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Automated Point-of-Care Clinical Diagnostic Device based on Embedded-Vision

Blessy Navara[1]
M.Tech Embedded Systems
Raghu Engineering College
Visakhapatnam, India

Mr. Siva Rama Rao Bodda[2] (M.E. IISc)
Associate Professor- Electrical engineering
Raghu Engineering College
Visakhapatnam, India

***Abstract*— an automated device for reading and interpreting Rapid Diagnostic Tests is implemented on an Raspberry Pi board. Customized embedded vision algorithm is used to interpret the RDTs which are used in point-of-care clinical diagnosis for infectious diseases such as malaria. The device not just aids in reading, interpreting the RDTs but also saves the results to a server, so that the concerned medical professional can analyze the results and also keep a quality check on the tests going on in a different geographical position. Therefore the system also aids in maintaining Electronic Health Records (EHR).**

Keywords— RDTs, Embedded vision, RaspberryPI OpenCV, GTK+.

I. INTRODUCTION

Point-of-care clinical diagnostics are providing a better and efficient clinical diagnosis for some of the most prevalent infectious diseases. In areas with limited resources, point-of-care diagnostics have already proved to be a bane. For instance, early and accurate diagnosis of malaria for medication and treatment is a challenge round the globe, especially in the remote and rural parts of the world with constrained resources. In the year 2015,214 million malaria cases and 438,000 deaths were recorded [1]. If infectious diseases like malaria are accurately diagnosed, all these deaths can be avoided with the right treatment. These diseases are diagnosed either through standard laboratory procedures or by using RDTs (Rapid Diagnostic Tests).RDTs offer good solution for such remote areas. RDTs are Lateral Flow Assays which gives the user a visual interpretation of the presence of the parasites. Few drops of patient's blood and buffer on RDT will trigger the chemical reaction. The reaction time is approximately 20 minutes after which, RDT is to be read and interpreted. The intensity depends on the concentration of parasites in the given specimen. However, skilled labor for interpretation of RDT is a setback. Interpretation is highly subjective and may lead to wrong diagnosis. Also, in manual method, there is no way one can save the results for future reference.

Embedded vision is the ability of an embedded system to capture images and take intelligent decisions using the defined algorithm. OpenCV is a set of computer vision libraries which enables the user to design intelligent systems. The device designed to interpret RDTs is based on ARM cortex-A7 processor implemented on Raspberry pi 2B board. So, images of RDT captured by camera are processed and a decision is taken by the system as to whether the sample is positive or negative or invalid. The device is designed to detect even small change in intensity of RDT, which makes the device accurate. It can also reject RDTs which are invalid. Also, it can save the results for later inspection and/or tracing by uploading all results to a server.

II. IMPLEMENTATION DETAILS

The paper describes the design of a graphical user interface in the proposed embedded system to collect the patient details and save patient details along with result to server. By doing so, the concerned medical professional can later log-in and analyze the results. The paper proposes a system which implements vision algorithm to read the rapid diagnostic test and to infer whether the result is a positive or negative or invalid. An automated system proposed by [4] identifies the malarial parasites in blood samples using image processing. Since the method in [4] is not suitable for regions where there is lack of skilled labor and necessary equipment, RDTs are used. In this paper, the device needs no additional laboratory equipment.

The paper is organized into the following subsections.

1. Design of system.
2. Design and integration of graphical user interface in the embedded system.
3. Customized embedded vision algorithm for reading and interpreting RDT.
4. Storing the patient details and result to the server

A. *Design of System*

The proposed system contains the following: an embedded processor, imaging device, display unit, input devices (mouse and keyboard). Raspberry pi2B board is used in this device.

Fig. 1: Hardware Setup showing Raspberry PI2B

Raspberry pi uses Broadcom BCM2836 Silicon-on-chip and is based on ARMv7 architecture. The reason for choosing Raspberry pi is *(1)*the board is based on Linux operating system (which makes development easier), *(2)* it supports Ethernet connectivity, on-board USB, CSI(Camera Serial Interface to connect the camera), *(3)*it is compact – well

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suitable for an embedded system, *(4)* it draws minimum power even when running with camera and input devices connected to it and *(5)*it is easily affordable.

Fig. 2: Complete setup along with RDT holder and display

Camera and input devices draw current from the board. The SoC(Silicon-on-chip) used in this board supports the vision libraries necessary for image processing. Since the operating system is a Linux distribution, we used GTK+ libraries required for development of GUI.
RDT holder is a simple mechanical arrangement to place the RDT in right orientation with the camera.

B. Design of grahical user interface in the embedded system
GNU Image Manipulation Program Tool Kit (GTK) is the library used for designing graphical user interface (GUI). The GUI designed here contains widgets for labels, text entry, and also for displaying image and results. By clicking the "NEW TEST "widget, user is asked to fill in all the patient details.
Prior to entering the details and beginning the test, user is required to place the RDT in RDT holder. Details include Patient Name, ID, Age, Gender and name of the test being done. After entering all the details, camera is triggered. The commands used to trigger the camera are run from a shell script, executed from within the main program. Image captured from the camera is preprocessed and analyzed. System takes a decision from the analysis and displays the result in GUI. Simultaneously, all patient details and results are uploaded to the server.

