weapons, the energy of each laser source is greatly different. So the requirement of higher dynamic range is presented in the laser detection system. For the problem of insufficient dynamic range in Imaging Laser Detection System (ILDS), a method by image processing to extend the system dynamic range is discussed based on the existing hardware of wide-angle telecentric fish-eye lens and CMOS camera device. Frame subtraction technique is commonly used in ILDS to recognize and locate the laser spot by filtering out background interference and noise. On this basis, it is proposed that in view of the receive laser energy's difference, uses the different method to expand the dynamic range. When the laser energy is low, the laser signal that may be submerged in noise can not be accurately interpreted and precisely localized. The technique of fuzzy weighted averaging filtering is used to get rid of noise and enhance detection sensitivity of the system, namely expansion detection lower limit. When the incident laser is strong, because the fish eye optical system would produce the reflection disturbance light, the imaging surface may be interfered by anomalous disturbance facula. Spot matching pattern recognition method is presented to remove the mixed light disturbance and enhance the recognition upper limit. The experimental results show that these methods can effectively improve the system's dynamic range and has a certain value of applied research.

2.3 Vision-based methods

Vision-based methods, however, are appropriate for accurately detecting potholes over a wide area at low cost. Many approaches using 2D images and video data have been studied. Pothole detection using 2D images was originally introduced by Koch and Brilakis . Their method involved searching for specific pothole features and determining pothole regions. They used a remote-controlled robot vehicle prototype equipped with a webcam (an HP Elite Autofocus) installed at approximately 60 cm above the ground. Buza*et al.* introduced a new unsupervised vision-based method that does not require expensive equipment, additional filtering algorithms, or a training phase. Jog *et al.* presented a new approach based on 2D recognition and 3D reconstruction for detecting and measuring the width, quantity, and depth of potholes using a monocular camera mounted on the rear of a vehicle .

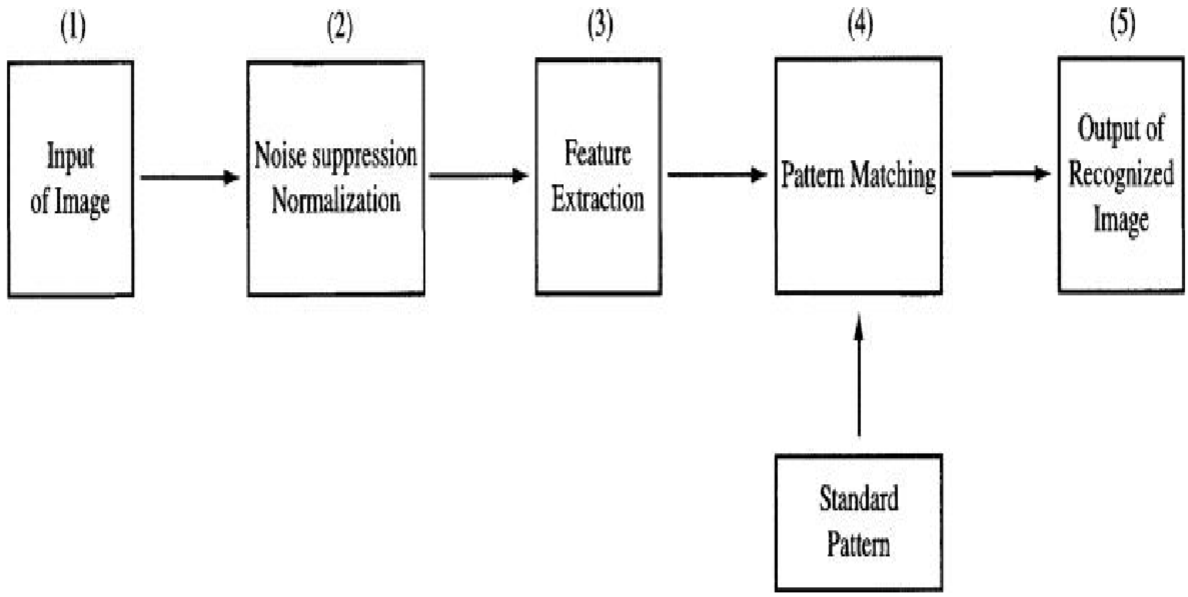

FIGURE 2.3 Vision based methods

CHAPTER - 3

Methodology

3.1 Proposed Pothole-Detection Algorithm

We are using a low complex strategy for detecting holes and detection of potholes in video frames sequences taken by a camera set inside a moving vehicle. The Region of interest for discovering the potholes is chosen as the image region where the road is seen with the most highest resolution. A threshold value based algorithm is used .the following features are extracted: its size, the regularity of the intensity surface, contrast with respect to background model, and the region's contour length and shape. The candidate regions are labeled as putative potholes by a decision tree according to these features, eliminating the false positives due to shadows of wayside objects.

This method for pothole detection is created on the basis that the potholes are represented in the terms of intensity of image having high values and algorithm intiated by using a threshold-based algorithm that generate a set of candidate regions by selection of areas of the image contains pixels having high intensity values.Each candidate region is analyzed and the regions containing potholes are distinguished from the regions containing object shadows (also represented with high intensity values) by doing analysis of some feature such are : pixel size, regularity, estimated depth, contour length and shape the appearance of a pothole in consecutive frames.

