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Designing Engineering System Multi Use Peristaltic Pump by 3D Printer

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Abstract: Peristaltic pumps are widely used in biomedical and industrial applications due to their precision, leak-free operation, and ability to handle sensitive fluids. However, optimizing their design for enhanced efficiency and durability remains a challenge. This study presents a 3D-printed peristaltic pump designed using a model-assisted approach to analyze pump performance before fabrication. The methodology involves numerical modeling, material selection for 3D printing, and experimental validation through pressure pulsation and volume displacement tests. Findings indicate that the proposed design improves flow rate consistency and reduces mechanical wear, making it suitable for biomedical applications and automated fluid control systems. These results highlight the potential of 3D printing in advancing peristaltic pump technology, offering cost-effective and customizable solutions for diverse applications.

Keywords: Peristaltic pump, 3D printing, biomedical engineering, fluid dynamics, model-assisted design, flow optimization.

Introduction

Pumps have a broad field of application and can be considered as energy transducers, converting primary kinetic energy (e.g., linear, or rotational motion of a rigid body) to hydrodynamic energy . A simplified view on the technical side of a pump reduces it into three main components which describe the operation principle [hydraulic pump very abstracted]: housing with fluid in- and outlet port, moving component(s) and transmission gear to drive the moved part via the primary energy source. Based on the operation principle hydraulic pumps, beside some exceptions like “the hydraulic ram” which uses the water hammer effect as primary energy source, can be categorized into two main groups, namely centrifugal pumps and (positive) displacement pumps. Schmitz and Murrenhoff gives a good overview of hydraulics in general. Centrifugal pumps have an open fluid connection from in- to outlet port, the impeller accelerates the fluid due to its rotational movement which causes centripetal forces (actio); in other words: the fluid is moved due to its centrifugal force caused by the impeller (reactio). In contrast to that, the in- and outlet ports of displacement pumps are disconnected by a sealing which is considered as “leak-free” flow, so the fluid volume “the displacement” is encapsulated and transported by the motion per turn. Some pumps of this kind have multi-sectioned and even parallel, and phase shifted displacement to smooth the flow rate and, consequently, reduce pulsations. The most common types of displacement pumps are gear pumps, screw pumps, rotary vane pumps, as well as piston pumps, which can further be divided into axial and radial piston pumps and, finally, peristaltic pumps . Except for peristaltic pumps, these displacement pumps have several features in common. The dynamic sealings, which enclose the displacement, are usually not intended to be made of soft materials and, therefore, consist of long and tight sealing gaps. Consequently, an acceptable amount of leakage occurs. Lower leakage requires more precise manufacturing and is expensive. The fact that such pumps mainly consist of rigid components with significantly higher strength than soft materials, higher maximum pressures ($p > 21$ MPa) can be withstood compared to peristaltic pumps. The figure shows the main principle components of a peristaltic pump with three rollers including a cross-section of it.[1]

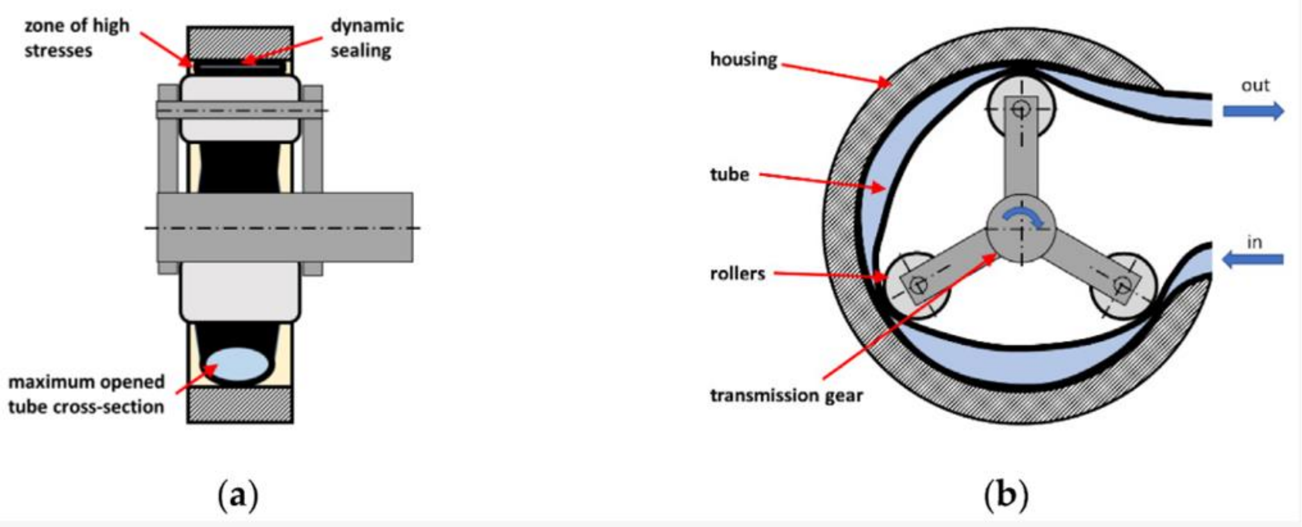

Fig1.1: Flexible tube based peristaltic pump principle with 3 rollers; (a) cross-section of the pump in frontal-view; (b) cross-section of the pump in side-view.

PERISTALTIC PUMPS

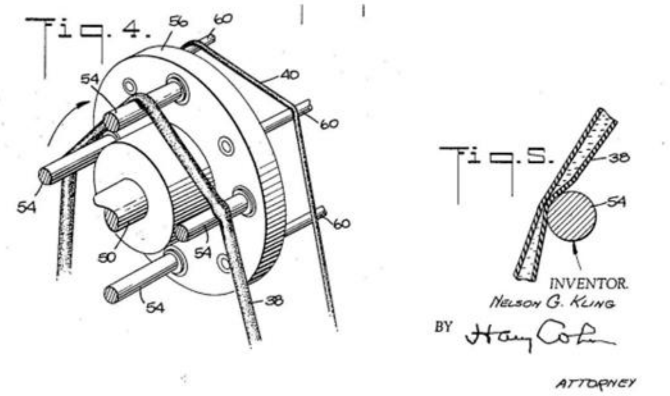

Fig1.2: Design illustration of Kling’s peristaltic pump design without a backplate.[2]

A peristaltic pump is one in which pumping is accomplished by pinching or squeezing the walls of a tube which contains material to be pumped such that the tube is collapsed shut at successive points along its length. In some forms, the pump tube is resilient, and in relaxed condition is maintained substantially cylindrical in cross-section by its renitence. When such a tube is used in the most common pump form, the form in which a cam presses the tube against a cylindrical inner wall, the tube becomes distorted. It tends to be stretched and twisted with each cam pass. The effect of that is twofold. The stretching reduces tube life, and the twisting causes the tubing to change its position in the pump housing, complicating housing design and increasing opportunity for malfunction. Most peristaltic pumps employ more than one cam, usually in the form of rollers, which rotate around a fixed axis. The pump tube is flexible and usually is resilient. Its ends are fixed relative to the axis of cam rotation. The mid-region of the tube is extended around the cam set in the plane of can set rotation. In some cases the tube is not forced against the wall of the pump cavity. Instead, the tube is stretched so tightly that it is pinched closed at the point engaged by the cam. In the region between the points of can engagement, the tube lumen is open to accommodate fluid. In other cases the tube is housed in a circular, usually cylindrical, cavity, and the tube is pinched shut at the point of engagement by the cam because the cam presses the tube against the circular cavity wall. In either case the tube is formed into a partial loop, into hairpin or horseshoe shape. The inner circumference is less than the outer circumference. If the tubing was formed as a straight length it must twist along its length when bent to horseshoe shape to compensate for the difference in inner and outer circumference. When the resilient tubing is squeezed closed the ratio of circumferences is changed and the renitence of the tube wall urges a reduction in the degree of twist. If, on the other hand, the tube is formed in horseshoe shape, if it assumes that shape when relaxed, then squeezing it to reduce the difference between inside and outside circumferences will urge twisting in an opposite direction. Thus it is that twisting is urged during pump opera tion whether the tubing be bent during installation or preformed to the shape it has when installed in a pump. It is true whether the tube is pinched by pressing it with the cam against a confining circular wall which encom passes the tube over its length, or whether the tube is pinched by the cam stretching the inner wall to meet the outer wall of the tube. The latter arrangement results in large forces tending to pull, then push, the ends of the tube in the direction of flow, and, partly for that reason, most peristaltic pumps include the encompassing wall. Even in such pumps, the forces that are exerted on the structures that hold the tube ends in place are sufficiently large to shorten tube life and to influence the design of the entire pump structure. The combined effect of the twisting and pulling of the pump tubing during pumping is to cause the tube to tend to move back and forth in the direction of the axis of cam rotation. In some cases that movement is sufficient to result in rubbing of the tubing against the end walls of the cavity in which the cam and tube are housed. The invention provides a pump and pump tube in which these several problems are minimized.[3]

PUMP DESIGN

There are two functional designs for peristaltic pumps. The pumps can be build either in a rotary or in a linearly manner. The common design is the rotary peristaltic pump that uses revolving contact elements to periodically compress the tube. These pumps are also referred to as roller pumps, since primarily rollers are used as contact elements. In most cases the tubing is placed in a raceway implemented in the pumps housing and aligned around a rotor with multiple rollers that press against the tube. To get the pump working without backflow, there are at least two opposing rollers necessary. Using more rollers will result in lesser pulsation but will increase the wear of the tubing as well, since there are more occlusions in the same time . In linear peristaltic pumps the tubing is placed flat on a platen and sequentially compressed by a peristaltic mechanism. The peristaltic mechanism consists of a set of at least three translational actuators and is usually driven by a camshaft.

