

Design and Development of Haemostatic Drug Delivery System

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Abstract

Vein localization and catheter insertion constitute the first and perhaps most important phase of many medical procedures. At present, catheterization is performed manually by trained and skilled personnel. This process can prove problematic, however, depending upon various physiological factors of the patient. In this paper initial work for localizing surface veins via near-infrared (NIR) imaging and structured light ranging has been carried out. The eventual goal of the system is to serve as the guidance for a fully automatic (i.e., robotic) catheterization device. This study aims at easing the process of vascular access to the doctor and making it automatic to a large extent and can be used to treat people in remote or hostile locations as in a battlefield as an aid to wounded soldiers where a human practitioner could not be present.

This work carried out is the conceptual prototype of an automated drug delivery system. It extracts the wrist vein structures, and selects the optimal drug needle insertion point. The gray scale images obtained from a low cost IR-webcam are poor in contrast, and usually noisy which make an effective vein segmentation a great challenge. A new vein image segmentation method is developed, based on enhancement techniques resolving the conflict between poor contrast vein image and good quality image segmentation. Gaussian and median filters are used to remove the high frequency noise in the image. The ultimate goal is to identify venous bifurcations and determine the insertion point for the needle.

The developed algorithm significantly enhances the image captured using the low cost webcam. The XY coordinates are extracted from the captured image based on the minutiae features mainly the ridge ending and ridge bifurcations. The extraction of the XY coordinate for the insertion of the haemostatic drug has been achieved using the crossing number algorithm. The 3D modelling and dimensional design of the drug delivery system has been developed using Solidworks platform. A hardware prototype has been fabricated based on the dimensional design. The motors are mounted on the hardware model and have been calibrated in order to obtain a precision of 1 mm. The acquired XY coordinates have been passed serially to the motors for automatic positioning of the syringe over the XY coordinates. We thus conclude that the developed system can successfully be used for automated drug delivery.

Key Words: Haemostatic Drug Delivery, Skeletonization, Minutiae Extraction.

1. INTRODUCTION

Vein detection and the catheter insertion have been the first and the most important phase of many medical procedures. At present the localization and catheterization are performed manually by a trained personnel or the physician. There are many ways of detecting the position of the veins and the underlying organs and the tissues such as X-ray, Computed Tomography (CT), Ultrasound and Magnetic Resonance Imaging (MRI) etc. These methods cannot be used in most of the conditions as they are expensive and complicated and includes invasive methods prior to the procedure. They also require repeated scans at times in order to obtain a clear image of the veins. This means that a large amount of ionizing radiation passes through the body of the patient. Ionizing radiation is very harmful and can cause damage to the tissues in several ways, such as genetic mutations in chromosomes which could lead to cancer.

The main objective of this study is to design and develop a table top Haemostatic Drug Delivery System consisting of an infrared camera and a hardware setup to direct the catheter or the syringe automatically on to the top of the vein imaged for the delivery of the haemostatic drug as shown in Figure 1. A jelly is used to act as the skin layer as it

represents the fat layer of the skin. Jelly or gelatin which is extract from animal connective tissue is used technically in biochemical industry as bone glue. Jelly has optical properties similar to skin [1]. A webcam is taken and modified to act as an infrared camera in order to view the subcutaneous veins on the arm or wrist of the patient. The image thus obtained is then processed using various image processing algorithms in order to locate a point on the main vein for the insertion of the catheter through which the haemostatic drug is to be delivered.

The setup consists of an NIR sensitive camera placed over the wrist with a NIR filter and a NIR LED Ring in front of the camera for better illumination of the region to image the sub cutaneous veins. The captured image is processed using different image processing algorithms for the extraction of the vein and for the localization of XY coordinated in the vein. The coordinates are passed on to a motor controller fixed on a hardware setup of the XY table. The motor is calibrated to position XY bed containing the syringe on to the top of the XY point marked on the imaged vein.

2. PROBLEM STATEMENT

A Haemostatic Drug Delivery System is a device used for detection and exact localization of a wrist vein for the delivery of haemostatic drug to the vein.