The video file which is used as the input for the system/algorithm is breaked into frames of 20 sec to process individually . This is because of the low processing power of the algorithm. The results (where the system had detected the pothole) are captured and extracted from the video file and saved into the "Results" folder . Some of the result images are presented below. Our proposed pothole-detection algorithm for the black-box camera is divided into three steps: Image cropping ,Gray scale conversion and Thresholding. First, we perform image cropping for removal of undesirable external regions. Secondly we perform gray scale conversion to convert the RGB image (three dimensional matrix) to gray scale (two dimensional matrix) having pixel values from 0 to 255. Further we perform thresholding based on the structuring element objects, returned by the STREL function (based upon the data images).

Later , the obtained number of white's or '1' valued pixels are counted and compared with there threshold value for the final decision. If the value is les than 8000 the road is declared 'clear' else the pothole detected message is flashed on the output screen.

Image cropping :

Cropping is the removal of undesirable external regions from a photographic or illustrated image. The procedure, for the most part, comprises of the evacuation of a portion of the fringe regions of a picture, to enhance its surrounding, to change the perspective proportion, or to emphasize or separate the topic from its experience. The process of cropping is common to the photographic, film processing, broadcasting, graphic design, and printing businesses. In general Cropping an image means making another image from a part of an original image. To crop an image using the Image Viewer, use the Crop Image tool.

Gray Conversion :

Gray conversion is done mainly to convert a RGB image (three dimensional matrix) to gray scale (two dimensional matrix) having pixel values ranging from 0 to 255.

Threshold approach :

Image thresholding is a simple, yet effective, way of partitioning an image into white and black pixels . We had put the threshold value to count the white pixels to "8000" after testing the a set of data for different values.

3.2 Algorithm Flow Chart

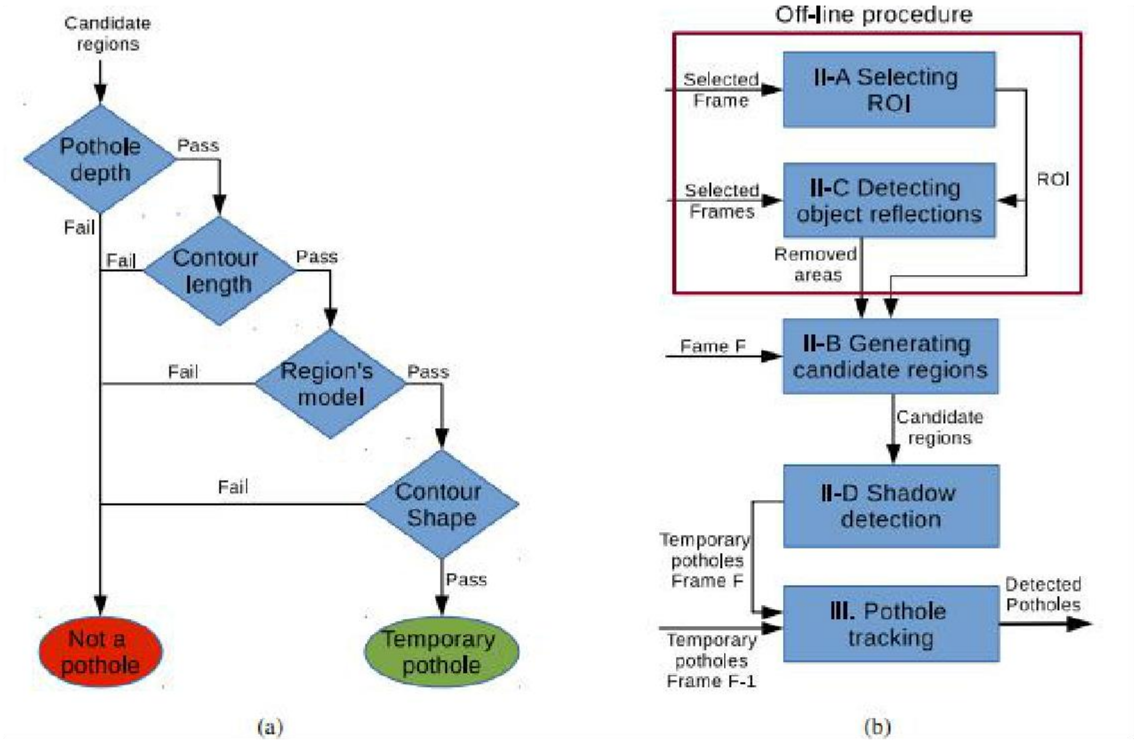

FIGURE 3.1 Algorithm Flow Chart

CHAPTER-4

Results and Discussion

A total of 2 video clips of potholed roads were collected using our phone camera. The video was recorded in sunny weather at noon. In this study, we do not consider conditions at night or weather conditions such as rain, snow, or wind. Figure shows examples of original input images and their corresponding pothole-detection results. In order to determine the accuracy of the proposed method, we manually counted the number of true positives, false positives, and false negatives. We did not count true negatives, because doing so with continuous video data is considerably ambiguous and uncertain:

- True Positives (TPs): correctly detected as a pothole;
- False Positives (FPs): wrongly detected as a pothole;
- False Negatives (FNs): wrongly detected as a non-pothole

Table shows the performance results for the proposed algorithm according to the number of TPs, FPs, FNs, and its sensitivity and precision. Sensitivity refers to the ratio of correctly detected potholes to actual potholes, and precision refers to the ratio of correctly detected potholes to the total number of detected potholes. The sensitivity and precision are thus calculated as follows:

- Sensitivity (True-positive rate): TP/(TP + FN);
- Precision (Positive-predictive value): TP/(TP + FP).

