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Final Report: OpenPersitaltic Pumps

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Introduction

For many technological and scientific purposes it has always been a challenge how to make liquids move with specific motion conditions. This is true specially in fields such as hydraulic and mechanical engineering and in many biological tasks, either for scientific research or for medical applications. This main goal can be achieved using different kind of pumps.

In biomedical sciences this is of great interest, because many biological phenomena involving fluids have determined behaviors that cannot be affected, because living beings depend on it. One great invention dedicated to solve this problem, particularly in blood transfusions was the peristaltic pump (1845). The main innovation of this device was that it has the ability to produce a pulsating flow of the blood, almost the same as the one produced by the heart.

The idea behind peristaltic pumps is to use a two-wheel system to occlude a part of a tube with liquid. Both wheels have 180º angles between them in order to press the tube in the first halve of the rotation until the liquid has a clear exit.In the second halve of the cycle the second wheel execute the same routine and the process goes on until it stops externally.

Because of it multipuprose function in a vast of biomedical applications, recently there has been a lot of initiatives, papers and designs which give instruction into how to build cheaper peristaltic pumps. The aim of this text is to cover some of the recent projects involved in the open design of peristaltic pumps, their main characteristics, how to implement them and which are the most important applications.

Main Characteristics

Basic system

Before going into too much detail is necessary to explain the basic elements of a peristaltic pump, and how the relate with each other. Every mechanical peristaltic pump must at least consider:

- n-wheel mechanism (normally 2 or 3)
- Circular casing
- Tube

The roller/wheel system rounds around a tube that is cased inside a circular envelop. While the wheels are moving they push one segment of the liquid isolated from the inlet and outlet. When one wheel separates from the wall, it allows the liquid to flow out. In the next figure it can be understand the basic mechanism described:

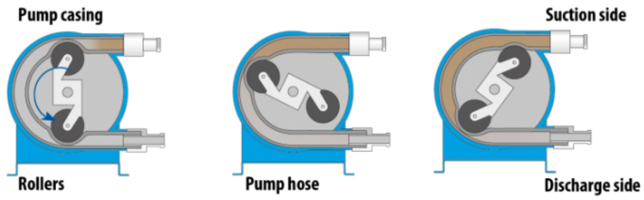

Figure 1: Working principle of peristaltic pump [1]

Design considerations

When designing a peristaltic pump, depending on the intended use, one must specify design considerations or constraints. In the area of biomedical applications, there are some important features that must be defined [1]:

- Shear stress: This is one of the most important in all blood transfusions systems, because as higher shear stress the chance of hemolysis increases. Which is undoubtedly inconvenient in any biomedical research or application.
- Flow rate: Depending on the task, people may want higer volumes in the output or smaller ones. Some pumps allow more flow rate than other, mainly because the rotor limits and the geometrical aspects of the pump.
- Pulsation frequency: For some highly precised tasks it must be necessary to move the liquid in a 'dosed' mode of operation that is only possible with small pulsation frequency. Also is really important when trying to adjust the pump to an specific pressure wave, mimicking cardiovascular flow.
- Amount of occlusion: This parameter called also amount of squeeze, changes because of the geometrical and mechanical considerations of the tube. The amount of occlusion is the minimal force needed to close the tube when the rollers are squeezing the tube against the wall. If this is not set properly, leaks may happen. At the same time if the force is too strong the lifetime of the tube gets shorted
- Biocompatibility of the tubes: For most biomedical applications is really important that the reactants and the cells don't get destroyed when passing trough the tubes. So it's necessary to have a neutral material that doesn't react with the substances and that has well treated walls in order to protect the cells that pass through.

For other purposes, there are other important characteristics that may be considered, such as duty cycles, temperature or abrasion resistance, and so on. But those restrictions are way to high for biological experiments.

Common bio-applications of peristaltic pumps

The most typical and common applications in this field are: Blood transfusions, hemodyalisis, ECMO machines, Apheresis, Autoanalyzer and Culture media dispensers.

Designs and parts of open peristaltic pumps

Once it is undestand the basics of general peristaltic pumps in biomedical field, now the open projects can be explored an so their details. In recent years there has been a lot of designers and scientists that have tried to develop their own self-crafted peristaltic pumps, because commercially available ones are too expensive.

This designs often include the whole mechanical and electronic systems. Usually using 3d-printed parts and micro-controllers for the whole system to work. The only aspect that is not so carefully crafted is tubing design, they commonly use standard tubes.

In order to show and explain the parts and mechanisms that make up the open peristaltic projects, only one design will be used as an example and the rest of them will be complementary.

For this description the design that will be used is the one created by an iGEM team from RWTH Achen University. The mean goal of the team was to achieve a highly precised controlled motion [2].