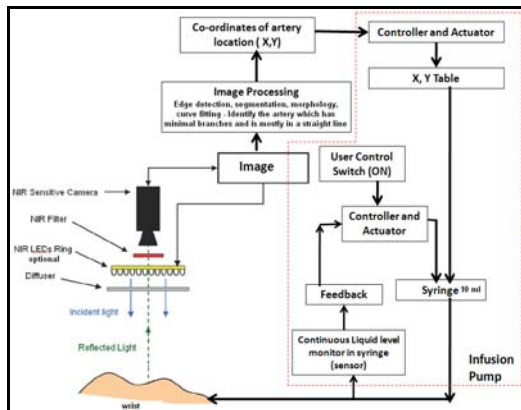


Fig. 1 Block diagram of haemostatic drug delivery system

A relatively newer technique to image veins is the NIR (Near-Infra-Red) imaging that uses light source whose wavelength lies in the near infrared region of the electromagnetic spectrum suitable for viewing the subcutaneous veins. The main objective is to design and develop an Automated Table Top Haemostatic Drug Delivery System using NIR imaging technique and image processing algorithms.

3. METHODOLOGY

- Literature review of the Drug Delivery System for its operating principle from the available and the open domain documents needed emphasis for system development and associated problems has been carried out
- Image processing algorithms for arterial identification, segmentation and co-ordinate extraction to efficiently localize arteries in a given NIR image has been reviewed.
- Data Acquisition and Development of Image processing algorithms has been carried out based on the literature review
- IR cameras, x-y table and other electronic components required for non-invasive NIR imaging and drug delivery is being identified and procured
- A set up for NIR imaging and acquire images of the wrist and its arteries has been developed
- A decision logic is being developed to localize the wrist arteries with minimal branches and mostly forms a straight line
- The robustness/validity of the developed algorithms by testing them on various images of different resolution and quality has been evaluated
- The x-y co-ordinates of the identified artery are obtained
- The developed X-Y table positioning algorithm have been tested for different cases of x-y co-ordinates
- The integration of software and hardware have been carried out

- The integrated system for various test cases are tested and validated

4. DESIGN AND IMPLEMENTATION

The Haemostatic Drug Delivery System consists of an infrared camera mounted to a hardware setup in order to direct the catheter or the syringe automatically on to the top of the imaged vein for the delivery of the haemostatic drug. Different image processing algorithms are used for the enhancement of the images of veins which are captured with the help of the infrared camera

4.1 Imaging System

The first step is the identification of the vein to which the drug has to be delivered. The imaging of the wrist vein is done with the help of NIR (Near Infrared) imaging technique. The NIR technique uses an IR light source whose wavelength lies in the near infrared region of the electromagnetic spectrum which ranges between 800 nm to 1400nm. The NIR light is absorbed and reflected back to receiver by blood with minimal scattering while the skin and subcutaneous fat scatter the light and attenuates the radiation. Thus blood is dark, while skin and fat appear light.

An array of infrared light-emitting diode (IR LED) and an IR camera modified from a webcam was used to capture the vein pattern in our system. The wrist vein pattern can be captured using a modified webcam with an attached IR filter by illuminating the wrist with a beam of infrared. The resulting images, the light-blocking capacity of deoxy-haemoglobin is highest at a wavelength of 760nm and is reduced by as much as 50% from its peak value at 850nm. Further, the light blocking capacity of oxy-haemoglobin is much lower at 760nm than at 850nm. Image is captured in colored JPEG format as 640 x 480 dimensions.

The imaging device procured acts as a normal camera and thus had to be modified for the viewing of the subcutaneous wrist veins. The first step in the modification of the webcam to an IR camera is the removal of the IR blocking filter placed behind the lens. The blocking filter is used to reduce the intensity of the IR radiations falling on the lens. The removal of the filter glass allows the passage of the IR intensity radiations along with the ambient light. The procured webcam and the image of the removed filter from the lens are as shown Figure 2(a) and 2 (b) respectively.

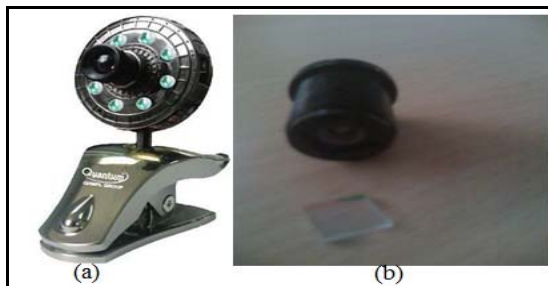


Fig. 2 Imaging device (a); removed IR blocking filter (b)



Fig. 3 Concentric arrangements of IR LED's for better illumination (a); parallel connection of IR LED's (b)

The LED array board is then fixed on to the webcam the lens is placed on to the centre as shown in Figure 4



Fig. 4 Imaging device with IR LED arrangement

4.2 Image Processing

The raw vein image captured from the camera has to be enhanced through several image pre-processing stages before the minutiae feature extraction can be done. The extraction of the veins from the raw image has been carried out through a sequence of steps or processes as shown in the Figure 5.