As shown in Table , the proposed method resulted in an overall sensitivity of 71%, with 88% precision. Thus, the method is more precise than it is sensitive. This means that the algorithm is robust to various kinds of similar objects such as manholes, patches, and shade. There were fewer FPs than FNs, owing to the diversity of the shape and size of potholes. Moreover, the proposed algorithm wrongly detected potholes that were especially bright or flat. We think that the algorithm can be improved by adding more conditions to the cascade detector with only a minimal increase to the algorithm’s complexity. Thus, we confirmed that the proposed pothole-detection system has can be utilized to collect pothole information.

Performance	Value
TP	22
FP	3
FN	9
Sensitivity (True-positive rate)	71%
Precision (Positive predictive value)	88%

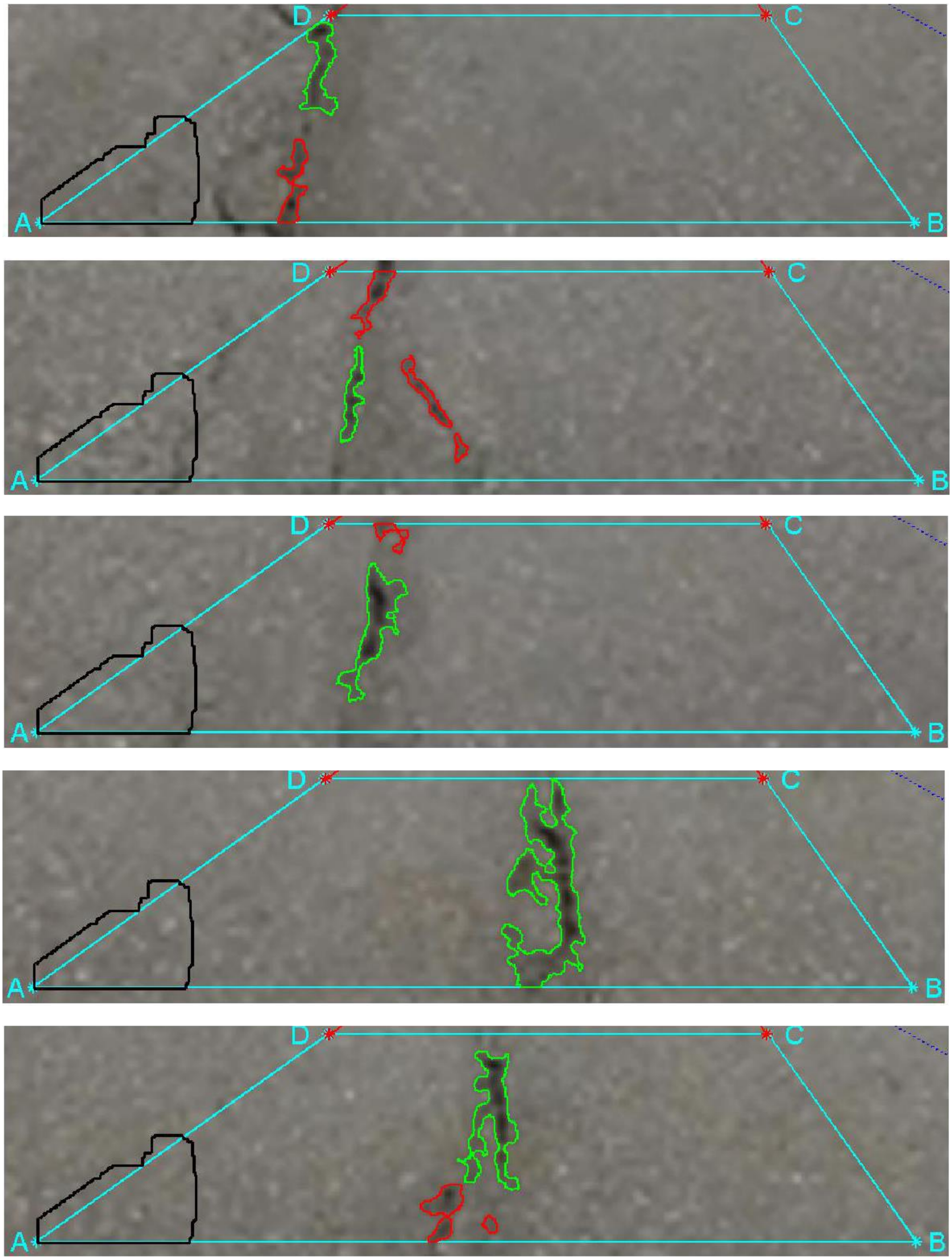

Fig 4.1 Image showing pothole detection

CHAPTER-5

Conclusion And Future Enhancement

5.1 Conclusion

The proposed pothole algorithm has been simulated with the MATLAB program and can much accurately identify potholes from the sample images . Further enhancements will allow us to detect potholes from videos or in real time

5.2 Future Enhancement

1. The identified potholes can be synced with google maps and other maping systems updated by every user's collected data and the information can be utilised by the government for maintenance purposes.

2. Removal of day light reflections as the might appear as pothole due to which the algorithm may detect it as pothole and reduce the efficiency of the system (for initial algorithm).

APPENDICES

A1. Image processing

Digital image processing is the use of computer algorithms to perform image processing on digital images. As a subcategory or field of digital signal processing, digital image processing has many advantages over analog image processing. It allows a much wider range of algorithms to be applied to the input data and can avoid problems such as the build-up of noise and signal distortion during processing. Since images are defined over two dimensions (perhaps more) digital image processing may be modeled in the form of multidimensional systems.

The generation and development of digital image processing are mainly affected by three factors: first, the development of computers; second, the development of mathematics (especially the creation and improvement of discrete mathematics theory); third, the demand for a wide range of applications in environment, agriculture, military, industry and medical science has increased.