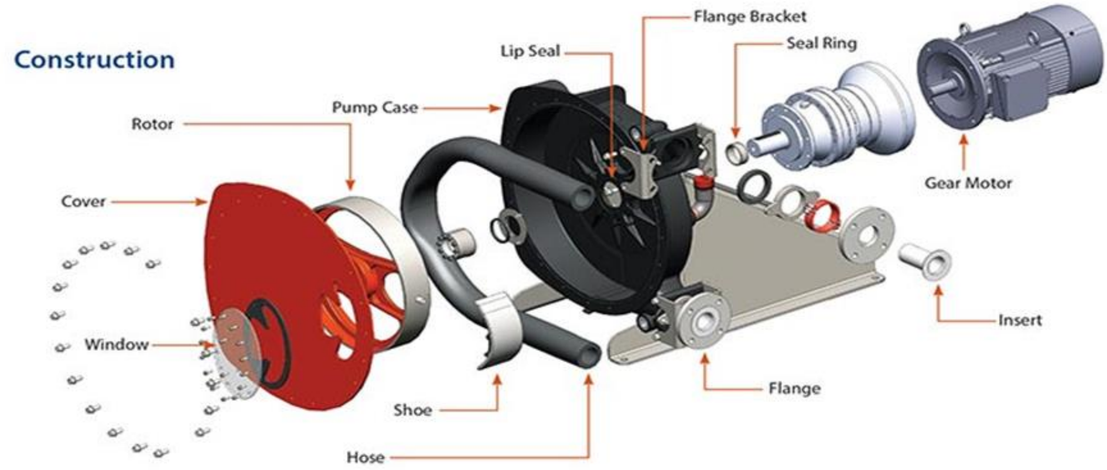

Fig1.3: The seal-free design and construction of peristaltic (hose) pumps makes them dry-run, self-priming and low-slip capable, and may eliminate the chance that leak paths will form or cross-contamination points will be created. [4]

Linear peristaltic pumps are found mainly in niche applications for medical purpose were accurate flow rate control is needed. The advantage of the linear peristaltic pump was clarified by Peek et al. as they studied the time to tubing rupture and the failure pattern of tubes in a rotary peristaltic pump . They identified three different failure patterns. Longitudinal creases are the result of multiple repeated folding of the tubing across its axis during the occlusion. Transverse tears and scallop-shaped defects in contrast indicate a high sheer stress on the tubing. In an additional experiment they showed that pure compression of the tube without sheering causes significantly less wear and did not initiate longitudinal creases. That means that in rotary peristaltic pumps the movement of the occlusion zone is responsible for the wear of the tubing. Therefore recalibration or changing of the tube is more often required than in linear peristaltic pumps. Hence the linear peristaltic pump provides better long term stability of the flow rate and better overall endurance of the tube.[5]

Types of Peristaltic Pumps

There are basically two types of peristaltic pumps [6]

- Hose pumps type peristaltic pump
- Tube pumps type peristaltic pump

The hose pump is designed to handle higher pressures. This implies the casing and process tube have to be stronger than that of the tube pump. The differences the hose pump exhibits from a tube pump can be listed as: thicker tubes (often called hoses), lubricant filled casings, larger pump size, and slower rotational speeds. To accommodate the larger forces, hose pumps tend to be larger than tube pumps and are made out of stronger materials. The single roller design with a 360 degree casing is more popular among hose pumps. Tube pumps often have a minimum of two rollers and can have as many as 12 rollers .[7]

Hose pump	Tube Pump
➢ Hose pumps work under high pressure, up to 10 bars. ➢ Casing and rollers are filled with lubricant to prevent abrasion and to dissipate heat. ➢ Reinforced tubes called 'hoses' are used and hence the name 'hose pump'	➢ Low pressure type. ➢ Casing and rollers are dry and use non-reinforced tube. ➢ Work below 5bars

Table1 : Difference between Hose & Tube pump[8]

CLASSIFICATION OF PERISTALTIC PUMPS BASED ON PRESSURE

Peristaltic Pumps are classified into two types based on the kind of pressure they use. They are:

High Pressure Peristaltic Pumps or Hose Pumps

These pumps are generally used in high pressure environment (up to 16 bar) and use shoes (rollers only used on low pressure types). They have casings which are filled with lubricants to help avoid damage caused by abrasion to the peripheral of the pump and to help dissipate the heat and hose pump are typically reinforced resulting in a very thick wall. For a given ID the hoses have much bigger OD than tubing for the roller pump .So that the liquids do not leak out of the tube due to the high pressures used while pumping. These reinforced tubes, often called "hoses". This class of pump is often called a "hose pump". This thicker wall, combined with a stiffer material typically used in the hoses make the forces necessary to occlude the hose much greater than for the tubing. This results in a bigger and slower pump (up to 50/60 RPM) and motor for a given flow rate with the hose pump than the roller pump, consuming more energy to run. The biggest advantage with the hose pumps over the roller pumps is the high operating pressure of up to 16 bars. With rollers max pressure can arrive up to 12 Bar without any problem. If the high operating pressure is not required, a tubing pump is a better option than a hose pump if the pumped media is not abrasive. With recent advances made in the tubing technology for pressure, life and chemical compatibility, as well as the higher flow rate ranges, the advantages that hose pumps had over roller pumps continues to erode.

Low Pressure Peristaltic Pumps or Tube Pumps

These pumps usually have dry casings and use rollers. Nonreinforced tubes are also used in these pumps because the pressure on the tubes is not very high. This class of pump is sometimes called a "tube pump" or "tubing pump". These pumps employ rollers to squeeze the tube. Except for the 360 degree eccentric pump design as described below, these pumps have a minimum of 2 rollers 180 degrees apart, and may have 8 or even 12 rollers. Increasing the number of rollers increase the frequency of the pumped fluid at the outlet, thereby decreasing the amplitude of pulsing. The downside to increasing number of rollers it proportionately increases number of squeezes, or occlusions, on the tubing for a given cumulative flow through that tube, thereby reducing the tubing life.[9]

Peristaltic Pump Advantages and Disadvantages

The **advantages** of the peristaltic pump are listed below.

- The first and important advantage of the peristaltic pump is in this pump, the operating fluid is saved from cross-contamination. Since the fluid is always enclosed in the pipe, it does not comes in contact with other parts of the pump. This saves the fluid from contamination or adulteration. This advantage specifically helps the pump to be used for medical procedures.
- Due to the mechanism of the pump, it allows precise control of the volume of the liquid to be transferred. The precise control allows the fluid to be filled in other containers and easily handled.
- Digital control of the pump. A digital signal processor can be embedded with the pump which enables the pump to have precise control. Precise control in the sense periodic release of fluid, control on volume, etc. Digital control also allows controlling the flow rate of the fluid, pressure, etc to be easily controlled.
- Electric Motor – Since the shaft is connected to an electric motor, this allows control over the volume of fluid. Since the speed of the motor can be easily controlled, it also controls the volume of the liquid to be transferred.

The **disadvantages** of the peristaltic pump are listed below.

The peristaltic pump has a limited number of disadvantages. One of them is the size of the hose pipe. This restricts the volume of the fluid to be transferred. The other major disadvantage is the wear and tear of the hose pipe. Since the hose pipe comes under pressure constantly from the rotor shaft, it becomes very important to note the healthiness of the pipe. Any small leakage in the pipe will spoil the whole application. In the case of medical units, the failure of a hosepipe can cause severe consequences. Hence it becomes very important to see the state of the pipe. In most of the cases, the pipe is replaced after every operation.[6]

Peristaltic Pumping Principle

Peristaltic pumping systems are (partly) flexible, silent, and fairly simple systems. It consists of a flexible member (hollow organs in nature or tubes in engineering), which is compressed by a force to (in most cases) fully close the inner conduit, resulting in a closed-off compartment being formed by the touching walls.

The closure points or contractions are driven down the conduit via muscle contractions (nature) or actuators (e.g., rollers, pistons, pneumatic chambers in engineering) in the direction of pumping (Figure). These motions result in a fluid transport.