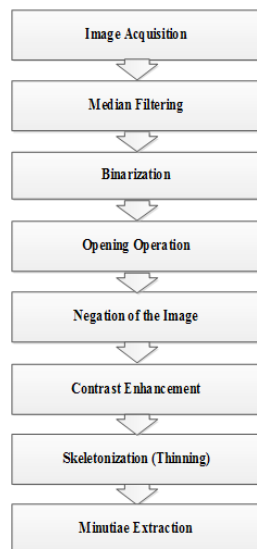


Fig. 5 Flow chart of the image processing algorithm

The raw vein image captured from the camera will be enhanced through several image pre processing stages before the minutiae feature extraction can be done. This section will discuss on each sub blocks of the image processing modules.

4.2.1 Image Capturing and Reading

The raw images of the wrist are captured using a modified IR camera. The images are then read in MATLAB using the basic commands for further processing and segmentation of the veins from the raw image.

4.2.2 Median Filtering

In digital Image processing, noise removal is one of the pre-processing techniques. The most common type of noise in any image is a 'salt and pepper noise' which appears as random occurrence of black and white pixels. One of the most common filters used for the removal of the 'salt and pepper noise' is a median filter.

Median filtering is done on an image matrix by finding the median of the neighborhood pixels by using a window that slides pixel by pixel. The main advantage of median filtering is that it preserves the image without getting blurred. For example, consider the matrix as shown in the Figure 6.

	123	125	126	130	140
	122	124	126	127	135
	118	120	150	125	134
	119	115	119	123	133
	111	116	110	120	130

Fig. 6 Matrix window selected for median filtering

The neighborhood values of the selected window after arranging in ascending order are 115, 119, 120, 123, 124, 125, 126, 127, 150. The median value i.e. the fifth value in the series is 124. Thus the mid value of the matrix i.e. 150 is replaced with the median value i.e. 124.

4.2.3 Binarization

Most feature extraction algorithms operate on binary images where there are only two levels of interest the black pixels, and the white pixels. Binarization is the process that converts a gray-level image into a binary image. In case of minutiae extraction the binarization of the image plays an important role as the black pixels represents the ridges and the white pixel represents the valleys. This improves the contrast between the ridges and valleys in the vein image, and consequently facilitates the extraction of minutiae.

Binarization of an image is done by replacing all pixels in the input image with luminance greater than level with the value 1 (white) and all other pixels below the luminance with the value 0 (black). Consider a grayscale image $I(i,j)$ with i rows and j columns, the binarization is performed by setting a threshold t , as given by 4.1.

$$B(i,j) = \begin{cases} I(i,j) = 1 & \text{if } I(i,j) > t \\ I(i,j) = 0 & \text{if } I(i,j) < t \end{cases}$$

4.2.4 Opening Operation

Morphological processing is described almost entirely as operations on sets. The morphological operations are performed using a structuring element (SE) which is a small image used as a moving window whose support delineates pixel neighborhoods in the image plane. Structuring Elements can have varying sizes with element values are 0 or 1. Thus the outputs of the morphological operations are determined by comparing the structuring element to the neighborhood of each pixel in the original image.

These two basic operations, dilation and erosion, can be combined into more complex sequences. The most useful of these for morphological filtering are called opening and closing. Opening consists of an erosion followed by a dilation and can be used to eliminate all pixels in regions that are too small to contain the structuring element. In this case the structuring element is often called a probe (Unknown, 2002), because it is probing the image looking for small objects to filter out of the image. The opening operation in set form is represented as shown in equation 4.2

$$A \circ B = (A \ominus B) \oplus B$$

Where

A = original image

B = structuring element

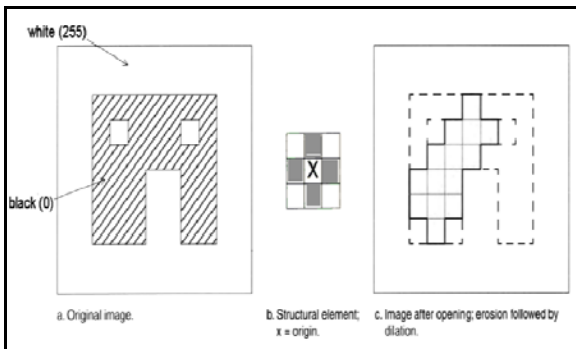


Fig. 7 Illustration of the opening process (Unknown, 2002)

