On-Board Touch Screen Graphical Interface Design For SoC-Based Arrhythmia Detector

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Abstract—Heart monitoring system is a device to carry out electrocardiogram (ECG) test. It can diagnose human's heart either in normal or abnormal condition based on ECG analysis. However, most of the current ECG device is bulky, expensive and lack of a user-friendly graphical user interface (GUI) for user interaction. This paper describes an on-board GUI design based on capacitive touch-screen Liquid Crystal Display (LCD) display. It is integrated with the in-house design of ECG processing unit and arrhythmia classifier to form a complete System-on-Chip (SoC) based arrhythmia detector. The whole system is implemented on the Altera Video and Embedded Evaluation Kit with Multi-Touch (VEEK-MT) FPGA development board. The touch screen GUI acts as a front-end menu to capture user input and retrieve the offline ECG data stored in external SD card, as well as back-end result display in terms of arrhythmia classification result, ECG raw signal display, and R-R interval. Prototyping result shows that this system is light-weight, cost-effective and suitable to be user for different groups of user according to their knowledge background, including patient, nurse, physician and cardiologist.

Keyword— ***Capacitive Touch Screen, Electrocardiogram (ECG) device, Graphical User Interface (GUI), Liquid Crystal Display (LCD), System-on-Chip (SoC)***

I. INTRODUCTION

Nowadays, the volume of Electrocardiogram (ECG) recorded in hospitals is increasing each year due to high population of people suffering from heart diseases [1]. Heart disease becoming a well-known phenomenon which even a teenager also have risk to get heart disease attack. Therefore, frequent heart condition checking is good in enhancing life care and health quality [2].

ECG is one of the non-invasive clinical methods that can measure the heart rate and diagnose abnormal condition of the heart [3, 4]. However, most of the commercial ECG device is bulky, expensive and mostly available in specialist hospital in urban city. Moreover, most of the ECG device does not equip with user friendly feature that help medical officer or medical assistant in ECG interpretation for heart disease screening. All aforementioned issues not only create burden to medical personnel serving in general hospital, but also to patients who are residing in rural area who suffer from long distance travelling to specialist hospital in urban city and long queuing to seek cardiologist consultation [5-7]. At the end may be it turns out that their heart condition is totally normally, which a lot of time and effort has been wasted.

This paper describes the development of an on-board graphical user interface (GUI) design based on capacitive touch screen Liquid Crystal Display (LCD). It acts as the front end user friendly interface to capture user input and display the arrhythmia classification result and related graph analysis. After integration with the in-house design of ECG processing and arrhythmia classifier, the complete portable System-on-Chip (SoC)-based arrhythmia detector is implemented on Altera Video and Embedded Evaluation Kit with Multi-Touch (VEEK-MT).

Advantages of this proposed system are it is fully standalone, light-weight, and portable. Besides, it is also cost-effective to general hospital or clinic as a heart disease screening device to improve health care service delivery. They could only refer the potential patient to seek cardiologist consultation in specialist hospital which normally require long distance travelling and long queuing, if the arrhythmia classification result turns out positive which indicates the patient may have risk to get heart disease. It is also affordable by normal user especially for aging patient to check their heart condition by capturing abnormal heart event directly at home [8]. As a result, it not only could reduce workload of nurse and medical staff in the specialist hospital but also improve the health care service quality in general hospital especially in rural area.

II. RELATED WORK

Capacitive touchscreens are more popular these days due to its high performance and high sensitivity compared to resistive touchscreen. Since human body is conductive, it will result a distortion of the screen's electrostatic field and then change in capacitance when human touch the screen surface [9]. Location of the touch can be determined by different technologies and sent to the microcontroller for processing. However, capacitive touchscreen cannot be used with a mechanical stylus or a gloved hand because it is not

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conductive and hence cannot detect changes of electrostatic filed. Besides, they are generally more expensive.