Because the complete instructions are too long for this text, the principal ideas will be summarized and accompanied by images. First they gather all the parts (electronics, mechanical and 3d printable). Then they made the electronic connections, for it was neccesary to have an arduino, stepper motor and LCD screen between other minor components. After it, all the circuits were tested and encased in the 3d printed boxing. Then they put the tube inside the circular casing, which allowed them to calibrate the dosing and pumping rates. The last step was to establish USB serial connection to the system so they can have remote control [2].

Specifications

Dimensions		95 x 106 x 102 mm (width x depth x height)	
Tubing			
Required Wall Thickness		1.6 mm	
Inner Diameter		0.8 - 4 mm	
Material, Shore A (hardness)		55°-60°	tested with silicone tubing, use tubing specially made for peristaltic pumps for best durability
		0.8 mm tubing	**4 mm tubing**
Volume Flow	Min:	0.2 mL/min	2 mL/min
	Max:	10 mL/min	100 mL/min
Dosing Volume	Min:	0.05 mL	0.5 mL
	Max:	1000 mL	1000 mL
Deviation from control input		< 2% (Dosing)	
Communication		Arduino: Serial port via USB (Type B plug)	

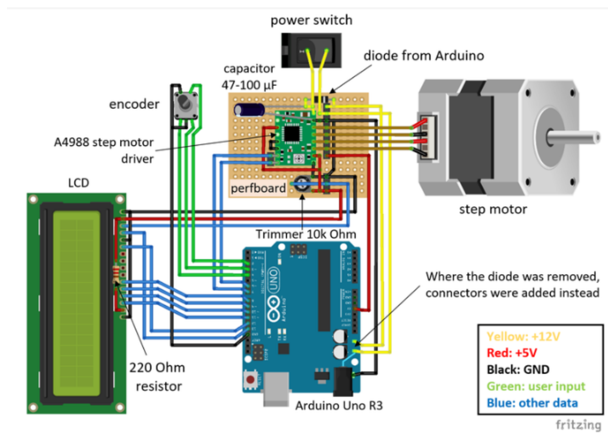

Figure 2: Table of design specifications and electronic wiring [2]

It's important to notice that in both this design and the many others found in the internet, the circular casing, where the tubing is placed, use metallic rollers. Mainly because they have bearings inside, which ensures a minimal friction resistance that plastic parts cannot engage. The specific design of these parts can be seen in the following, picked up from a github repository:

Figure 3: Design of the wheeled part [3]

State of the Art

Within the context of peristaltic pumps in biomedical research, an interesting view of the state of the art is the following: common commercialized mechanical peristaltic pumps, Micro pumps designs (mainly for microfluidics) and open peristaltic pumps.

Mechanical peristaltic pumps

There are plenty of mechanical pumps, but a good view of them is to separate them into three categories, based on their use. Here there is a table that summarize them

Type	Model	Principle	Inner tubing diameter	Height	Max. speed	Contraction ratio	Flow rate/ velocity of content	Pressure	Transported media
Peristaltic roller pump: Hose pump	LSM 2000 (LSM Pumper)[162]	Hose compression through two diametrically opposed rotating rollers[162]	20 cm[162]	2.9 m[162]	–	100%[162]	300 000 L h^{-1}[162]	4 bar, max. 10 bar[162]	Sludge, glue, acids, concrete, fish, food[162]
Peristaltic roller pump: Hose pump	Mouvex Abaque HD 100 (Mouvex PSG Dover)[163]	Hose compression through two diametrically opposed rotating shoes[163]	10 cm[163]	1.54 m[163]	45 rpm[163]	100%[163]	58,000 L h^{-1}[163]	16 bar[163]	Sludge, clay slurry, lead sulfate, pyrite slurry[163] Max. solid particle size: 1.5 cm[163] Max. Soft particle size: 2.5 cm[163]
Peristaltic roller pump: Tube pump	Dialysis pumps, infusion pumps, metering pumps, laboratory tube pumps (Watson–Marlow Pumps,[164] Curlin and Moog[165])	Tube compression through rollers, roller numbers range from 2 to 12[164,165]	0.12–25 mm[164,165]	>1 m	50 rotations per hour[165] to 650 rpm[166]	100%	0.0 μL $min^{-1}$to 35 L min^{-1}[164]	Up to 7 bar[164]	Infusion media, blood, food slurries, liquids[164]

Figure 4: Table showing different types of mechanical based peristaltic pumps [4]

Micro pumps

Because the main topic of this document is the use of pumping systems in biological fields, is important to mention how different pumping systems have been applied in microfluidics. The following is a table with recent designs (usually MEMs technologies)