4.2.5 Skeletonization

Skeletonization or thinning is the process of reducing an object in a digital image to the minimum size necessary for machine recognition of that object (Erin Hastings, 1992). All thinning algorithms can be classified as one of two broad categories 1) iterative thinning algorithms or 2) non-iterative thinning algorithms. The parallel thinning algorithm is used in this paper in order to reduce the size of the captured veins into line representations for machine representation of the image. In parallel thinning algorithm the decision for individual pixel deletion is based on the results of the previous iteration. Parallel thinning usually considers a 3 x 3 neighborhood around the current pixel.

Here each pixel of the image is compared with the neighboring pixels of the image. If P1 is the main pixel of the image on which the manipulations has to be done, then the 8-neighbourhood of P1 is as shown in the Figure 8.

P9 (i-1,j-1)	P2 (i-1,j)	P3 (i-1,j+1)
P8 (i,j-1)	P1 (i,j)	P4 (i,j+1)
P7 (i+1,j-1)	P6 (i+1,j)	P5 (i+1,j+1)

Fig. 8 The 8-neighbourhood of pixel P1

The Four pixel, P(2), P(4), P(6) and P(8), are called the direct neighbors. The four pixels, P(3), P(5), P(7) and P(8), are called the indirect neighbors.

If I = the original binary image in which black pixels are “0” and white pixels are “1”. The object in the image is made of connected white pixels. J and K are temporary images to be used in each iteration of the algorithm. J is the (n-1)th iteration output and K is the current, or nth, iteration output. P (i, j) is the current pixel under consideration. Two other variables used in the algorithm are A and B. A of pixel P1 is defined as the sum of all the pixels from P2 to P9. B of pixel P1 is the count of the number of 0 to 1 transitions in a clockwise circle from P9 back to itself. An example for the calculation of B is as shown in the Figure 9.

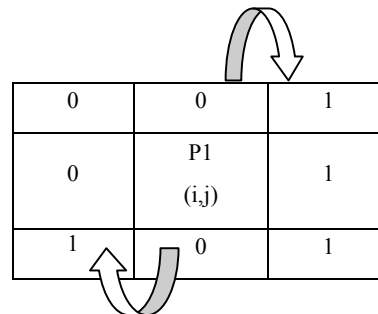


Fig. 9 Representation for calculation of B

The value of B would be equal 2 since there are two 0 to 1 transitions in a clockwise order.

B is the nonzero neighbor of current pixel P(1) given in equation 4.3 (Zhang Y. Y, et.al, 1992)

$$B = \sum_{k=2}^9 p[k] \quad (4.3)$$

The weight number of P(1) which is J is defined using 4.4. (Zhang Y. Y. et.al, 1992)

$$J = \sum_{k=2}^9 p[k] * 2^k \quad (4.4)$$

Connection number of P(1) which is A is defined in equation 4.5 (Zhang Y. Y, et.al, 1992)

$$A = \sum_{k=2}^9 \overline{p[k]} * (p[k+1] \cup p[k+2]) \quad (4.5)$$

Where $\overline{p[k]} = 1-p(k)$, P(8)=P(0).

A=0..... P is the interior (hole) or isolated point

A=1.....P is the edge point

A=2.....P is the connecting point

A=3.....P is the branching point

A=4.....P is the crossing point

4.2.6 Minutiae Extraction

Minutiae are the major features present mainly in the finger prints and the veins. Minutiae include

- Ridge ending – the abrupt end of a ridge
- Ridge bifurcation – a single ridge that divides into two ridges
- Short ridge, or independent ridge – a ridge that commences, travels a short distance and then ends
- Island – a single small ridge inside a short ridge or ridge ending that is not connected to all other ridges
- Ridge enclosure – a single ridge that bifurcates and reunites shortly afterward to continue as a single ridge
- Spur – a bifurcation with a short ridge branching off a longer ridge
- Crossover or bridge – a short ridge that runs between two parallel ridges
- Delta – a Y-shaped ridge meeting
- Core – a U-turn in the ridge pattern

The main types of minutiae extracted from the wrist veins in this case are ridge ending and the ridge bifurcation. The images representing the ridge ending and ridge bifurcation are as shown in the Figure 10(a) and Figure 10 (b) respectively.

