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Multistage Air Bubble Detection and Fluid Analysis for Dialysis Machines

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Abstract:- One of the prevalent diseases that leads to accumulation of waste in the body is the acute and chronic renal failure. Until the illness lasts, dialysis is the primary option to remove waste from the body. In the process of dialysis, fluids are transferred via tubing or other conduits. It is very important to know and control the characteristics of fluid prior to infusion into the patient. Bubbles can be created or may appear during intravenous infusion into the patient's body. Even if small amount of air is infused into the patient, they block the tiny blood vessels in the body (blocking oxygen and nutrients). Oxygen deprivation to any of the sensitive organs can result in lethal consequences. In addition, it is necessary to know the type of fluid flowing through the tubing. This paper presents a multistage approach to detect the air bubbles, the type of fluid in the tube and finally remove the air bubbles. The air bubbles and the type of fluid are sensed using Machine Learning model based on TensorFlow, Infrared Transmitter and Receiver, Laser Transmitter and Receiver. The STM32F401 Nucleo-64 RE (MCU) controls all operations and ensures that air bubbles are not infused into the patient by controlling the valves and the pump. The use of more suitable and efficient technologies will enhance medical aid and minimize therapy complications.

Keywords:- *Air bubble Detection, Dialysis, Fluid Analysis, Infrared, Laser, Machine Learning, Multistage detection, Processing-3, STM32 microcontroller.*

I. INTRODUCTION

Dialysis is the process of removing excess toxins, water and other solutes from the blood in people whose kidneys can no longer work efficiently. Hemodialysis, Peritoneal dialysis and acute dialysis involve one or the other forms of fluids running through the fluid lines like blood, dialysate, saline, etc. It is very important to detect and remove air bubbles from the fluid lines. If fluid with air embolisms is pumped into the patient's body, the air embolisms can block the narrow blood vessels leading to deprivation of oxygen to cells leading to death of cells and the consequences can be lethal. Detection of air bubbles and determining the type of fluid flowing in the tubing accurately is the main idea of the project; it is followed by the removal of air embolisms from the tubing. This completes the entire model of sensing, determining the threat and taking the correct action to remove the threat.

Machine learning involves preparing the software program perform a task on its own without explicitly programming and setting the rules. The model is programmed using python with TensorFlow as the primary machine-learning library. It is trained with predefined images of bubbles to recognize similar bubbles in the new images/frames captured by the camera in real-time. The accuracy of the model increases with the training and the model can be improvised and customized by the programmer.

Infrared light is a type of electromagnetic radiation with wavelength greater than that of visible light. The main advantage of using infrared in this application is that the light passes through the walls of the tubing and all kinds of fluids flowing in the tubing like blood, dialysate, water with ease and provide intensity variation for any kind of changes (e.g.: air bubbles, clots) in the fluid flowing in the tubing.

Laser light is known for its coherence, this property allows laser light to stay narrow and focused over long distances. The air bubbles and the type of fluid flowing in the tube can be determined by measuring the intensity variations at the receiver end. The whole setup is encased in an opaque case. The Signal to Noise ratio while using this technique is very good and it produces variations even for the smallest air bubble. MCU processes the conditioned signals of all the sensors and takes appropriate decisions to ensure that air bubbles are not infused into the patient.

II. METHODOLOGY APPLIED

The primary sensing technologies include Machine-learning model based on TensorFlow to capture real-time data from the camera and detect bubbles, infrared transmitter and receiver-based sensing and the final detection technique is by using laser transmitter and processing the intensity variations at the receiver for detecting bubbles. The STM32F401 Nucleo-64 RE is used as a primary Microcontroller unit for all operations. It controls all the operations, Analog to Digital conversions, timings, reading inputs from the sensors, controlling the pump and the valves. The pump and the valves control the flow of fluid into the patient and the drain bag (part of fluid with air embolisms will be pushed into this bag). A graphical user interface to know the real -time state of the machine is developed using Processing-3.

III. EXPERIMENTAL DETAILS

Circuits for sensing the type of fluid and air bubbles in the flow lines using infrared transmitter and receiver and laser transmitter and receiver are designed. The output signal is conditioned (filtered and amplified) and is fed to the MCU.