In literature, the motion is often described as a traveling wave moving along a flexible conduit wall. The mathematical description and investigation of the peristaltic pumping motion began in the 1960s as simplified sinusoidal wave in the ureter followed by many theoretical considerations, for example, van Duyl, Srivastava and Srivastava, Takabatake and Ayukawa, Pozrikidis, Takabatake et al., Griffiths, Siddiqui et al.,Li and Brasseur, Siddiqui and Schwarz, Kumar and Naidu, Mekheimer et al.,Dobrolyubov and Douchy, Walker and Shelley, Takagi and Balmforth, Vahidi et al., Misra and Maiti, Sinnott et al., Klochkov, and Ali et al.In nature, peristaltic movement is often based on the interplay of longitudinal and ring muscle contractions (Figure 1.4 - a), together with the dimensions of the given tube, i.e., diameter and length, govern amplitude ratio, gap height, wave order, velocity ,and the number of waves. Therefore, these parameters highly differ in the aforementioned organs such as the duodenum, the small and large intestine, the human ureter, the esophagus, and the hearts of most annelids, holothurians ,and arthropods.

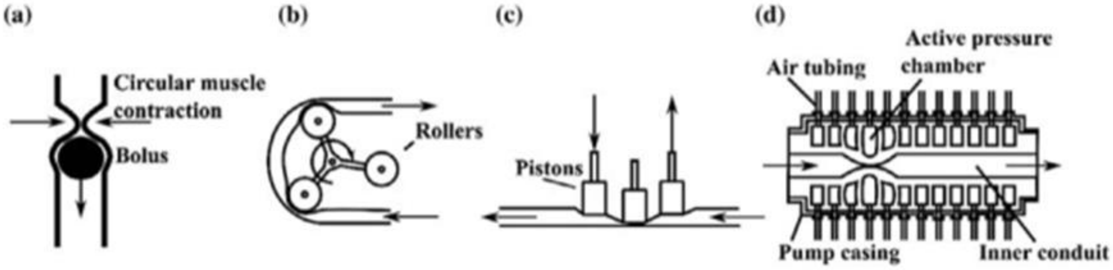

Fig1.4: Overview of peristaltic pumping systems. a) Simplified biological peristaltic pumping of the esophagus or intestine. Two main designs oftechnical peristaltic pumps in engineering: b) rotary peristaltic tube/roller pump .c) linear peristaltic pump with piston actuators . d) Biomimetic pneumatically drivenperistaltic pumps as artificial esophagus for food bolus testing with pneumatic chambers forming the conduit wall .

In common engineering, two designs are the most prominent ones in peristaltic pumps: 1) rotary peristaltic pumps with two or more rollers compressing a flexible tube for relatively large pumps (Figure1.4 - b) and 2) a linear peristaltic pump design (Figure1.4 - c), in which the tube is crimped with three or more piston- or finger-like actuators, which are often used in microscale pump applications. It is to be noted that linear peristaltic pumps and peristaltic micro pumps need three or more pump chambers to generate positive net flow rate, if not a flow in both directions would be generated and valves would be needed. In rotary peristaltic pumps (Figure1.4 - b), two rollers can generate flow rate if a trailing roller crimps the tube before the leading roller lifts off. In this way, backflow is prevented.

The working principle by which fluid motion is generated in biomimetic peristaltic pumps (Figure1.4 - d) is similar to that of common pumps in engineering.

However, not only the used materials differ but also the actuators are differing from technical pumps (e.g., electroactive polymers, shape memory alloys, and/or polymers), pneumatic chambers (e.g., flexible silicone actuators, flexible foam actuators or flexible rubber actuators) (see Figure1.4 - d),flexible elastomers or magnetic elastomers, polymers or fluids are used to generate the peristaltic motion in a tube. Most biomimetic developments try to integrate the actuators directly into the tube or to make the tube self-actuating as in most biological models (e.g., the esophagus). Figure gives an overview of various peristaltic pumping systems.[10]

Applications of Peristaltic Pump

There is a variety of use of the peristaltic pump. It is mostly used in the medical field and for laboratory applications. In medical applications, the blood can be transferred from one part to another. In the surgical processes like dialysis, this becomes very helpful. In laboratory applications like chemical laboratories, it is used as chemical feeders. Also, it is used to fill different vessels with chemicals.

Other medical applications include pumping IV fluids through an infusion device, other liquids for which cross contaminations have to be strictly avoided, aggressive chemicals, etc. They are also used in critical operations like bypass surgery hemodialysis etc. Apart from medical and laboratory applications, they are also used in agriculture applications to pump out huge quantities of water. Also suited to induce some agriculture chemicals on the crops. Also used to pump abrasives and viscous fluids.[6]

Literature Review

- **Shawn W. Walker & Michael J. Shelley**

In 2010, they have studied the variational method to optimize peristaltic pump wave shapes for both biological and industrial applications. Focused on a two-dimensional channel with Navier–

Stokes fluid, it minimizes input fluid power while adhering to constraints on average flux and channel area. Using shape differential calculus and sequential quadratic programming, the approach tackles an infinite-dimensional optimization problem. The numerical implementation includes finite element methods, explicit front-tracking, and computational techniques. Optimized shapes differ from previous profiles, showcasing effectiveness and emphasizing potential applications in understanding biological processes and optimizing mechanical pumps in industries.

The variational method they presented for optimizing the shape of a peristaltic traveling wave holds potential applications in understanding biological processes like mucus transport in the lungs and embryonic transport in the reproductive system. Additionally, it can be instrumental in optimizing industrial pumps that operate based on peristalsis. [15]

- **Nagi Elabbasi , Jorgen Bergstrom and Stuart Brown**

In 2011, they have studied used COMSOL Multiphysics, delved into the intricate dynamics of peristaltic pumping, emphasizing the interplay between tube deformation and fluid movement. Focused on a 180-degree rotary peristaltic pump with metallic rollers and an elastomeric tube, the study investigates the impact of design variations like tube occlusion, diameter, and roller speed on flow rate and stress within the tube. Peristaltic pumps, valued for handled delicate fluids and offering robust, low-maintenance solutions, are explored for applications requiring resistance to abrasive or corrosive fluids. The studied underscores the importance of optimal pump design influenced by factors such as fluid properties, flow rate, and tube specifications.

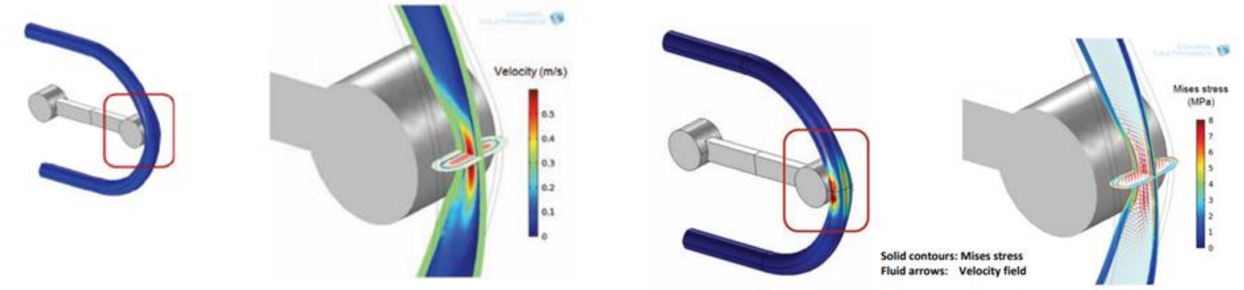

Fig2.1 – A, Velocity contours for one pump configuration. B, Mises stresses and velocity field in pump

The studied, used a computational model in COMSOL Multiphysics, analyzes how variations in peristaltic pump design impact its performance, focusing on tube occlusion, diameter, and roller speed. Figures show deformed geometry, fluid velocity, and Mises stresses under specific conditions. The studied observes local backflow dured roller contact, addressed by modifying geometry or used spring-loaded rollers. Ongoing research explores effects of roller speed, tube occlusion, and fluid viscosity, with future enhancements planned for considering rate-dependent tube deformation and non-Newtonian fluids .[16]

- **Konrad Leopold Hoffmeier, Dirk Hoffmann, Karl-Heinz Feller**

In 2014 , they have studied new peristaltic pump design aiming to minimize pulsatile flow, utilizing at least four pumping chambers with a developed flow schedule. The prototype achieved only 11% pulsation of the mean flow rate. The studied acknowledged challenges, including control strategy limitations and manufacturing inaccuracies, highlighting a trade-off between pump retail price and flow consistency.