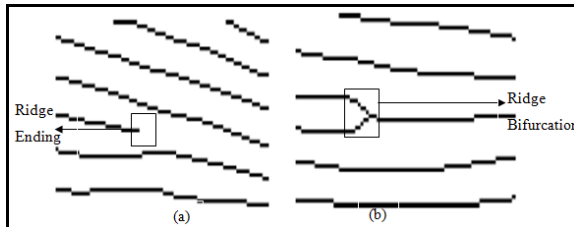


Fig. 10 Ridge ending (a); ridge bifurcation (b) (Raymond Thai, 2003)

The most commonly employed method of minutiae extraction is the Crossing Number (CN) concept. This method is applied on to a skeletonised image where the ridges flow patterns are 8 connected. The minutiae are extracted by scanning the local neighborhood of each ridge pixel in the image using a 3 x 3 window. The CN value is then computed, which is defined as half the sum of the differences between pairs of adjacent pixels in the eight-neighborhood (Raymond Thai, 2003). The ridges can be classified into ridge ending, bifurcation or non-minutiae depending on different properties as shown in the Table 4.1. For example, a ridge pixel with a CN of one corresponds to a ridge ending, and a CN of three corresponds to a bifurcation.

The minutiae mainly the ridge endings and the bifurcations points are extracted using this method and the values of X and Y are stored into another array in order to find the XY point which has to be given to the motor.

Table 1 Properties of crossing number

Crossing Number (CN)	Property
0	Isolated Point
1	Ridge Ending Point
2	Continuing Ridge Point
3	Bifurcation Point
4	Crossing Point

The CN for a ridge pixel P is given in 4.6 (Raymond Thai, 2003)

$$CN = 0.5 \sum_{i=1}^8 |R_i - R_{i+1}|, \quad R_8 = R_1 \quad (4.6)$$

Where P_i is the binary pixel value in the neighborhood of P with $P_i = 0$ (or 1). After the computation of the CN for the ridge pixel, the pixel can be classified according to the property of its CN value. As shown in Figure 11(a) and Figure 12(b).

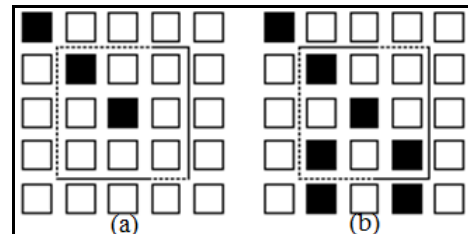


Fig. 11 Examples of a ridge ending, CN = 1 (a); bifurcation pixel, CN = 3 (b) (Raymond Thai, 2003)

The XY pixel points acquired from the images are first converted into a scale on the image and then these points are given to the motor controller through a USB to serial port via TTL/level converter. The inputs given to the controller are in the form of pulses. The serial commands to the motor are as shown

- N0<Position><CR> - Go to command with feedback full speed. Will return prompt when motor reaches end position
- N1<Position> <Speed><CR> - Go to command with speed setting & feedback. Will return prompt when motor reaches end position
- P<Position><CR> – Go to position no feedback. Will return prompt as soon as the command is accepted
- S<CR> – Shows current position of the motor.

CR stands for carrier return which equal to entering the statement or command.

The main problem faced here is the setting of the home position of the motor. This is because every time the motor powers on the current position is set as the home position. The XY bed has to be aligned to one corner of the device in order to provide proper space for the camera for imaging the vein. The setting of home position is the prime objective. This is done by attaching a switch to the XY bed and giving pulses for unlimited rotation of the motor. The switch is operated through a relay circuit. The circuit is made in such a way that once the motor controller gets restarted once the

switch the external frame on the device. Thus the home position is set. A two way switch connected in parallel to the relay is then switched on once the home position is set. This allows the flow of continuous current to the motor which was first obstructed when the switch was on. The circuit diagram for the relay circuit is as shown in the Figure 12.