A1.1 Image As A Matrix

As we know, images are represented in rows and columns we have the following syntax in which images are represented:

$$f(x,y) = \begin{bmatrix} f(0,0) & f(0,1) & f(0,2) & \cdots & f(0,N-1) \\ f(1,0) & f(1,1) & f(1,2) & \cdots & f(1,N-1) \\ \vdots & \vdots & \vdots & & \vdots \\ f(M-1,0) & f(M-1,1) & f(M-1,2) & \cdots & f(M-1,N-1) \end{bmatrix}$$

Equation 1

The right side of this equation is digital image by definition. Every element of this matrix is called image element , picture element , or pixel.

A1.2 Digital Image Representation In Matlab

$$f = \begin{bmatrix} f(1,1) & f(1,2) & \cdots & f(1,N) \\ f(2,1) & f(2,2) & \cdots & f(2,N) \\ \vdots & \vdots & & \vdots \\ f(M,1) & f(M,2) & \cdots & f(M,N) \end{bmatrix}$$

Equation 2

In MATLAB the start index is from 1 instead of 0. Therefore, f(1,1) = f(0,0). Henceforth the two representation of image are identical, except for the shift in origin. In MATLAB, matrices are stored in a variable i.e X, x, input_image , and soon. The variables must be a letter as same as other programming languages.

A1.3 Purpose Of Image Processing

The purpose of image processing is divided into 5 groups. They are :

Visualization - Observe the objects that are not visible.

Image sharpening and restoration - To create a better image.

Image retrieval - Seek for the image of interest.

Measurement of pattern – Measures various objects in an image.

Image Recognition – Distinguish the objects in an image.

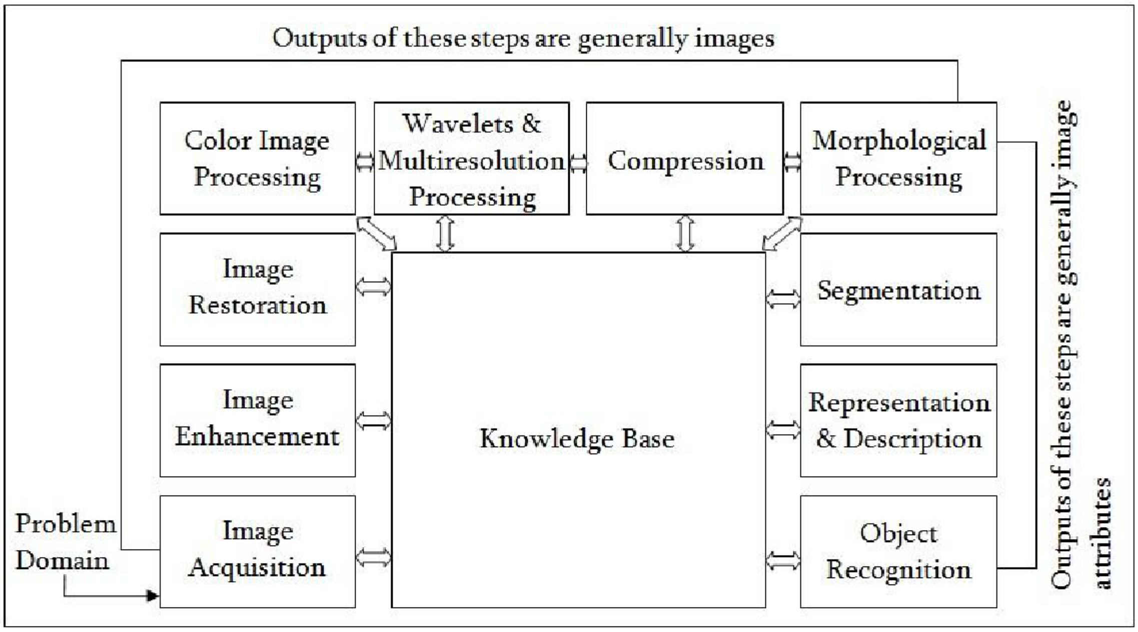

FIGURE A1.1. Fundamental Steps In Digital Image Presentation

A1.3.1 Image Acquisition

This is the first step or process of the fundamental steps of digital image processing. Image acquisition could be as simple as being given an image that is already in digital form. Generally, the image acquisition stage involves preprocessing, such as scaling etc.

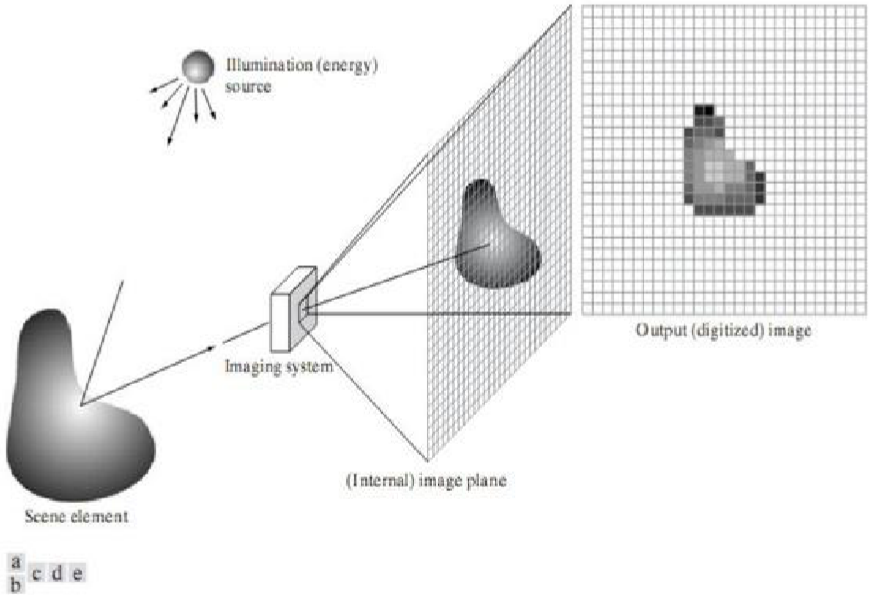

Figure A1.2 .Image Acquistion

A1.3.2. Image Enhancement

Image enhancement is among the simplest and most appealing areas of digital image processing. Basically, the idea behind enhancement techniques is to bring out detail that is obscured, or simply to highlight certain features of interest in an image. Such as, changing brightness & contrast etc.