GUI is a type of human computer interface to allow user to point mouse or cursor to a particular graphical icons and visual indicator, causing a hidden list of commands to be automatically executed. The main advantages of GUI is it create a richer and intuitive interface so that the user could interact with the underlying system. Besides, learning curve of GUI is also shorter which is suitable for a new user. In addition, it consists of multi-view ability compared to command line interface (CLI). However, GUI is generally not efficient in executing low-level control and advanced commands compared to CLI.

One of the previous research done by Yati *et.al* [10] stores offline dataset at USB portable device and plugged into the ECG biomedical embedded system (ECG-SoC). Then, the offline dataset is executed for ECG pre-processing and Heart Rate Variability (HRV) feature extraction. In each execution stage, intermediate output files are generated to plot the result in graph form and finally display on host PC using Matlab. One of the limitations of this research is it lacks of a user-friendly GUI as it relies on CLI running in uC-linux terminal to retrieve the offline dataset, to display the processing status and analysis result. Besides, this embedded system is also not fully standalone system because it depends on host personal computer (PC) to display raw ECG data graph and R-R interval graph.

In terms of commercial ECG devices such as Welch Allyn CP 150 [11], their advantages are it contains an advanced filter that can take an accurate reading of optimal ECG trace quality, able to store up to 100 test results on the device or transfer to a USB memory stick, and quick ECG readings with self-interpretation. However, the devices are bulky and expensive, and lack of user-friendly GUI in helping non-expert user in ECG interpretation. Besides, its screen is small so is difficult for doctor to view the ECG signal. In addition, it is resistive touch screen and not sensitive compare with capacitive touch screen.

III. ON-BOARD FRONT END TOUCH SCREEN GRAPHICAL INTERFACE DESIGN

Fig. 1 shows the top-level system architecture of the SoC-based arrhythmia detector after integration with the in-house ECG processing unit and arrhythmia classifier. The system architecture consists of Nios II processor and few standard peripherals. The Nios II processor acts as the system top level controller to execute the embedded operating system (uC-OS II), peripheral device driver and ECG processing software module. Each of the peripheral is communicate to each other through Avalon System Interconnect Fabric. In this paper, the authors focus on the description of GUI design which mainly consists of SD card controller, multi touch controller and LCD controller as well as their associated device drivers.

Fig.2 shows the functional process flow of the complete system implemented on the Altera VEEK-MT FPGA development board. As shown in Fig. 2, the on-board touch screen GUI for SoC-based arrhythmia detector consists of five main menus which are *Welcome* menu, *Patient ID* menu, *Information* menu, *Computation* menu and *Result* menu. The *Welcome* menu is the first screen display when the system is power-up and ready for the ECG analysis. The *Patient ID* menu retrieves patient information and associated offline ECG record that stored in an external SD card based on a unique user ID. The *Information* menu displays the patient personal information from the retrieved patient file. After that, *Computation* menu send commands to the Nios II processor to start ECG processing and arrhythmia classification and displays the computation status. Lastly, the *Result* menu displays the arrhythmia classification result and graphical analysis in terms of ECG raw signal and R peak detection.