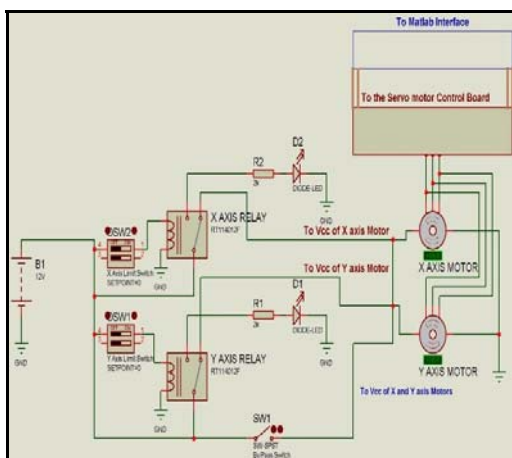


Fig. 12 Home positioning control circuit

The implemented model of the relay based on the design is as shown in the Figure 13

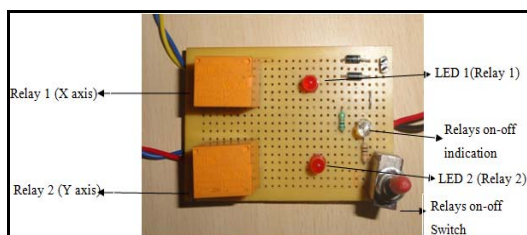


Fig. 13 Home positioning control circuit

4.3 Hardware Design

The design of the drug delivery system is the next phase of the study. The device should consist of a syringe holding mechanism and 2 motors in order to move the table or the syringe bed in both X and Y directions respectively. The motor is coupled to the screw using a gear mechanism of ratio 1:3 i.e. for one rotation of the motor the screw rotates 3 times. The procured motor consists of a controller for controlling the position and the rpm (rotations per minute) of the motor. The feedback mechanism allows the motor to remind the current position and also to return to the original home position when the delivery of the drug is completed.

4.3.1 Motor

The motor is responsible for the movement of the XY bed in both X and Y axis. The motor used in this device is a DC geared motor with an rpm of 100 as shown in Figure 14.

The technical specifications of the motor are

- Motor with Quad encoder which also gives direction of movement
- Operating Voltages 3V-12V DC

- 200 RPM through motor driver
- Torque 2.3 K.gcm
- Resolution 1384 CPR (Base motor)
- 6Pin Interface M+,M-,ENC_B,VCC,ENC_A,GND



Fig. 14 Encoder DC servo motor with driver

4.3.1.1 Motor Calibration

The precision of the instrument is the most important task because the improper positioning of the syringe can be hazardous to the patients. Thus the motor calibration has to be done depending upon the precision required. In this study the motor is calibrated to a precision of 1mm.

1. Number of pulses required for one complete rotation (360°) of motor = 80000;
2. Number of pulses for 10 rotation = 800000;
3. Distance of XY table moved in 10 rotations = 22 mm
4. Therefore, to move the motor for a distance of 1mm = $800000/22 = 36363$ pulses.

Thus on an input of 36363 pulses, the motor tends to move a distance of 1 mm. This value is then multiplied for both X and Y values in order to position syringe

4.3.2 XY Table

The design of the XY table is done in Solid Works software platform. The designed 3D model of the device is as shown in the Figure 15

The hardware model is implemented using the available resources and the finalized implemented 3D model of the Drug Delivery System is as shown in the Figure 16.

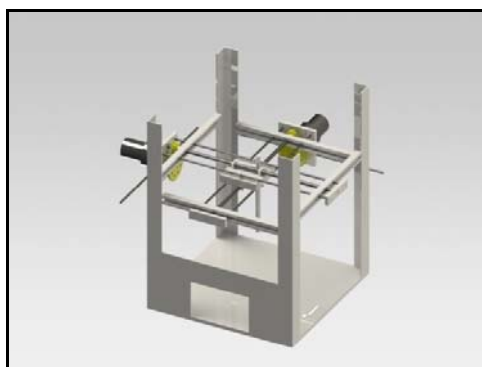


Fig. 15 3D Design of drug delivery device



Fig. 16 Figure displaying the device with syringe and the motor

5. RESULTS AND DISCUSSION

5.1 Image Acquisition

The images captured using the modified IR webcam are of the resolution of 480 x 640 pixels. An image used for testing and validation of the algorithm are as shown in Figure 17