The studied recognized challenges in achieved perfect pulsation-free flow in a linear peristaltic pump due to control strategy limitations and system latencies in LabView. Synchronization issues and statistical fluctuations in linear drives, coupled with manufacturing inaccuracies and additional fluctuations from a camshaft, contributed to slight flow variations. Proposed improvements include latency-independent optimization strategies or a real-time operating system. However, manufacturing precision remains a perpetual challenge, necessitating a trade-off between cost and flow consistency. The prototype, while adjustable for only one tubing type at a time, demonstrates the feasibility of an inherently pulsation-free tube pump without additional dampers or complex online control.[17]

- **Mr. Shakil H Choudhari & Mr. M. V Kharade**

In 2016, they studied identifying the fundamental natural frequency of peristaltic pump. Effect of vibration on performance of peristaltic pump to know the natural frequency and mode shapes of peristaltic pump by numerical method by use of software ANSYS Workbench. They put some assumption like validation for structural and fluid degrees of freedom (DOFs). Electrical and thermal DOFs may be present in the coupled field mode-frequency analysis using structural DOFs, the structure has constant stiffness and mass effects, there is no damping, unless the damped eigen solver (MODOPT, DAMP or MODOPT, QRDAMP) is selected.

The equation of motion for an undamped system is

$[M]\{\ddot{u}\} + [K]\{u\} = \{o\}$ (1)

For a linear system, free vibrations will be harmonic, of the form as,

$\{u\} = \{\emptyset\}i \cos \omega i\, t$ (2) Thus, Equation (2) becomes,

$(-\omega i\ 2[M] + [K])\{\emptyset\}i = \{0\}$ (3)

The general structure of a Finite Element Analysis involves the following three steps, the description of the geometry, the physical characteristics and the mesh (pre-processing) the application of finite element analysis. (solution)

the visualization and interpretation of the results of the solution. (post processing). Table below indicates six mode shapes of Peristaltic Pump assembly and respective frequencies.

Sr. No.	Mode Shape	Frequency (Hz)
1	1	665.63
2	2	672.28
3	3	862.79
4	4	973.45
5	5	1315
6	6	1654.6

Table2. 1 - six mode shapes of Peristaltic Pump assembly and respective frequencies

They found out from the modal analysis the fundamental frequency

of the pump assembly is 665.63 Hz. The operating maximum frequency of the pump is 120 rpm or 12.56 Hz. The operating frequency and the natural frequency are far away and hence there is no chance of resonance. It is now necessary to test the other possibilities for vibration in pump.[18]

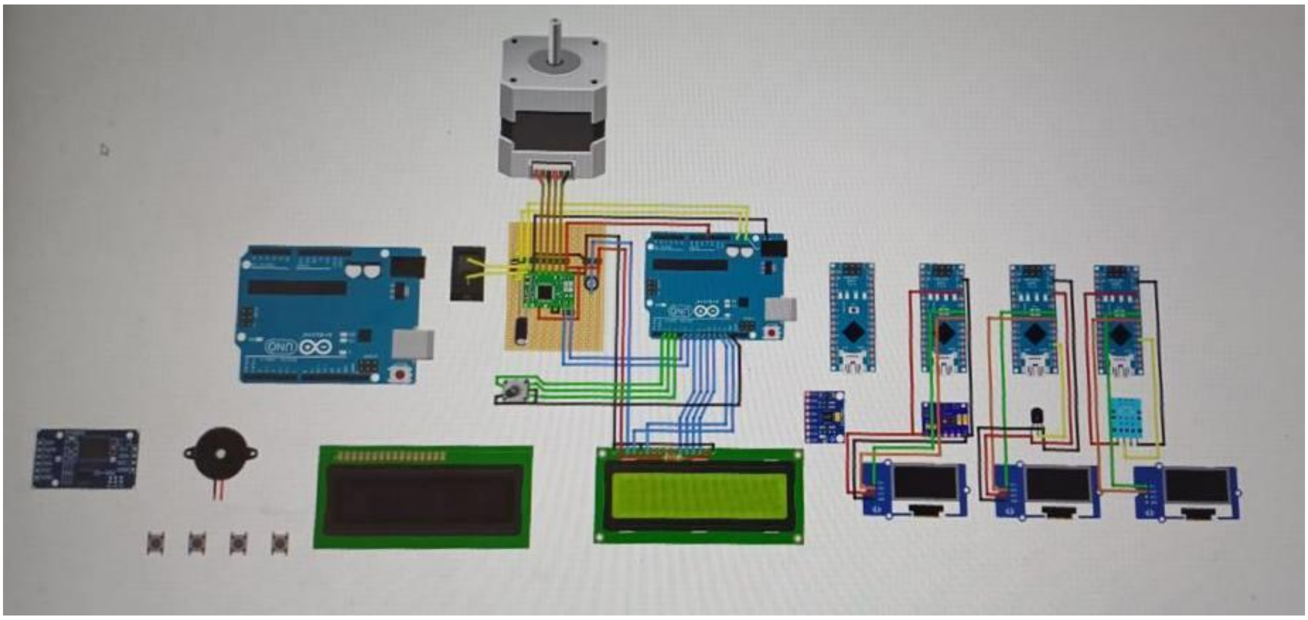

Fig3.1 ingredients of Pump peristaltic functional

Bubble Sensor

As shown in Fig3. 2 and Fig3. 3, the bubble sensor is used to stop the motor in case of a bubble passing through the tube. The IR sensor is placed in the way of the fluid tube. The circuit consists of a photo diode and a photo transistor to detect the bubble, and these components are connected to an LM358 operation amplifier.

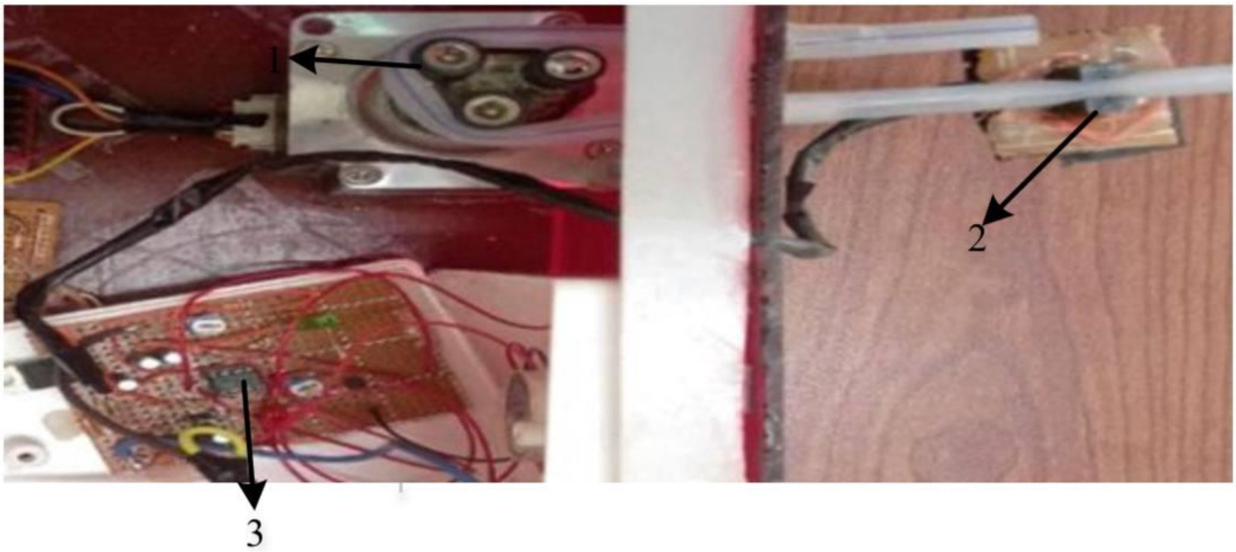

Fig3.2 Snap shot of the bubble detector circuit: 1 – Motor, 2 – Photo diode and photo transistor, and 3 – LM358 operation amplifier

The signal is amplified in case of a bubble insertion to indicate its detection, and the buzzer will be ON to alarm the user and stop the motor at the same time.