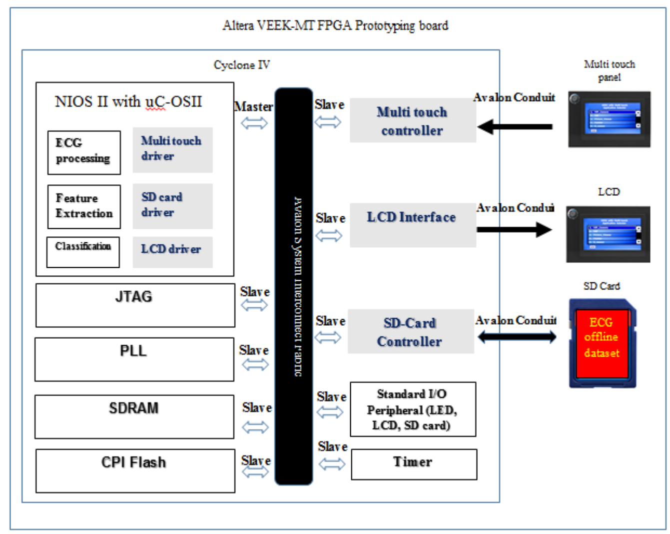

Fig. 1. Top-Level System Architecture

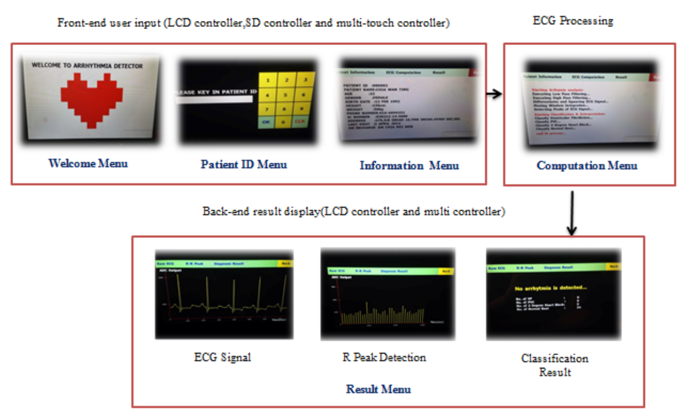

Fig. 2. Functional process flow

Fig. 3 shows the top-level application subroutine functional diagram of the SoC-based arrhythmia detector which corresponds to the functional process flow as shown in Fig. 2. It utilizes many standard header files (e.g. *stdio.h*, *string.h*, *stdlib.h*, etc) to provide the standard C functions. In addition to that, since the GUI development of each menu will utilize the multi-touch controller, LCD controller and SD card controller, their associated device driver header files, such as *multi_touch.h* to support touch screen interface, *alt_tpo_lcd.h* to support interface with LCD controller, *simple_graphics.h* to support simple graph plotting routines on LCD display, and *sd_controller.h* to support read/write operations to/from a SD card through the help of uC-OSII in FAT file management system provided in *fat_file.h* and *fat.h* are also included.

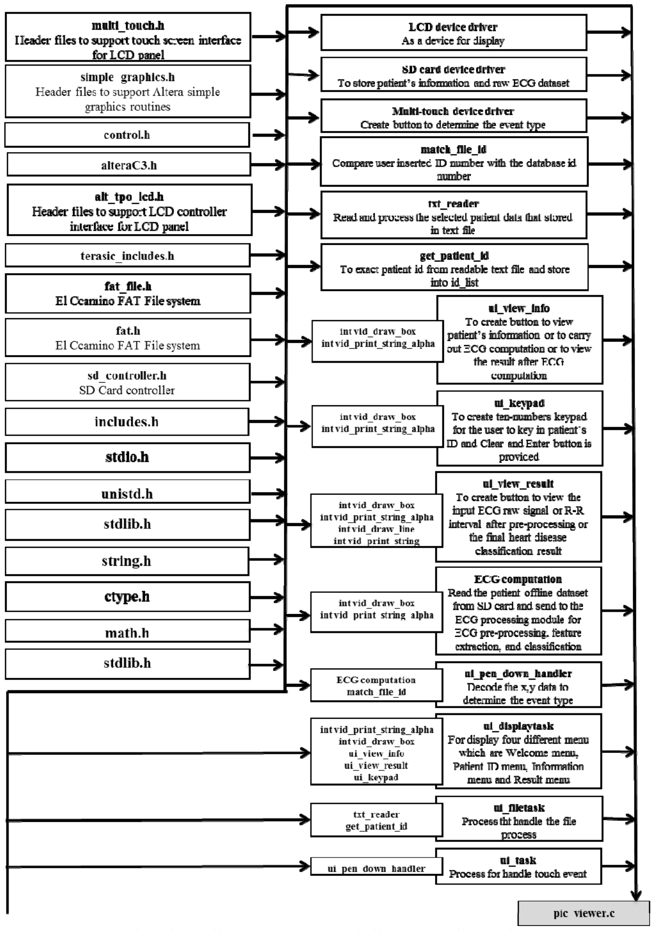

Fig. 3. Top-level application structural diagram of SoC-based Arrhythmia Detector