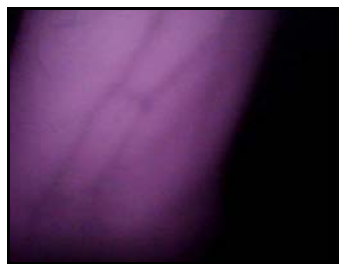


Fig. 17 Image captured for testing

5.2 Image Segmentation

The segmentation is done in order to separate the hand from the background image. This is done in 4 parts. The first part includes the selection of the red color components of the image and also converting all the other color components to the red color components. The second stage is the binarization where all the red components of the image are converted into white pixels ('1') and the else to black ('0'). This is followed by the negation of the image. The final stage consists of replacing all the white pixels of the image by the corresponding pixels in the original image. The final image is the segmented image of the hand with a black background. The result of segmentation of the test image is as displayed in Figure 18 (a).

5.3 Thresholding

The segmented image has to be thresholded in order for the further processing and for separating the sub cutaneous vein and localization of XY co-ordinates on the vein. The thresholding is done in such a way that all the pixels above a certain luminance are set to high (255) and the other pixels below the luminance is set to low (0).

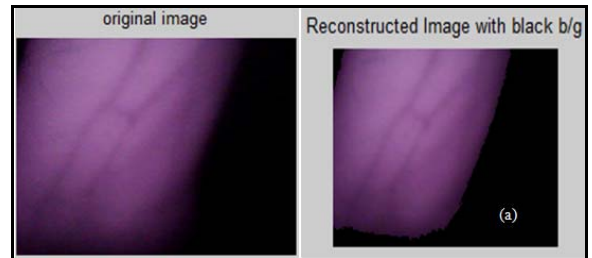


Fig. 18 Segmentation operation of test case (a)

The image is thresholded and is as shown in Figure 19 (a).

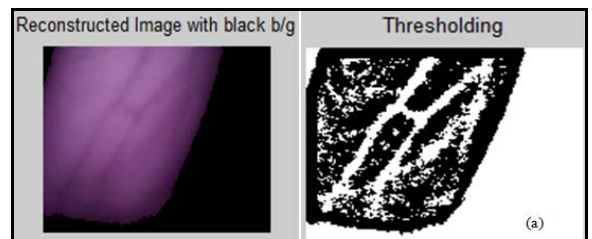


Fig. 19 Results of thresholding of segmented images test case (a)

5.5 Median Filtering

The thresholded image consists of noise which has to be filtered. The most commonly used filters are the median and Gaussian filters. Median filters are more efficient for the removal of noises. The main advantage of median filtering is that it preserves the image without getting blurred. The images obtained as a result of using Median filter on the thresholded images of test case 1 and test case 2 is as shown in the Figure 20 (a).

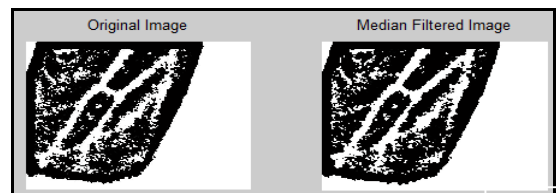


Fig. 10 Median filtering for test case (a) (a)

5.6 Opening Operation

The images obtained after median filtering contains minute white pores which has to be eliminated. Opening consists of an erosion followed by a dilation and can be used to eliminate all pixels in regions that are too small to contain the structuring element. The structuring element used in this process is as shown in Figure 21.

1	0	1
0	1	0
1	0	1

Fig. 11 Structuring element for opening operation

The result of opening operation for the filtered image is as shown in the Figure 22 (a)

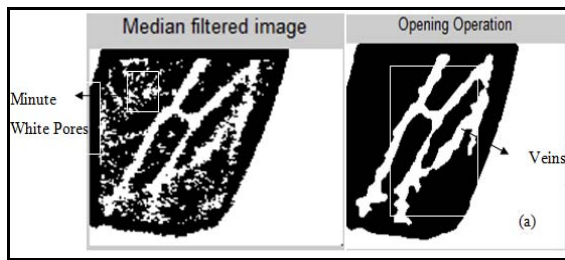


Fig. 12 Opening operation for test case (a)