PIC12F675 is a microcontroller , where pins 1, 5, and 8 are connected to VSS and GND, respectively. Pins 3, 4, 6, and 7 are connected to the motor drive control, i.e. L298N. The motor drive controller board module dual h Bridge DC Stepper and the Bipolar Nema 23 stepper motor with 1.8 deg are used to control the pump work. The circuit of the microcontroller is shown Fig3.4.[29]

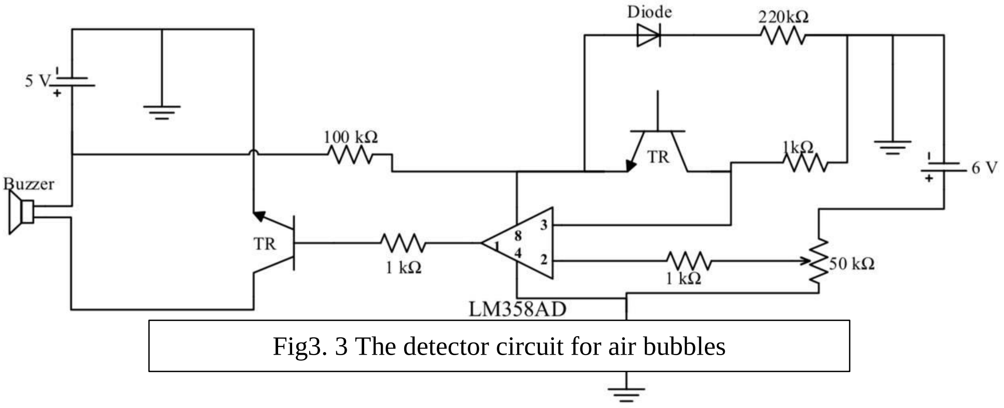

Fig3. 3 The detector circuit for air bubbles

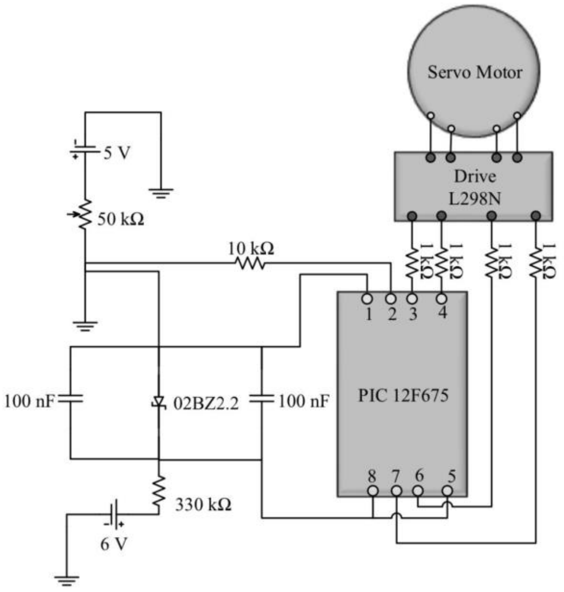

Fig3.4 The circuit for microcontroller connection

Body Temperature Sensor

A long-range UHF RF identification (RFID) sensor has been designed using a 0.35- ¿m CMOS standard process. The power-optimized tag, combined with the ultralow-power temperature sensor, allows an ID and a temperature reading range of 2 m from a 2-W effective radiated power output power reader. The temperature sensor is based on a ring oscillator, where the temperature dependence of the oscillation frequency is used for thermal sensing. The temperature sensor exhibits a resolution of 0.035°C and an inaccuracy value lower than 0.1°C in the range from 35°C to 45°C after two-point calibration. The average power consumption of the temperature sensor is only 110 nW at ten conversions per second while keeping a high resolution and accuracy. These properties allow the use of the RFID as a battery less sensor in a wireless human body temperature monitoring system.

The temperature sensors will send the readings to a microcontroller using X bee wireless communication. To send the real-time data to health monitoring database, wireless local area network (WLAN) has been used. Arduino with Ethernet shield based on IEEE 802.11 standard has been used for this purpose. Test results from a group of voluntary shows the real-time temperature reading successfully monitored locally (at home) and remotely (at doctor's computer) and the readings are comparable to commercial thermometer.[30]

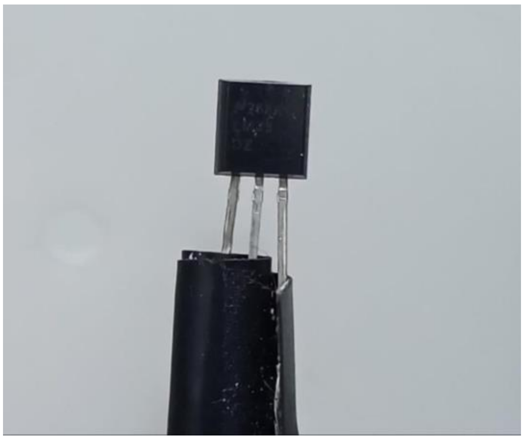

Fig3.5 Body temperature Sensor

Vibration Sensor

is critical to monitor and ultimately preserve the health state of engineering systems The need exists for high-sensitivity, low-noise vibration sensors for various applications, such as geophysical data collection, tracking vehicles, intrusion detectors, and underwater pressure gradient detection. In general, these sensors differ from classical accelerometers in that they require no direct current response, but must have a very low noise floor over a required bandwidth.

Theory indicates a capacitive micro machined silicon vibration sensor can have a noise floor on the order of 100 ng//spl radic/Hz over 1 kHz bandwidth, while reducing size and weight tenfold compared to existing magnetic geophones. With early prototypes, we have demonstrated Brownian-limited noise floor at 1.0 /spl mu/g/Hz, orders of magnitude more sensitive than surface micro machined devices such as the industry standard ADXL05. [31]

Fig3.6 Vibration Sensor

Pulse and oxygen sensor

Pulse oximetry is a ubiquitous noninvasive medical sensing method for measuring pulse rate and arterial blood oxygenation. Conventional pulse oximeters use expensive optoelectronic components that restrict sensing locations to finger tips or ear lobes due to their rigid form and area-scaling complexity. In this work, we report a pulse oximeter sensor based on organic materials, which are compatible with flexible substrates.

Green (532 nm) and red (626 nm) organic light-emitting diodes (OLEDs) are used with an organic photodiode (OPD) sensitive at the aforementioned wavelengths. The sensor’s active layers are deposited from solution-processed materials via spin-coating and printing techniques. The all-organic optoelectronic oximeter sensor is interfaced with conventional electronics at 1 kHz and the acquired pulse rate and oxygenation are calibrated and compared with a commercially available oximeter. The organic sensor accurately measures pulse rate and oxygenation with errors of 1% and 2%, respectively.[32]

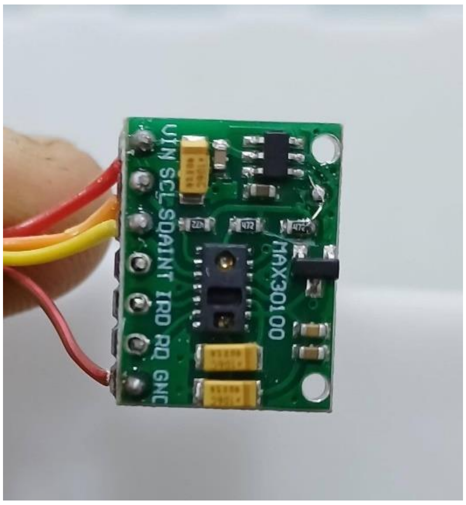

Fig3.7 Pulse and oxygen sensor

Online monitoring

Intravenous (IV) therapy provides a rapid therapeutic effect. However, errors in infusion rate can lead to over-dosing and under dosing, potentially causing severe side effects for patients. To prevent incidents, medical staff visually monitors medication injection information (MIF) such as current flow rates (CFR) and injection volume. In this study, we propose an internet of things (IoT) system that automatically controls the CFR and remotely monitors the MIF. First, a peristaltic pump is designed to infuse parenteral fluids based on the “drop-by-drop” phenomenon.

Second, a computer vision-based on deep learning algorithm provides real-time video and counts the fluid dropping to derive the MIF. Finally, the CFR is automatically applied as a feedback signal to regulate the infusion cycle of the peristaltic pump. After embedding all systems in our prototype, we evaluate the system performance according to IV therapy protocols used in clinical practice. In our experiments, the mean accuracy of the fluid injection using the peristaltic pump was 99.23% and the dropping count was the highest at 98.25%. Furthermore, the average accuracy of the CFR using the feedback system was 99.3%. Based on our results, we confirmed that automated control of infusion rate is possible in IV therapy and computer vision-based on deep learning can be utilized for feedback sensors and monitoring system. Therefore, we believe that our method is the practical solution that can increase patient safety and work efficiency of clinical staffs.[33]

Fig3.8 Online monitoring

Temperature and humidity sensor

Capacitive sensors are the most commonly used devices for the detection of humidity because they are inexpensive and the detection mechanism is very specific for humidity. However, especially for industrial processes, there is a lack of dielectrics that are stable at high temperature (>200 °C) and under harsh conditions.

We present a capacitive sensor based on mesoporous silica as the dielectric in a simple sensor design based on pressed silica pellets. Investigation of the structural stability of the porous silica under simulated operating conditions as well as the influence of the pellet production will be shown. Impedance measurements demonstrate the utility of the sensor at both low (90 °C) and high (up to 210 °C) operating temperatures.[34]

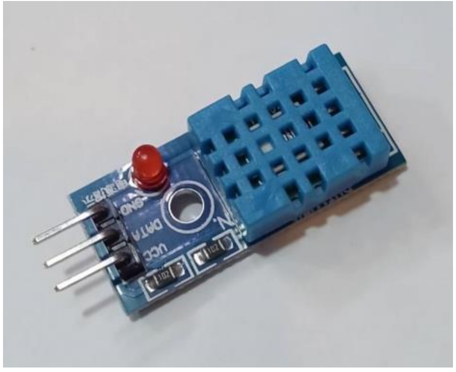

Fig3.9 Temperature and humidity sensor

Air pollutant sensor

Air pollution exposure characterization has been shaped by many constraints. These include technologies that lead to insufficient coverage across space and/or time in order to characterize individual or community-level exposures with sufficient accuracy and precision. However, there is now capacity for continuous monitoring of many air pollutants using comparatively inexpensive, real-time sensors. Crucial questions remain regarding whether or not these sensors perform adequately for various potential end uses and whether performance varies over time or across ambient conditions.