The authors develop the application program in *pic_viewer.c* as top-level application file. The functionality of each menu is described in *ui_view_info*(), *ui_keypad*(), *ui_view_result*(), *ECG_computation*(), respectively, which later will be called by the *ui_displaytask()*. A lot of lower level functions has been called, such as *ui_task*() to handle the touch event, *ui_pen_down_handler*() to decode X and Y coordinates from touch-screen location, *ui_filetask*() to handle the file reading/writing process, and so on. All these lower level functions utilize the underlying controller device driver functions, which will be further described in following subsections.

A. SD Card Controller

SD card is used to store patient's information and patient's raw ECG data. The patient's information stored in the SD card is retrieved and display on thin-film-transistor (TFT) LCD touch screen (subsystem of VEEK-MT) after user keys in the correct user ID. Whereas, patient's raw ECG data in SD card is stored in an array and is used in the ECG computation and ECG graphs display. Fig. 4 and Fig. 5 show the device driver structural diagram and process flow chart to open a file from SD card, respectively.

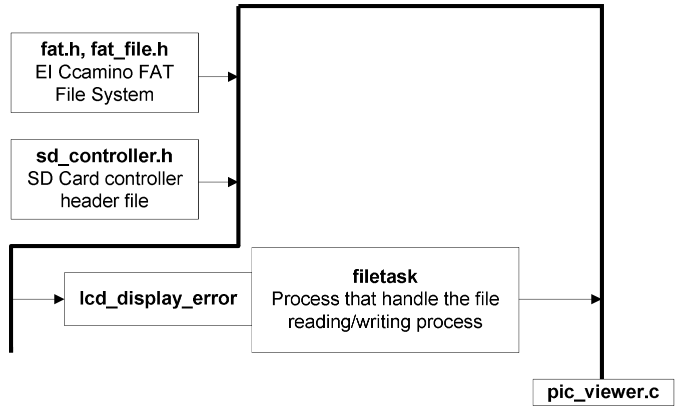

Fig. 4. Structural diagram of SD Card Device driver

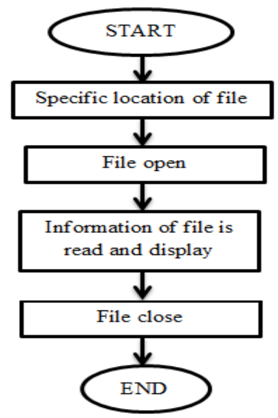

Fig. 5. Behavioral flow chart to open a file from SD card

B. Multi touch controller

Fig. 6 shows the structural diagram of multi-touch controller device driver, which recognize the presence of one or more than one points which contact with the screen surface. It is used in multiple menu development to capture user input for operation selection. For example, in *User ID* menu, the user could select to insert a unique patient ID by pressing ten-digit keypad, press the *Clear* button to reset the user ID, press *Enter* button to confirm the number, or press the *Back* button to go return to *Welcome* menu.