Actuation method	Advantages	Disadvantages
Electrostatic	Low power consumption Simple-to-control stroke Fast response Planar structure Small footprint and size	High operating voltage Small stroke Electrolysis (for polar working fluids)
Motor	Low operating voltage Large stroke Peristalsis-friendly Flexibility to couple to various transmission mechanisms	Complex external mechanism required for handling rotary motion Non-planar structure Relatively large
Piezoelectric	Fast response Large actuation force Large membrane displacement Simple structure Planar structure	High operating voltage Small stroke Complex and bulky driving circuit
Pneumatic	Simple-to-control actuation force Large stroke Small footprint Soft-lithography-friendly	Slow response Non-planar structure External compressed air and control valves required Not portable
Thermal (Thermopneumatic Phase-change Shape memory alloy Hydrogel)	Low operating voltage Simple driving circuit Large stroke Large actuation force Planar structure Small footprint and size	High power consumption Slow response Temperature elevation in working fluid

Figure 5: Table of comparision between different methods of micropumps [5]

In the paper from which the figure comes, there's also a picture that indicates the maximum flow rate for each type of pump, given specific size and working pressure. Being electrostatic, motor based and piezolectric the ones with the highest flow rates in ranges of 1mL/min and 10mL/min [5].

Open peristaltic pumps

When referring to open hardware systems, it's important not only to talk about peristaltic pumps. Also syringe pumps should be considered, because they are low cost and easy to craft. However they have limitations which are correctly addressed by open source peristaltic pumps. In this case it's difficult to show a table because every open desing have different reported parameters, due to a lack of protocols.

What it can be rather explained are the advantages of using open peristaltic pumps vs syringe pumps or MEMs pumps or classical commercial available peristaltic pumps. For the latter one the clear difference is cost, commercial pumps costs from 300 USD up to 1000 USD, while open pumps could be crafted for 120 USD or less depending where do you buy the materials. In relation with micropumps, despite there's different range of prices, in many cases for third world countries, those technologies are not available and the importation costs are not only monetary, also time dependent. Finally between syringe pumps, which is the most similar device from the state of the art, there are 2 main reasons why to prefer peristaltic pumps: they can continuously work because they don't have the volume limitation of the syringe and they allow closed looped tube systems, which are crucial in vascular experiments or applications either for microfluidics or extracorporeal circulation [6].

Potential applications

First of all, the most important use for the device that it has been reviewing in this article is the use of cheap, easy to craft and almost worldwide available peristaltic pumps. That will allow to use this machine for the same purposes that the common device is use for but for a broad community of STEM and health related professionals.

Nevertheless, some tasks cannot be achieved for an open project, for example it is not expected to be used for hemodialysis or for blood transfusions in clinical conditions with real patients, for safety reasons. However in almost all handling fluids biological experiments such as vascular mechanics, microfluidics movement, even in tissue engineering (cell disposal or blood flow in newly formed vessels) the use of this low cost tools can be increadibly usefeul and sort of painkiller for researchers. Taking one specific example of the ones recently mentioned, and focusing on clinical applications, as Behrens et al. said, this technology could be applied to point of care liquid handling for microfluidic devices [6]. Another interesting application can be the simulation/testing/calibration of different flow conditions for patients with extracorporeal circulation machines in order to do massive or fast studies about hemolysis or clogging rates.

One last potential application of this device is to be used for teaching prototyping technologies, due to its ease of crafting, compared with other prototypable designs.

Documentation and openness

Plenty of designers and investigators allowed the freely use of their designs on open peristaltic pumps. The licenses found for these desgins are often Creative Commons license. Nevertheless some designs doesn't have any license at all.

Repos, sites, wikis, files

Here are a few links for github or other pages that contains instructions into how to build different peristaltic pumps:

- 3DP-peristaltic-pump-stepper (no license found): `https://github.com/jkugalde/3DP-peristaltic-pump-stepper`
- 3D-Printed-Peristaltic-Pump (no license found): `https://github.com/NaimFuad/3D-Printed-Peristaltic-Pump`.
- Open-source, 3D-printed Peristaltic Pumps for Small Volume Point-of-Care Liquid Handling (CC license) [6]: `https://www.nature.com/articles/s41598-020-58246-6`.
- Precise Peristaltic Pump (CC license) [2]: `https://www.instructables.com/Open-Source-Peristaltic-Pump/`.
- Open-Source-Peristaltic-Pump (MIT license): `https://github.com/umutcvc/Open-Pump`.

References

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[3] Ugalde, J. (2022, January 19). 3D printed peristaltic pump. Retrieved June 30, 2022, from GitHub website: https://github.com/jkugalde/3DP-peristaltic-pump-stepper

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[5] Forouzandeh, F., Arevalo, A., Alfadhel, A., Borkholder, D. A. (2021). A review of peristaltic micropumps. Sensors and Actuators A: Physical, 326, 112602. https://doi.org/10.1016/j.sna.2021.112602

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