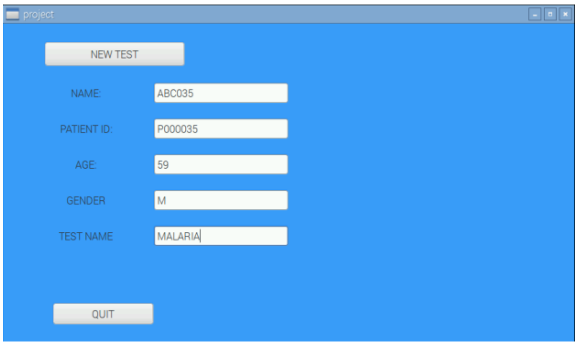

Fig. 3: Patient details fill-in widget of GUI implemented with GTK+

Fig. 4: Test result and image displayed in GUI

C. Customised Embedded vision algorithm to read and interpret RDT
Raw image captured from camera contains noise. High frequency noise samples are removed from the image by applying a 3x3 Gaussian filter. The 3-channel image is converted into a single channel gray scale image for further processing.
The subject of interest in captured image is the red band formed due to the reaction between chemical coated strip and the parasite. Intensity of this red band is not constant for every sample under test. Intensity depends on concentration of parasite in the given sample. Results for color based image segmentation were not always accurate for the above stated reason. So color based segmentation could not be used in this algorithm. Since the system should be able to operate in any working conditions, light is a primary concern.

So a modified threshold algorithm called adaptive threshold is used in the proposed system. In this algorithm, threshold value varies for each individual pixel based on the gray level values of surrounding pixels. Width of red band is generally 0.5mm to 1mm. So a 5x5 matrix of surrounding pixels is considered for every pixel for which a threshold is calculated. Threshold value for each pixel is calculated using the formula

$$T_{(x,y)} = \frac{1}{n^2} \sum_{i=x-2}^{x+2} \sum_{j=y-2}^{y+2} P_{(x,y)} - c \qquad (1)$$

Where
$P_{(x,y)}$ is the pixel value at (x, y).
N is the value to define a *nxn* square matrix around the pixel at (x, y).

C is a constant subtracted from the mean weighted average. $T_{(x,y)}$ is the threshold value calculated for the pixel at (x, y).

Threshold operation is done using the formula

$$if\ P_{(x,y)} > T_{(x,y)}\ then\ P_{new\ (x,y)} = Max\ value \qquad (2)$$

$$else\ if\ P_{(x,y)} > T_{(x,y)}\ then\ P_{new\ (x,y)} = 0$$

Max value is 255

Each pixel is changed to 0 or 1 based on the threshold value calculated using eq. (1).
After the above operation, a binary image is obtained. Now, the subject of interest is in white pixels on a background of black. To extract the band, connected components are calculated on the obtained image. Connected components are sequences of linked pixels. Here, sequences are extracted by finding the pixel values linked to each other. By calculating the number of sequences returned, the system takes a decision if the result is positive or negative or invalid. Results are time-stamped and then sent to the server