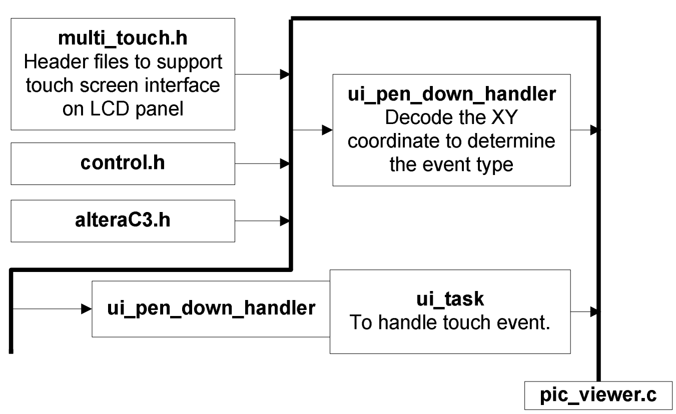

Fig. 6 Structural diagram of Multi-touch device driver

The main function of the multi-touch controller is the *ui_task*() which handle the touch event by calling respective handler function to respond to user interaction on screen. For example, it will call the *ui_pen_handler*() to determine the XY coordinate and event type when the capacitive screen is touched to determine the next operation. Fig. 7 shows the behavioral flow chart to create a touch box on LCD screen to capture user input in certain XY coordinate.

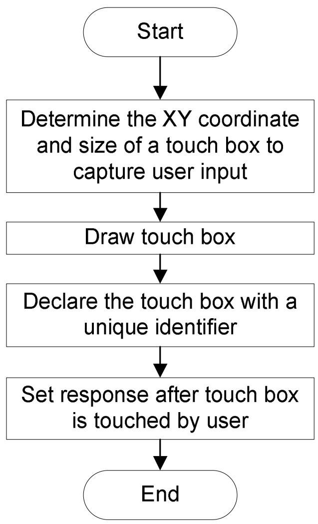

Fig. 7. Behavioral flowchart to create a touch box on screen

C. LCD controller

LCD acts as a device to display different menu on touch screen including *Welcome* menu, *Patient ID* menu, *Information* menu and *Result* menu. LCD is important in this system. Without LCD, patient's information which read out from SD card will not have device to display and touch box that created do not displayed on touch screen and also cannot be controlled by user.

Fig. 8 shows the device driver structural diagram. The main function of the LCD controller is the *display_task*() which display the expected designed layout on LCD screen, by calling the lower level functions, such as *vid_print_string*(), *vid_draw_box*() and *lcd_display_error*().

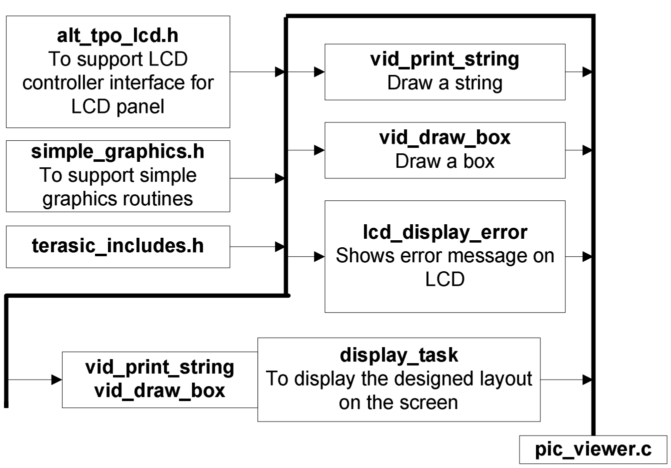

Fig. 8 Structural diagram of LCD device driver

IV. Result and Discussion

A. Welcome menu

After the system is reset or power-up, the first *Welcome* menu will be shown on LCD touch screen as shown in Fig. 9. This *Welcome* menu acts as a starting menu to welcome user and begin the heart rate detection process. The user needs to touch any part of the Welcome menu to enter next *Patient ID* menu.

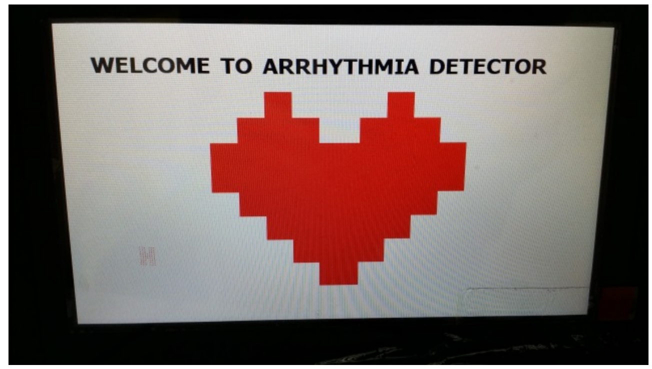

Fig. 9 *Welcome* menu

B. Patient ID menu

Fig. 10 shows the *Patient ID* menu which consists of a ten-digit keypad for the user to key in the patient's ID. The number that is keyed in by the user will be displayed in the text box. If the user finds that he has keyed in wrong number, he can touch *CLR* button to reset the number, or the user can confirm the number by pressing *OK* button to enter next *Information* menu.