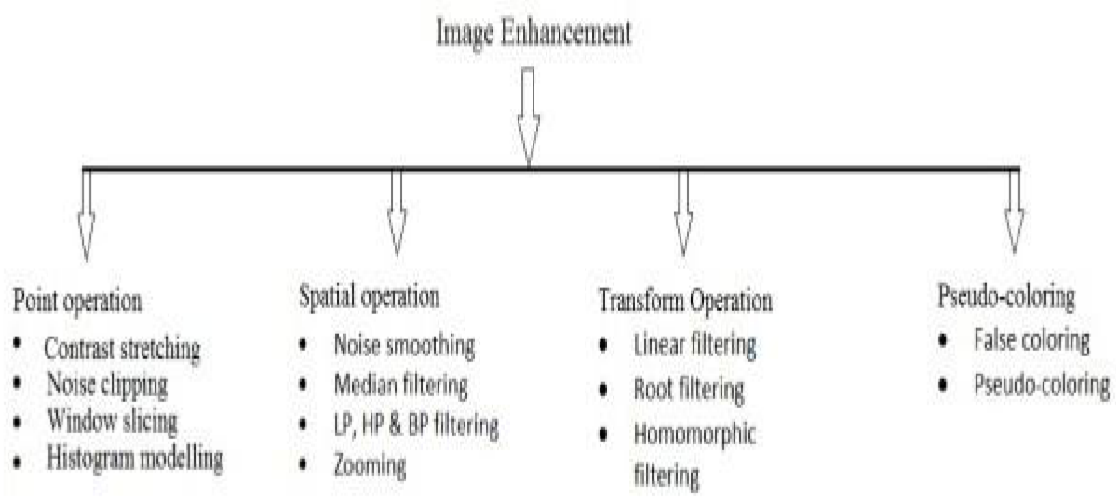

Figure A1.3 Image enhancement

A1.3.3. Image Restoration

Image restoration is an area that also deals with improving the appearance of an image. However, unlike enhancement, which is subjective, image restoration is objective, in the sense that restoration techniques tend to be based on mathematical or probabilistic models of image degradation.

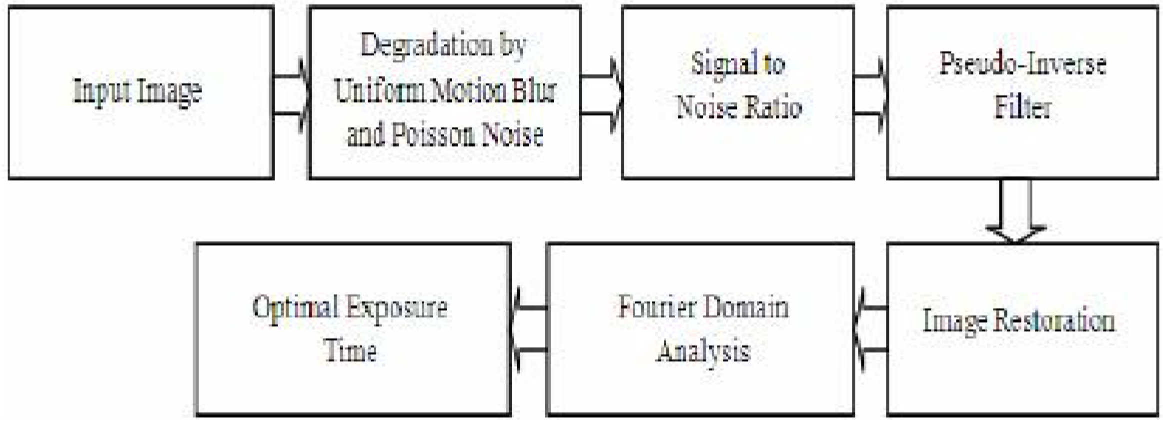

Figure A1.4 Image Restoration

A1.3.4. Color Image Processing

Color image processing is an area that has been gaining its importance because of the significant increase in the use of digital images over the Internet. This may include color modeling and processing in a digital domain etc.

A1.3.5. Wavelets and Multi resolution Processing

Wavelets are the foundation for representing images in various degrees of resolution. Images subdivision successively into smaller regions for data compression and for pyramidal representation.

A1.3.6. Image Compression

Compression deals with techniques for reducing the storage required to save an image or the bandwidth to transmit it. Particularly in the uses of internet it is very much necessary to compress data.