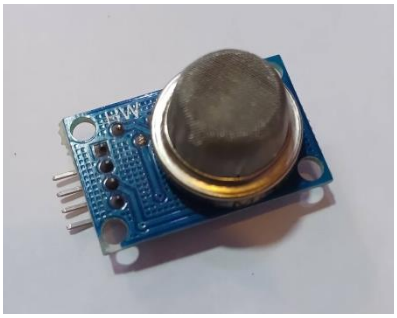

Fig3.10 Air pollutant sensor

Performance scrutiny of sensors via lab- and field-testing and calibration across their lifetime is necessary for interpretation of data, and has important implications for end users including cost effectiveness and ease of use. We developed a comparatively lower cost, portable, in-home air sampling platform and a guiding development and maintenance workflow that achieved our goal of characterizing some key indoor pollutants with high sensitivity and reasonable accuracy. Here we describe the process of selecting, validating, calibrating, and maintaining our platform – the Environmental Multi-pollutant Monitoring Assembly (EMMA) – over the course of our study to-date. We highlight necessary resources and consider implications for communities or researchers interested in developing such platforms, focusing on PM2.5, NO, and NO2 sensors. Our findings emphasize that lower-cost sensors should be deployed with caution, given financial and resource costs that greatly exceed sensor costs, but that selected community objectives could be supported at lesser cost and community-based participatory research strategies could be used for more wide-ranging goals.[35]

Principle of :

4.1.1 Peristaltic Pump

As the rotor turns, the rollers move along the tube, compressing it. This compression creates a sealed section in the tube between two rollers. The movement of the rollers along the tube pushes the fluid within the sealed section of the tube forward. When a roller compresses the tube, the fluid in front of the roller is forced away from the compression zone. As the roller moves and releases the tube, the elasticity of the tube's material causes it to regain its original shape, creating a vacuum or suction. This suction draws more fluid into the tube from the input side. The sequential compression and relaxation of the tube as the rollers rotate create a peristaltic action, mimicking the way that the gastrointestinal tract moves food. This provides a continuous, steady, and gentle pumping action that prevents the fluid from being sheared or agitated excessively.

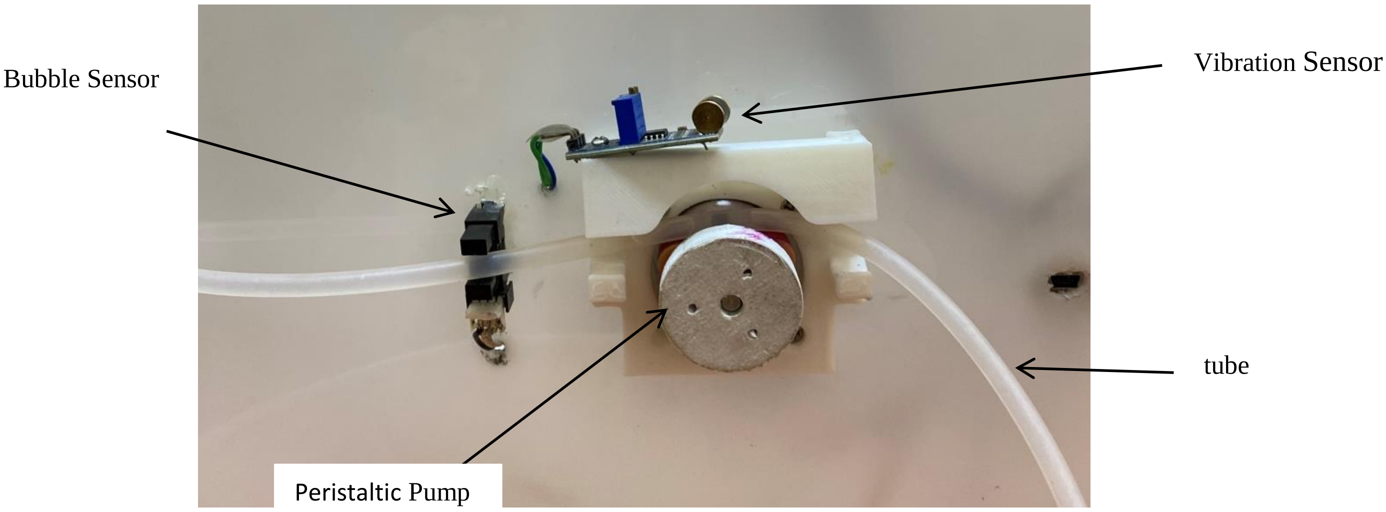

Fig4.1 - Peristaltic Pump, Bubble Sensor, Vibration Sensor and tube

4.1.2 Bubble Sensor

The principle behind a bubble sensor involves detecting changes in certain physical properties of the liquid caused by the presence of bubbles. Here's how it generally works(see in fig 4.1) :

1. **Optical Detection:** Optical bubble sensors use light beams (such as infrared or visible light) that pass through the liquid. When the light encounters bubbles, it is scattered or absorbed differently compared to when it passes through only the liquid. A photodetector measures the intensity or pattern of the transmitted light, and any deviations from the baseline indicate the presence of bubbles.
2. **Conductivity or Impedance Detection:** Some bubble sensors operate based on changes in the electrical conductivity or impedance of the liquid caused by the presence of bubbles. When bubbles are introduced into the liquid, they can disrupt the flow of electric current or alter the impedance of the liquid. Sensors measure these changes and trigger an alert when they exceed a certain threshold.
3. **Pressure Differential Detection:** In certain applications, bubble sensors utilize pressure differentials to detect bubbles. They measure the pressure at different points in the liquid flow path. If there is a sudden drop or fluctuation in pressure, it may indicate the presence of bubbles obstructing the flow.
4. **Data Processing and Alerting:** Regardless of the detection method used, bubble sensors typically include signal processing capabilities to interpret the sensor output and determine the presence, size, and concentration of bubbles. When bubbles are detected, the sensor may trigger an alarm, pause the system, or take corrective actions to prevent adverse effects.

4.1.3 Vibration Sensor

They operate on the principle of detecting changes in acceleration and converting these changes into electrical signals that can be measured and analyzed. Here’s how they work(see in fig 4.1):

1. **Piezoelectric Effect:** Many vibration sensors utilize the piezoelectric effect, which is the ability of certain materials to generate an electric charge in response to applied mechanical stress. These sensors typically consist of a piezoelectric crystal or ceramic material.
2. **Mounting:** The vibration sensor is mounted onto the surface of the object or system being monitored. When vibrations occur, the sensor experiences mechanical stress or acceleration, causing the piezoelectric material within the sensor to deform slightly.
3. **Generation of Electrical Signal:** As the piezoelectric material deforms, it generates a small electric charge proportional to the applied force or acceleration. This charge is collected by electrodes within the sensor and converted into an electrical voltage signal.
4. **Signal Processing:** The electrical signal produced by the vibration sensor is then processed by electronic circuitry within the sensor or by external signal processing equipment. This processing may involve amplification, filtering, or digitization of the signal to make it suitable for measurement and analysis.
5. **Output:** The processed electrical signal is outputted in a format that can be interpreted and analyzed by users or other monitoring systems. This output may be in the form of analog voltage signals, digital data streams, or wireless transmissions, depending on the specific design of the sensor.
6. **Analysis and Monitoring:** The output from the vibration sensor can be used for various **purposes**, including monitoring the condition of machinery, detecting faults or anomalies, assessing structural integrity, and identifying sources of vibration or mechanical stress.

Pulse Oximetry

1. **Optical Absorption Characteristics:** Pulse oximeters function by exploiting the different absorption characteristics of oxygenated and deoxygenated hemoglobin (the molecule in red blood cells that carries oxygen) in the blood. Oxygenated hemoglobin absorbs more infrared light and less red light, whereas deoxygenated hemoglobin absorbs more red light and less infrared light.
2. **Light Emission and Detection:** A pulse oximeter uses a pair of small light-emitting diodes (LEDs) facing a photodetector through a translucent part of the patient's body, usually a fingertip or earlobe(see fig4.2) . One LED emits red light, and the other emits infrared light. As these lights pass through the blood, they are absorbed differently by oxygenated and deoxygenated blood.
3. **Signal Processing:** The photodetector senses the amount of light that passes through the blood and reaches it, capturing the varying absorbance's due to the pulsatile nature of blood flow (i.e., the pulse). The device calculates the ratio of the red to infrared light absorption, which changes with the pulse. This ratio is used to determine the SpO2 level, as it corresponds to the proportion of oxygenated hemoglobin in the blood.
4. **Display:** The calculated oxygen saturation and pulse rate are then displayed on the oximeter. Most devices show a percentage that indicates the level of oxygen saturation in the blood, with normal levels typically between 95% to 100%.