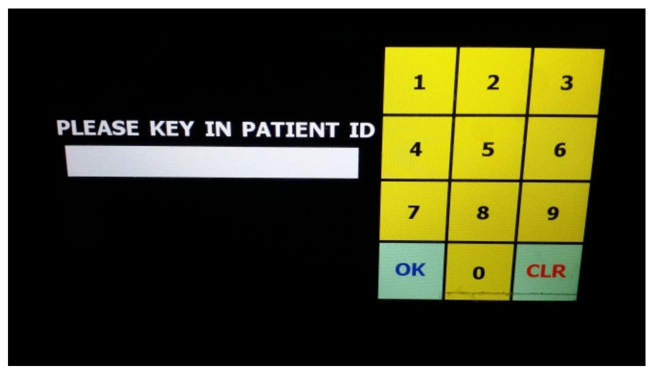

Fig. 10 *Patient ID* menu

C. Information menu

In the *Information* menu, if the inserted patient ID in the previous *Patient ID* menu is correct and verified by registration database stored at SD card, then the patient information will be shown on the LCD as shown in Fig. 11, otherwise "UNKNOWN PATIENT ID" will display to remind user that his/her ID is typed wrongly.

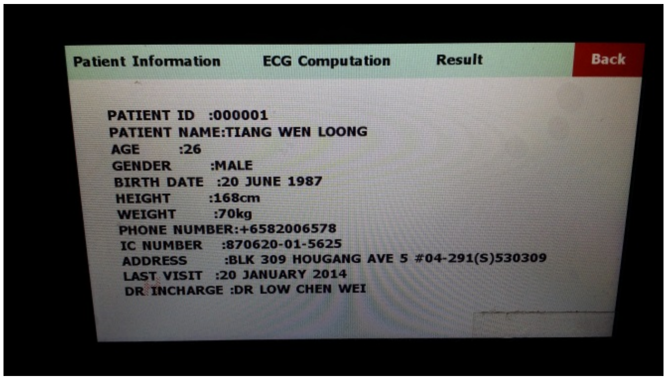

Fig. 11 *Information* menu

As shown in Fig. 11, there are four touch buttons on the top of the *Information* menu as shown in Fig. 11. The first button is patient information button to ensure the user can return to view the patient detail information. The *ECG Computation* and *Result* buttons is to enter the *Computation* menu and *Result* menu, respectively. Lastly, this menu consists of *Back* button to enable user return back to the *Patient ID* menu to retriever other patient file.

D. Computation menu

The *Computation* menus send the user commands to Nios II processor to start computing the in-house design of ECG pre-processing, feature extraction, and arrhythmia classification [12]. Along the computation, the computation status will be displayed as shown in Fig. 12. After the computation process is completed, the user can touch the *Result* button to view ECG analysis result.