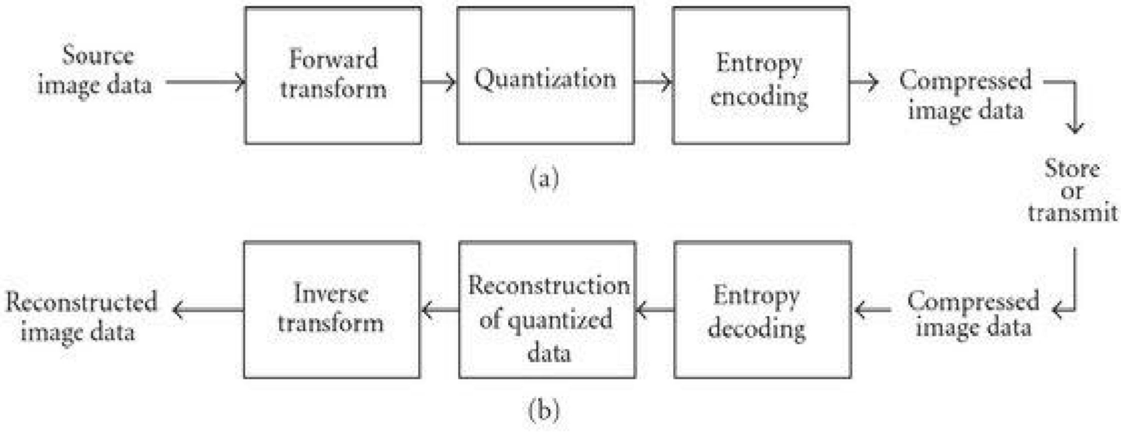

Figure A1.5 Image Compression

A1.3.7. Morphological Processing

Morphological processing deals with tools for extracting image components that are useful in the representation and description of shape.

A1.3.8.Image Segmentation

Segmentation procedures partition an image into its constituent parts or objects. In general, autonomous segmentation is one of the most difficult tasks in digital image processing. A rugged segmentation procedure brings the process a long way toward successful solution of imaging problems that require objects to be identified individually.

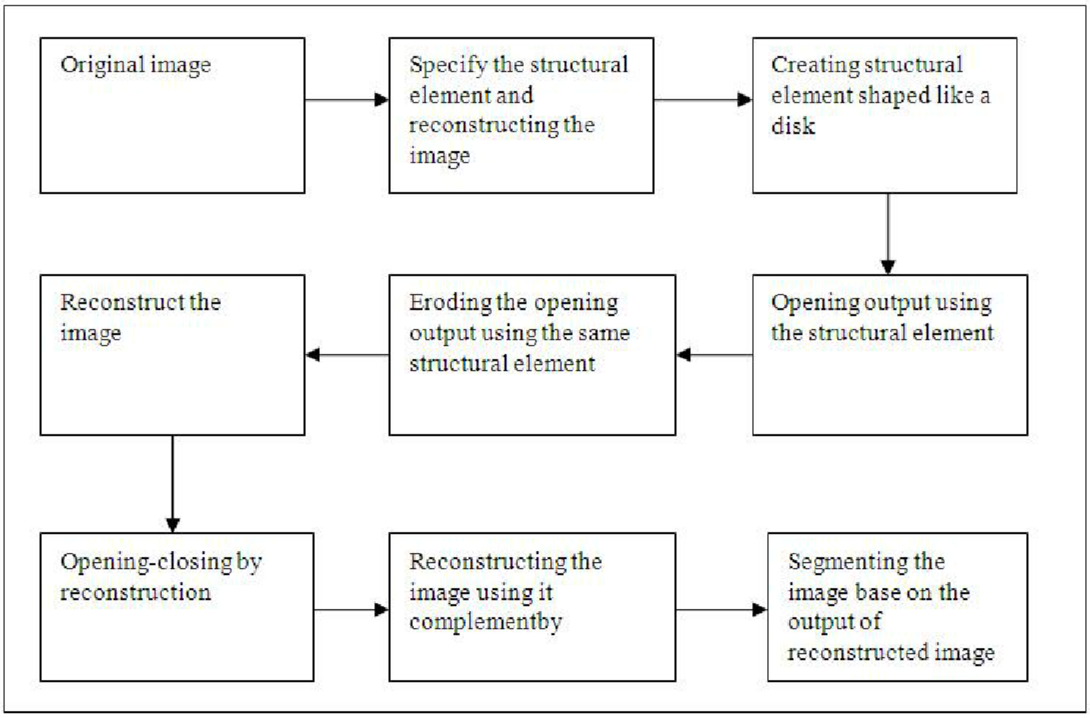

Figure A1.6 Image Segmentation

A1.3.9. Representation and Description

Representation and description almost always follow the output of a segmentation stage, which usually is raw pixel data, constituting either the boundary of a region or all the points in the region itself. Choosing a representation is only part of the solution for transforming raw data into a form suitable for subsequent computer processing. Description deals with extracting attributes that result in some quantitative information of interest or are basic for differentiating one class of objects from another.

A1.3.10. Object recognition

Recognition is the process that assigns a label, such as, “vehicle” to an object based on its descriptors.

A1.3.11. Knowledge Base

Knowledge may be as simple as detailing regions of an image where the information of interest is known to be located, thus limiting the search that has to be conducted in seeking that information. The knowledge base also can be quite complex, such as an interrelated list of all major possible defects in a materials inspection problem or an image database containing high-resolution satellite images of a region in connection with change-detection applications.