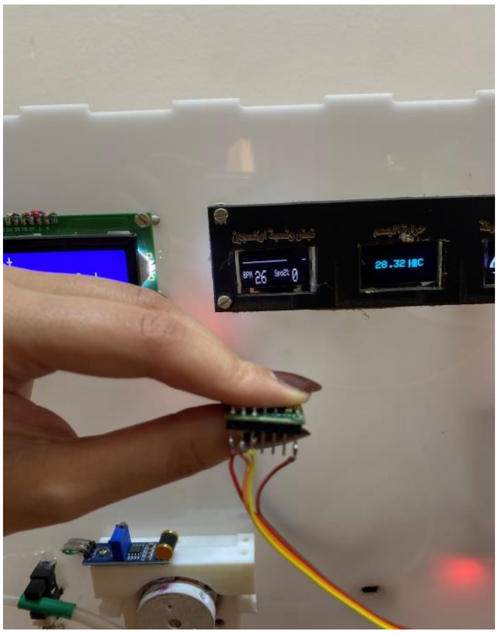

Fig4.2 Pulse Oximetry

LM35

The LM35 is a linear temperature sensor whose output voltage is linearly proportional to the Celsius (Centigrade) temperature. It is fabricated using monolithic IC technology which integrates analog and digital circuits on a single semiconductor substrate.

- The output of the LM35 is linearly proportional to the temperature it measures, with a scale factor of 10 mV/°C. This means that for every degree Celsius increase in temperature, the output voltage of the sensor increases by 10 millivolts.
- The standard LM35 sensor can measure temperatures from -55°C to +150°C. There are also variants of the LM35 that are designed to operate up to 1°C or down to lower temperatures like -205°C (LM35CZ).
- The sensor directly outputs an analog voltage, which eliminates the need for any external calibration. The simplicity of this output allows the LM35 to interface directly with analog-to-digital converters (ADCs).

The LM35 does not require recalibration or external calibration circuitry. The inherent calibration of the LM35 simplifies its integration into any system.

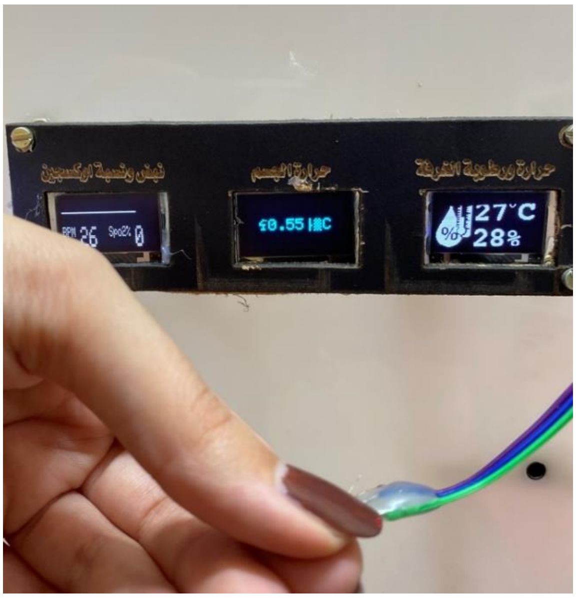

Fig4.3 temperature body

DHT11

The DHT11 is a digital temperature and humidity sensor that operates based on the principles of capacitive humidity sensing and thermistor temperature sensing. Here's a breakdown of how each component works:

- **Capacitive Humidity Sensing**

Sensor Construction:

- The humidity sensing component of the DHT11 consists of a capacitive humidity sensor. This sensor includes two electrodes with a moisture-holding substrate (usually a polymer or paper) between them. The electrical properties of this substrate change with the absorption or desorption of water vapor.

Operation Principle:

- The capacity of the capacitive sensor changes as the relative humidity (RH) changes. The change in capacitance occurs because the dielectric constant of the substrate changes with moisture content. The more moisture the air holds, the higher the capacitance.

Signal Processing:

- The sensor's electronics convert the capacitance changes into a digital signal that corresponds to the humidity level. This digital output can be read directly by a microcontroller.

- **Thermistor Temperature Sensing**

Sensor Construction:

- The temperature sensor part of the DHT11 is based on a Negative Temperature Coefficient (NTC) thermistor. A thermistor is a type of resistor whose resistance varies significantly with temperature.

Operation Principle:

- In the case of an NTC thermistor, the resistance decreases as the temperature increases. This property is utilized to measure temperature. The thermistor is part of a voltage divider within the sensor circuitry, where the voltage across the thermistor changes with temperature.

Signal Processing:

- The change in voltage across the thermistor is converted into a digital value that represents the temperature. The sensor's internal circuitry processes this value, which is then available to be read by a microcontroller.

- **Combined Operation and Output**

- The DHT11 sensor integrates both the humidity and temperature sensors into a single unit with a digital interface. The sensor includes an onboard microcontroller that handles all data acquisition from the humidity and temperature sensors. It processes this data and outputs a serial digital signal that encodes both temperature and humidity readings.
- The digital output is typically a serial stream of bits that includes integral and decimal parts of the temperature and humidity measurements, error-checking bits, and start/stop signals.

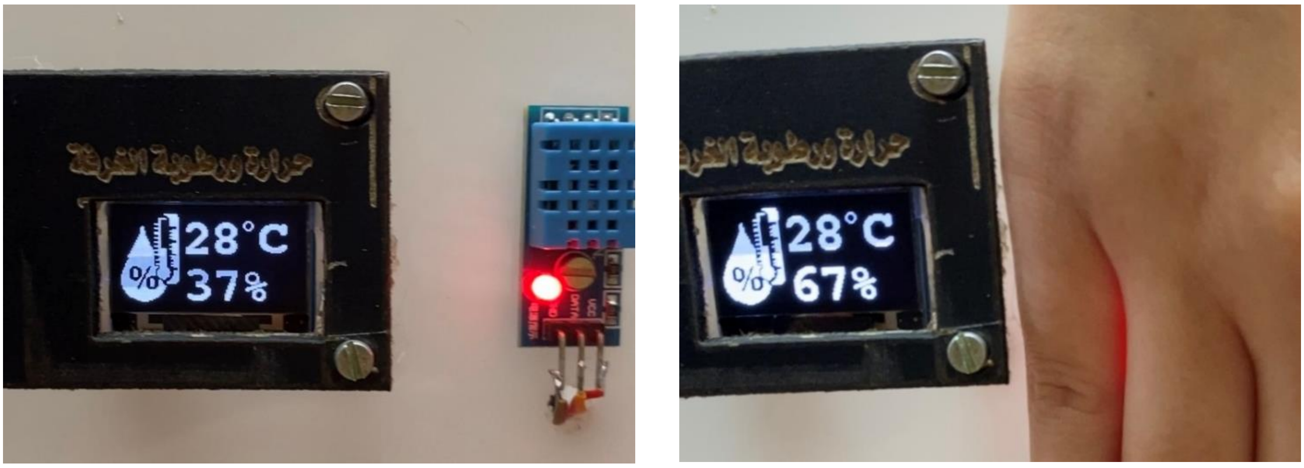

Fig4.4 – A: room temperature and humidity meter , B : when placing the hand on the sensor

- **Integration in Meters**

In a typical room temperature and humidity meter, these sensors are integrated into a single device, often with a digital display that shows both temperature and humidity levels. The device may include additional features like:

- Logging and tracking changes over time.
- Alerts for when certain temperature or humidity thresholds are crossed.
- Integration with home automation systems for controlling HVAC systems based on the readings.

Blood pressure device

These devices have an electronic pressure sensor and a microprocessor.

Procedure:

1. **Cuff Inflation**: The cuff is automatically inflated using an electric pump to a pressure high enough to completely occlude the artery.
2. **Measuring Oscillations:** The device measures the oscillations in the cuff pressure caused by the pulsations of the artery as the cuff is automatically deflated. These oscillations correlate with changes in arterial volume under the cuff and are influenced by the arterial pressure.
3. **Calculating Blood Pressure:** The microprocessor analyzes the magnitude and timing of these oscillations to calculate systolic, diastolic, and sometimes mean arterial pressure.