D. Storing patient details and result to the server

ABC001	P000001	23	F	MALARIA	NEGATIVE	Wed Aug 17 14:21:39 2016
ABC002	P000002	10	M	DENGUE	POSITIVE	Wed Aug 17 14:22:46 2016
ABC003	P000003	10	F	DENGUE	POSITIVE	Wed Aug 17 14:52:17 2016
ABC004	P000004	20	M	MALARIA	POSITIVE	Wed Aug 17 14:53:26 2016
ABC005	P000005	89	M	TYPHOID	NEGATIVE	Wed Aug 17 14:55:26 2016
ABC006	P000006	54	M	MALARIA	NEGATIVE	Wed Aug 17 15:50:40 2016
ABC007	P000007	15	F	MALARIA	POSITIVE	Wed Aug 17 16:20:48 2016
ABC008	P000008	84	M	DENGUE	NEGATIVE	Wed Aug 17 16:24:47 2016
ABC009	P000009	32	M	TYPHOID	NEGATIVE	Thu Aug 18 12:05:06 2016
ABC010	P000010	30	F	TYPHOID	NEGATIVE	Thu Aug 18 12:12:55 2016
ABC011	P000011	64	M	MALARIA	NEGATIVE	Thu Aug 18 12:13:43 2016
ABC012	P000012	51	F	TYPHOID	NEGATIVE	Thu Aug 18 12:14:58 2016
ABC013	P000013	16	M	TYPHOID	POSITIVE	Thu Aug 18 12:24:13 2016
ABC014	P000014	12	M	DENGUE	POSITIVE	Thu Aug 18 12:27:57 2016
ABC015	P000015	15	F	DENGUE	POSITIVE	Thu Aug 18 12:28:14 2016
ABC016	P000016	38	M	DENGUE	POSITIVE	Thu Aug 18 12:29:04 2016
ABC017	P000017	39	F	MALARIA	NEGATIVE	Thu Aug 18 12:33:51 2016
ABC018	P000018	34	M	TYPHOID	POSITIVE	Thu Aug 18 12:39:22 2016
ABC019	P000019	46	M	MALARIA	POSITIVE	Thu Aug 18 12:40:23 2016
ABC020	P000020	27	F	TYPHOID	POSITIVE	Thu Aug 18 12:44:00 2016
ABC021	P000021	23	F	TYPHOID	POSITIVE	Thu Aug 18 12:44:54 2016
ABC022	P000022	19	F	DENGUE	NEGATIVE	Thu Aug 18 12:45:38 2016
ABC023	P000023	54	M	DENGUE	POSITIVE	Thu Aug 18 12:46:03 2016
ABC024	P000024	84	M	MALARIA	POSITIVE	Thu Aug 18 13:53:43 2016
ABC025	P000025	32	F	TYPHOID	POSITIVE	Thu Aug 18 13:54:32 2016
ABC026	P000026	65	M	MALARIA	POSITIVE	Thu Aug 18 13:55:28 2016
ABC027	P000027	54	M	TYPHOID	NEGATIVE	Sat Aug 20 14:39:00 2016
ABC028	P000028	26	M	TYPHOID	NEGATIVE	Sat Aug 20 14:39:35 2016
ABC029	P000029	48	F	DENGUE	NEGATIVE	Sat Aug 20 14:53:46 2016
ABC030	P000030	23	M	MALARIA	NEGATIVE	Sat Aug 20 14:54:31 2016
ABC031	P000031	26	M	TYPHOID	NEGATIVE	Sat Aug 20 14:55:29 2016
ABC032	P000032	6	F	DENGUE	POSITIVE	Sat Aug 20 14:56:28 2016
ABC033	P000033	8	M	MALARIA	POSITIVE	Sat Aug 20 14:57:11 2016
ABC034	P000034	51	M	TYPHOID	NEGATIVE	Sat Aug 20 15:22:13 2016
ABC035	P000035	59	M	MALARIA	NEGATIVE	Mon Aug 22 12:10:07 2016

35 rows in set (0.00 sec)

mysql>

Fig. 5: Screenshot of database showing the patient details and test result

A LAMP server is designed on Ubuntu 14.04 32-bit system. Apache is used as server, Mysql is used as database and PHP is used for scripting. As soon as results are obtained, a program sends the patient data and corresponding image to the server. Server database is updated every time a new test result is obtained. Samples which are already tested in laboratory are checked on this device and the results are uploaded to database.

Doctor login from a different region would show the above database.

III. EXPERIMENTAL ANALYSIS

We configured the Raspberry pi board with the required version of operating system, and libraries, i.e. OpenCV, GTK+. OpenCV provides the necessary libraries for image processing. Camera is integrated with the board in such a way that it is triggered only after all patient details are filled in. All the different modules of software and hardware are tested recursively to obtain a fault-proof system.

Fig. 6: Binary image showing the region of red band

After image processing, high frequency noise is removed to obtain a smoothened image. Modified adaptive threshold algorithm used in this system gives the accurate result. As seen in fig.6 the red band is identified and, marked in green color. We tested each sample recursively to determine system's reliability and repeatability. Binary image is shown in fig for a negative sample of Malaria test.

IV. ALGORITHM

The proposed automated system implements the following steps. Steps 1-3 are to be done by the user.

1. Placing RDT in the RDT holder
2. Clicking "NEW TEST" widget on GUI to take in the patient details
3. Filling in the Patient details
4. Camera is triggered automatically after patient details are filled in.
5. Image is captured and saved to the device.
6. Preprocessing: removal of high frequency noise using Gaussian smoothening filter.
7. Conversion of 3-channel image to single channel gray scale image
8. Applying modified adaptive threshold to obtain a binary image, thereby isolating the subject of interest.
9. Finding the linked pixels in the binary image to extract the sequence, i.e. the required red band.
10. Decision making: based on the sequences extracted from the binary image, system takes the decision about the test in place.

V. CONCLUSION

Above proposed system can be used to read, interpret and maintain Electronic Health Record (EHR) at a low cost in point-of-care diagnostics. Relying on embedded vision to interpret RDTs makes the system fault-proof and reliable. By integrating the system to server, it helps in maintaining Electronic Health Record (EHR). A medical professional can remote-login from a different geographical position to monitor, trace and can even keep a quality check. Thus, the device can aid in point-of-care diagnosis.

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BIOGRAPHY

Ms. Blessy Navara is currently pursuing her M.Tech in Embedded systems in JNTU. She received her B.Tech Degree in Biomedical Engineering from JNTU, Andhra Pradesh. Her subjects of interest are Biomedical Engineering, Image Processing and Embedded systems.

Mr. B. Sivarama Rao received his Bachelor's degree from SRKR Engineering College. He received his Masters from IISc Bangalore. He worked in Advanced Engineering Group in the R&D of TVS Motors. His key area of research is Embedded Systems. He is currently working as Associate Professor in Raghu Engineering College