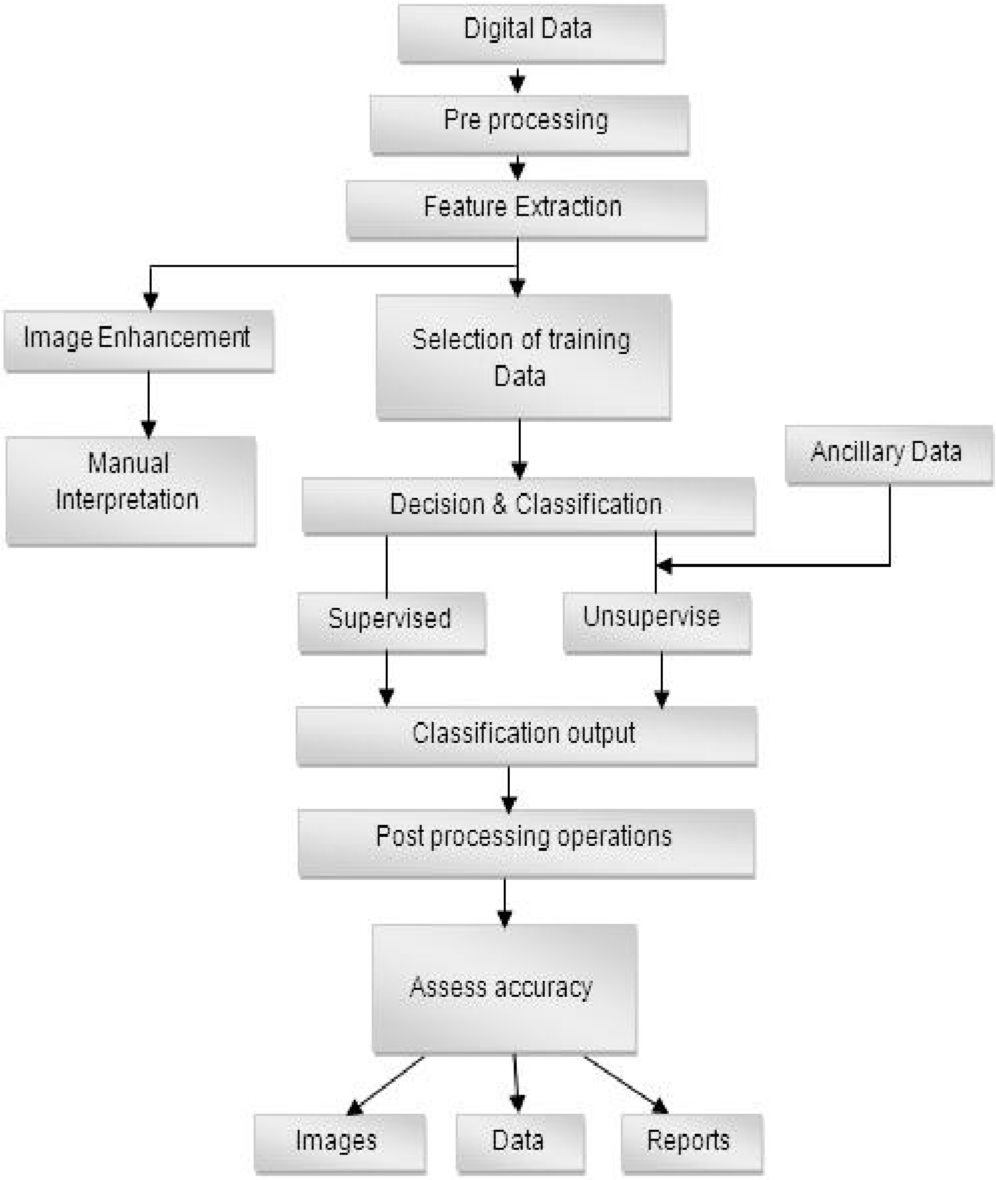

Figure A1.7 Knowledge Base

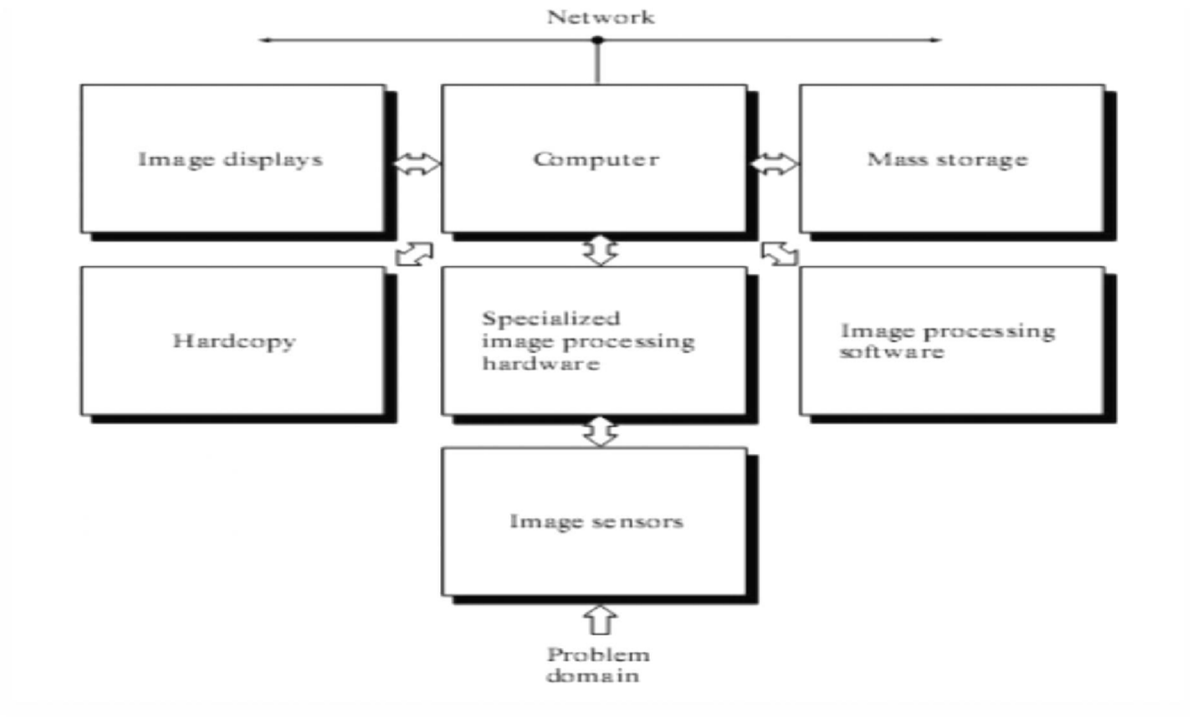

Figure A1.8 Components Of Image Processing System

1. Image Sensors : With reference to sensing, two elements are required to acquire digital images. The first is a physical device that is sensitive to the energy radiated by the object we wish to image. The second, called a digitizer, is a device for converting the output of the physical sensing device into digital form. For instance, in a digital video camera, the sensors produce an electrical output proportional to light intensity. The digitizer converts these outputs to digital data.