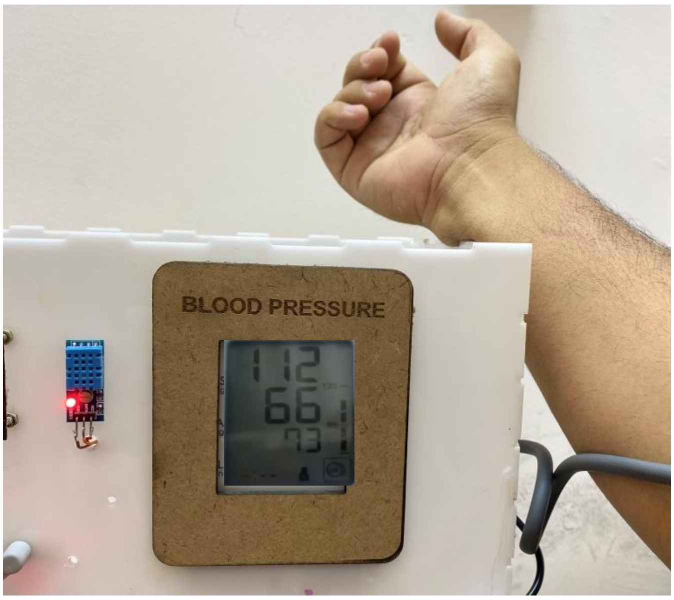

Fig4.5 - Blood pressure device

Online monitoring camera

The principle of online monitoring cameras involves the continuous capture, transmission, and analysis of visual data in real-time or near-real-time over a network. Here's how it works:

1. **Continuous Video Capture:** Online monitoring cameras are equipped with sensors and lenses that continuously capture video footage of the monitored area or environment. These cameras may use various technologies such as CCD (Charge-Coupled Device) or CMOS (Complementary Metal-Oxide-Semiconductor) sensors to convert light into electrical signals, which are then processed into digital video data.
2. **Data Transmission:** The captured video data is transmitted over a network, such as a local area network (LAN), Wi-Fi, or the internet, to a central monitoring station or cloud-based platform. This transmission can occur via wired or wireless connections, depending on the camera's configuration and the infrastructure available.
3. **Real-time or Near-real-time Analysis**: Upon reaching the monitoring station or cloud platform, the video data is analyzed in real-time or near-real-time using video analytics software or algorithms. These algorithms can detect and identify various objects, events, or anomalies within the video footage, such as motion detection, object tracking, facial recognition, or abnormal behavior recognition.
4. **Alerts and Notifications:** Based on the analysis results, the monitoring system can generate alerts, notifications, or alarms to alert security personnel or system operators of any detected events or abnormalities. These alerts may be sent via email, text message, or integrated with other communication systems for immediate action.

Fig4.6 Online monitoring

5. **Remote Access and Control:** Users can remotely access the live video feed or recorded footage from the monitoring cameras using desktop computers, laptops, smartphones, or tablets. Remote access allows users to monitor the premises in real-time, review past events, and take appropriate actions as needed.

ECG

It operates on the principle of detecting the electrical signals generated by the heart as it contracts and relaxes. Here's how it works:

1. **Electrodes Placement:** The ECG involves placing electrodes, which are small, adhesive patches containing conductive gel, on specific locations on the body. Typically, electrodes are placed on the chest, arms, and legs.
2. **Detection of Electrical Signals:** The electrodes detect the electrical signals generated by the heart, known as action potentials, as they spread through the heart muscle during each heartbeat. These signals represent the depolarization and repolarization of the heart's chambers.
3. **Amplification and Filtering:** The electrical signals detected by the electrodes are very weak and can be easily affected by noise and interference. Therefore, the signals are amplified to make them easier to measure accurately. Additionally, they may be filtered to remove unwanted noise from the signal.
4. **Signal Display:** The amplified and filtered signals are then displayed graphically on a monitor or paper printout. The display typically shows a series of waves, each representing a different phase of the cardiac cycle.

5. **Interpretation of Waves:** The waves on the ECG represent different electrical events in the heart:

- P wave: Represents atrial depolarization (contraction).
- **QRS complex:** Represents ventricular depolarization (contraction) and atrial repolarization (relaxation).
- **T wave:** Represents ventricular repolarization (relaxation).

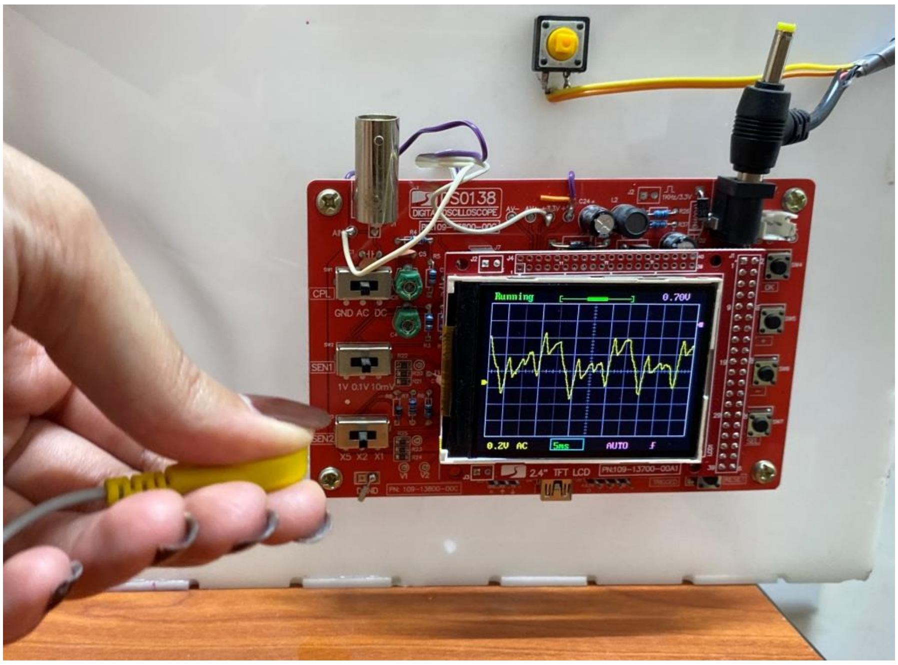

Fig4.7 ECG

4.1.4 Liquid Crystal Display (LCD 16X2)

0|Start

Start pumping, the operation mode is depending on the mode selected at “6) Mode”

1|Volume

Set the dosing volume, is only considered if “Dose” is selected at “6) Mode”

2|V.Unit:

Set the volume unit, options are:

“mL”: mL

“uL”: µL

“rot”: rotations (of the pump)

3|Speed

Set the flow rate, is only considered if “Dose” or “Pump” is selected at “6) Mode”

4|S.Unit:

Set the volume unit, options are:

“mL/min”: mL/min

“uL/min”: µL/min

“rpm”: rotations/min

5|Direction:

Choose pumping direction: “CW” for clockwise rotation, “CCW” for counterclockwise

6|Mode:

Set operation mode:

“Dose”: dose the selected volume (1|Volume) at the selected flow rate (3|Speed) when started

“Pump”: pump continuously at the selected flow rate (3|Speed) when started

“Cal.”: Calibration, pump will perform 30 rotations in 30 seconds when started

7|Cal.

Set calibration volume in mL. For calibration, the pump is run once in calibration mode and the resulting calibration volume which was pumped is measured.

8|Save Sett.

Save all settings to Arduinos EEPROM, values are retained during power off and reloaded, when the power is turned on again

9|USB Ctrl

Activate USB Control: Pump reacts to serial commands sent via USB

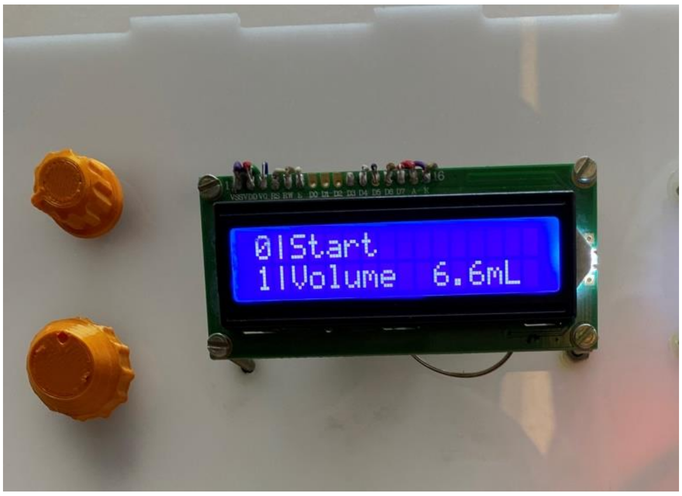

Fig4.8 Liquid Crystal Display (LCD 16X2)

Limitations

- **For pump** : The driver was changed because at first it was giving insufficient current to move the pump.
- **For Tube** : The tube has a modulus of elasticity that isn't suitable for the pump.
- **For Pulse Oximetry**: The accuracy can be affected by factors such as poor circulation to the extremity being used (e.g., cold fingers), movement artifacts (shaking or moving the body part), and interference from external light. Additionally, certain pigments in nail polish or skin, and the use of certain artificial nails, can interfere with the accuracy of the readings.
- **For DHT11** : The DHT11 requires a 1-2 second recovery time between readings to allow the capacitive sensor to stabilize, making it suitable for applications where rapid measurement changes are not critical.

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