5.7 Skeletonization

The resultant image obtained after opening has to be thinned to the minimum size necessary for machine recognition of that object. A parallel thinning algorithm has been used for the thinning of the sub cutaneous veins in the image. The skeletonized image is as displayed in Figure 23(a)

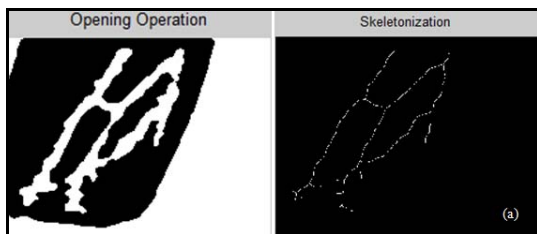


Fig. 13 Result of skeletonization for test case (a)

5.8 Minutiae Extraction

The extractions of these features are done using the crossing number algorithm. A bifurcation point is selected from the image and set as the XY coordinate which acts as the point for the injection of the drug. The ridge bifurcations has been identified and marked for the test cases and these images are fused on to the original images as shown in the Figure 24(a).

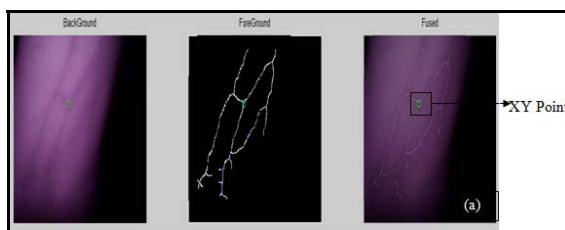


Fig. 14 Minutiae extraction and localization of XY coordinates based on ridge bifurcation for test case (a)

5.9 Serial Communication

The obtained XY coordinates are then passed to the motor controller through USB serial port. The value is then multiplied with the calibrated motor value i.e. 36363 to position itself to the XY coordinate with a precision of 1 mm. The syringe positioning mechanism based on the XY coordinates is as shown in Figure 25.

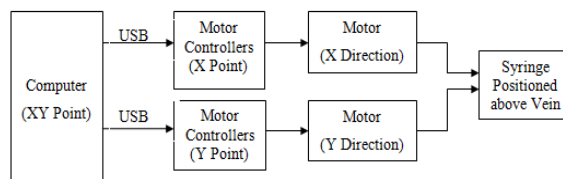


Fig. 15 Syringe positioning mechanism based on XY coordinates

6. CONCLUSIONS

NIR imaging proved to be an appropriate technique for efficient identification of the sub-cutaneous veins. Image acquisition is done using a cheap consumer webcam, modified to take pictures in the NIR wavelength. The image taken is then preprocessed using a Gaussian filter followed by a median filter for a double noise reduction. The enhancement of the images obtained from the low cost webcam for vein localization has been done. The output image is processed using morphological operators mainly opening and skeletonization for the extraction of the vein image from the captured image. The skeletonization of the sub cutaneous veins has been done using the parallel thinning algorithm which preserves the connectivity of the patterns and produces thinned and perfect skeletons. The Crossing Number method was then implemented to perform extraction of minutiae which was able to detect valid bifurcations and ridge endings from the thinned image. The points are marked on the veins based on the minutiae classification and the point on the ridge bifurcation is set as the XY coordinate of the vein on to which the syringe has to be positioned. The 3D model of the drug delivery system is designed in Solidworks Software platform. A hardware model of the device is developed based on the design dimensions. Two motors of 100 rpm and a torque of 4.8 Kgcm for controlling the syringe bed in X and Y directions is fixed to the device and calibrated to a precision of 1mm. A circuit for the home positioning of the motor has been designed and implemented. The XY coordinates are passed serially to the motors and the syringe is automatically positioned over the corresponding XY position on the vein. We thus conclude that the developed system can successfully be used for automated drug delivery.

REFERENCES

- [1] Shankpal P., 2008. *Bone Investigation using Optical Detectors (BIOD)*, M.Sc thesis, University of Warwick, School of Engineering
- [2] Thai R., 2003. *Fingerprint Image Enhancement and Minutiae Extraction*, The University of Western Australia.
- [3] Unknown, 2002. *Morphological operations on binary images*, Technical University of Cluj-Napoca.
- [4] Zhang Y. Y., Wang P. S. P., 1992. *A New Parallel Thinning Methodology*, College of Computer Science, Northeastern University.