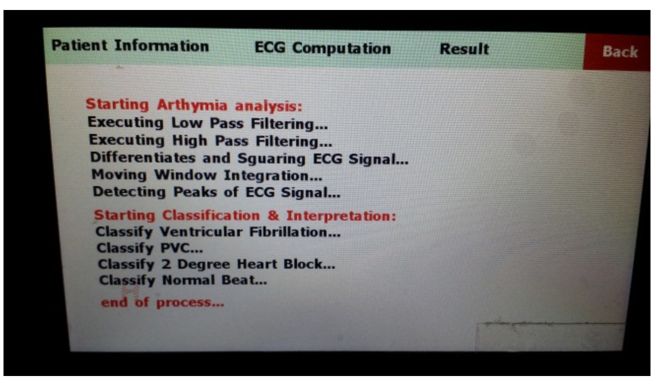

Fig. 12. *Computation* menu

E. Result menu

In *Result* menu, it consists of four main buttons. The user could select to display the input ECG raw signal (Fig. 13) retrieved from offline ECG dataset stored at SD card, or R-R interval after ECG pre-processing and feature extraction are completed (Fig. 14). For non-expert user, they could choose to directly view the final heart disease classification result as shown in Fig. 15. For example, Fig. 15 shows that a particular patient has a risk of arrhythmia because PVC is detected. Therefore, this patient should be referred to specialist consultation as soon as possible. A *Back* button is provided in this menu to ensure user can go back to the *Patient ID* menu.

Fig. 13. Graph of raw ECG data

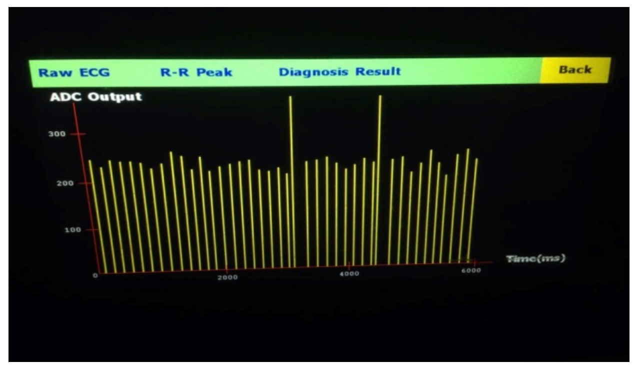

Fig. 14. R-R interval graph

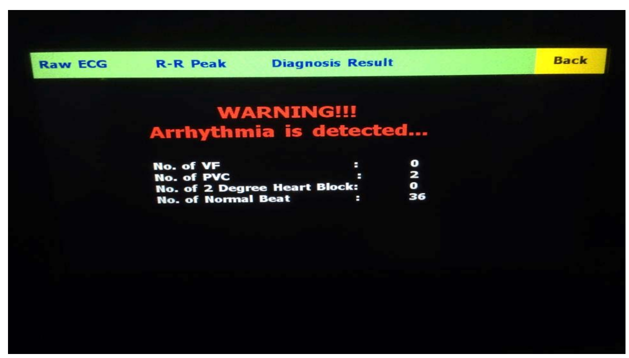

Fig. 15. Heart disease arrhythmia classification result

This design is highly portable as it is implemented into an FPGA and the screen display is scalable to fit the device. The limitation of this system is it can only process 6000 ECG dataset which is 30 seconds data due to memory limitation. Moreover, only 640 out of 6000 ECG dataset can be used to plot the raw ECG and R peak detection graphs due to its resolution (480×800). In addition, the current system can only process one offline ECG data attached to one patient due to the current patient file management stored at SD card is not structured and organized.

V. CONCLUSION

This paper has presented a front-end on-board graphical interface design for System-on-Chip (SoC) based arrhythmia detector after integration with the in-house design of ECG pre-processing, feature extraction and arrhythmia classifier. Result has shown that this device is highly portable as a quick screening tool to detect cardiac activity anywhere, anytime, within seconds. Besides, it is cost-effective which affordable by different groups of user, and light-weight comparing to the current ECG monitoring system which are very bulky and expensive. The future works for this system including improvement on *Patient ID* menu, and design a structured and organized patient file management stored at SD card, so that the system could process more than different ECG dataset attached to each patient based on user selection. In addition to that, the display on graph analysis could be further improved to fit the whole ECG graph into LCD touch screen instead of selected 640 out of 6000 ECG dataset. If whole ECG graph can fit into LCD touch screen, the zooming function can be included to make this system become more interactive.

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