2. Specialized Image Processing Hardware : Specialized image processing hardware usually consists of the digitizer just mentioned, plus hardware that performs other primitive operations, such as an arithmetic logic unit (ALU), which performs arithmetic and logical operations in parallel on entire images. One example of how an ALU is used is in averaging images as quickly as they are digitized, for the purpose of noisereduction. This type of hardware sometimes is called a front-end subsystem, and its most distinguishing characteristic is speed. In other words, this unit performs functions that require fast data throughputs (e.g., digitizing and averaging video images at 30 framess) that the typicalmain computer cannot handle.

3. Computer : The computer in an image processing system is a general-purpose computer and can range froma PC to a supercomputer. In dedicated applications, some timesspecially designed computers areused to achieve a required level of performance, but our interest here is on general-purpose image processing systems. In these systems, almost any well-equipped PC-type machine is suitable for offline image processing tasks.

4. Software : Software for image processing consists of specialized modules that perform specific tasks. A well-designed package also includes the capability for the user to write code that, as a minimum, utilizes the specialized modules. More sophisticated software packages allow the integration of those modules and general-purpose software commands from at least one computer language.

5. Mass Storage : Mass storage capability is a must in image processing applications. An image of size 1024*1024pixels, in which the intensity of each pixel is an 8-bit quantity, requires one megabyte of storage space if the image is not compressed. When dealing with thousands, or even millions, of images, providing adequate storage in an image processing system can be a challenge. Digital storage for image processing applications falls into three principal categories:

(1) Short-term storage for use during processing

(2) On-line storage for relatively fast re-call

(3) Archival storage, characterized by infrequent access.

Storage is measured in bytes (eight bits), Kbytes (one thousand bytes), Mbytes (one million bytes), Gbytes (meaning giga, or one billion, bytes), and Tbytes (meaning tera, or one trillion, bytes). One method of providing short-term storage is computer memory. Another is by specialized boards, called frame buffers, that store one or more images and can be accessed rapidly, usually at video rates (e.g., at 30 complete images per second).The latter method allows virtually instantaneous image zoom, as well as scroll (vertical shifts) and pan (horizontal shifts). Frame buffers usually are housed in the specialized image processing hardware unit Online storage generally takes the form of magnetic disks or optical-media storage. The key factor characterizing on-line storage is frequent access to the stored data. Finally, archival storage is characterized by massive storage requirements but in frequent need for access. Magnetic tapes and optical disks housed in “jukeboxes” are the usual media for archival applications.

6. Image Displays: Image displays in use today are mainly color (preferably flat screen) TV monitors. Monitors are driven by the outputs of image and graphics display cards that are an integral part of the computer system. Seldom are there requirements for image display applications that cannot be

met by display cards available commercially as part of the computer system. In some cases, it is necessary to have stereo displays, and these are implemented in the form of headgear containing two small displays embedded in goggles worn by the user.

7. Hardcopy : Hardcopy devices for recording images include laser printers, film cameras, heat-sensitive devices, inkjet units, and digital units, such as optical and CD-ROM disks. Film provides the highest possible resolution, but paper is the obvious medium of choice for written material. For presentations, images are displayed on film transparencies or in a digital medium if image projection equipment is used. The latter approach is gaining acceptance as the standard for image presentations.

8. Networking : Networking is almost a default function in any computer system in use today. Because of the large amount of data inherent in image processing applications, the key consideration in image transmission is bandwidth. In dedicated networks, this typically is not a problem, but communications with remote sites via the Internet are not always as efficient. Fortunately, this situation is improving quickly as a result of optical fiber and other broadband technologies.

A1.4 Characterstics Of Digital Image Processing

- It uses software, and some are free of cost.
- It provides clear images.
- Digital Image Processing do image enhancement to recollect the data through images.
- It is used widely everywhere in many fields.
- It reduces the complexity of digital image processing.
- It is used to support a better experience of life.

A1.5 Advantages Of Digital Image Processing

- Image reconstruction (CT, MRI, SPECT, PET)
- Image reformatting (Multi-plane, multi-view reconstructions)
- Fast image storage and retrieval
- Fast and high-quality image distribution.
- Controlled viewing (windowing, zooming)

A2. MATLAB

MATLAB (matrix laboratory)is a multi-paradigm numerical computing environment and proprietary programming language developed by MathWorks. MATLAB allows matrix manipulations, plotting of functions and data, implementation of algorithms, creation of user interfaces, and interfacing with programs written in other languages.

Although MATLAB is intended primarily for numerical computing, an optional toolbox uses the MuPAD symbolic engine allowing access to symbolic computing abilities. An additional package, Simulink, adds graphical multi-domain simulation design for and model-based dynamic and embedded systems.

As of 2018, MATLAB has more than 3 million users worldwide. MATLAB users come from various backgrounds of engineering, science, and economics.

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