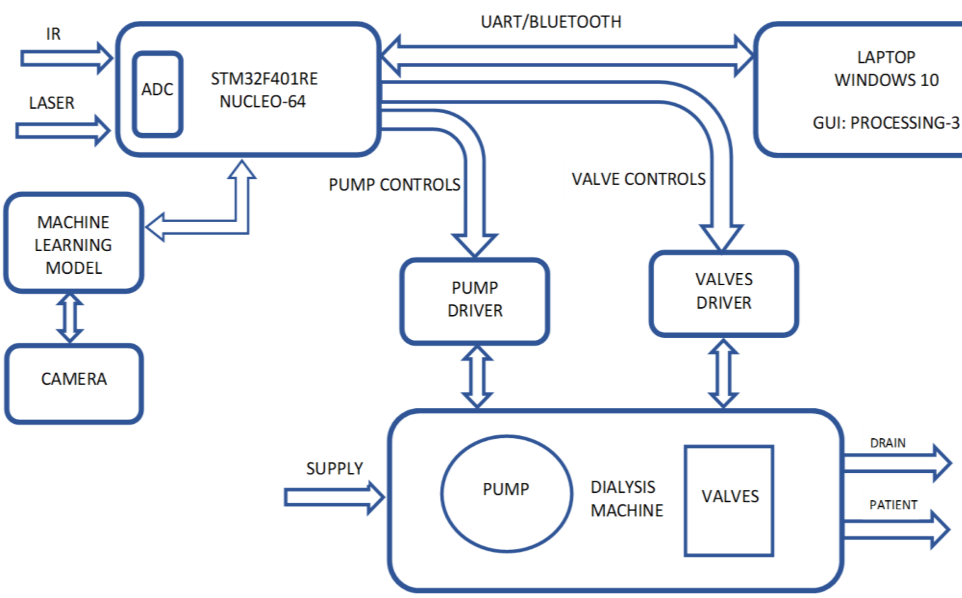

Fig 1:- Overall block diagram of the entire system

A Machine-learning model is programmed in in python using TensorFlow to detect bubbles in the flow lines. The data pre-processing includes training images are collected and then LABELIMG is used to label the detectable portions (Bubbles). The file formats are Inter-converted and TF records are generated. FASTER_RCNN_RESNET101_COCO is selected for its precision to detect even small bubbles with moderate speed. The model is trained for detecting bubbles and the progress is monitored on the TensorBoard. After training a python program is generated for capturing data in real-time from camera and tested.

STM32F401 12-bit internal ADC is used to covert the analog signals from the sensors to digital signals. The data from all the different sensing models is processed in the STM32 appropriate decisions are taken based on the signal. If an air bubble is detected, the valves and motors are controlled in such a way as to push the fluid with bubbles into the drain bag and send only the fluid without air embolisms to the patient.

An application is built in the computer using 'Processing-3' to give a real-time indication/description of the current state of the machine, the type of liquid fluid flowing pipes, the state of the motor, the state of the valves, the approximate size of the bubble, indications of the bubbles detected, etc.

IV. RESULTS AND DISCUSSION

The Infrared sensor gives voltage variations in Millivolts for small bubbles, filtered to detect variations and amplified. The DC voltage level is used to detect the type of liquid i.e. Water, Dialysate and Blood's equivalent. This method of sensing is used to detect air embolisms and the type of fluid in wide range of fluids like blood, dialysate, saline, water and various other fluids.

The Laser receiver gives good voltage variations for bubbles. The SNR is very good as compared to the infrared even when the received signal is in millivolts. The DC voltage level at the receiver is used to detect the type of liquid i.e. Water, Dialysate and Blood's equivalent. This method can only be used in fluids that are colourless (or slightly coloured) and provides good SNR for even tiny variations due to small bubbles.

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The ADC of the MCU reads these voltage levels from these sensing units and based on the thresholds set, it takes appropriate decisions to remove the bubbles by controlling the motors and the valves. It also communicates the decisions to the GUI via UART communication. The GUI gives a real-time display/description of the current state of the machine, the type of liquid fluid flowing pipes, the state of the motor, the state of the valves, the approximate size of the bubble, etc.

The custom machine-learning model trained to detect bubbles detects air embolisms with good confidence percentage. The better is the model selection for the application and the better the model is trained, the better are the results and even the smallest bubbles can be detected.

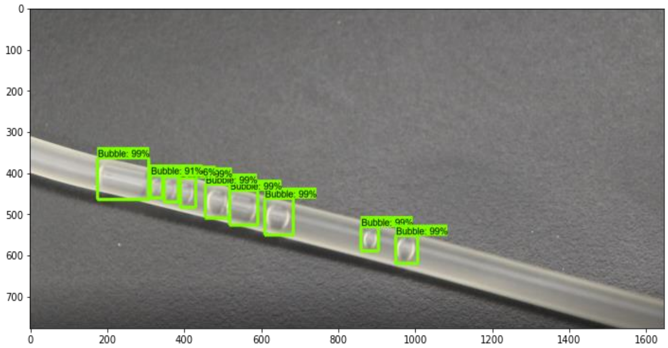

Fig 2:- Detection of air bubbles using the machine learning model with good confidence percentage

V. CONCLUSION

The main objective of the project is to enhance medical aid, improve medical technology and minimize therapy complications while performing dialysis. There are various types of dialysis and each of them are unique and the way the therapy is performed is unique. This project provides three ways to determine the air embolisms and each method has its own advantages and disadvantages for sensing the air bubbles in different types of fluids like saline, blood, dialysate, etc. The purpose of having three techniques for sensing is to determine which technique is most efficient and appropriate for a particular type of dialysis

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