Developing the drive system of a syringe infusion pump for drug delivery and blood sampling

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***Abstract* - Continuous and slow administration of medications such as analgesics, cytostatics, thrombolytics, anesthetics, as well as parietal fluids or nutrients is essential for patients with complex and/or chronic diseases because any change in infusion rate, by only a few ml per hour, can have dramatic effects for an emergent patient. Therefore, it is necessary to use an automatic drug infusion system that allows the possibility of adjusting the specific parameters of the infusion rate and the administration of medical fluids continuously, for a long time, with high accuracy.**

In this paper, was designed a syringe pump for drug delivery and sampling/drainage of intracavitary fluids. This module allows the possibility of use injector as an infusion pump or as a suction pump for collecting various biological samples such as blood, plasma, lymph or intracavitary fluids. This would be an advantage in terms of cost, time of preparation, and use of the device in the hospital or outpatient.

The infusion and suction system was implemented using a nut screw mechanism driven by a 42shdc4043z-22b bipolar stepper motor, controlled by an Arduino board.

Keywords - syringe pump, Arduino, bipolar stepper motor, biological sampling, intracavitary fluid drainage, infusion pump, suction pump

I. INTRODUCTION

A syringe pump or syringe driver is a small pump used to deliver small amounts of fluid in a specific environment. Syringe pumps have a wide range of applications from electrospinning, microdialysis, microfluidics to organ perfusion, in fields from health care to pharmaceutical industries. There are two broad types of pumps: research syringe pump and infusion pump.

An infusion system is a portable infusion pump for delivering small to high volume of medical fluids with high precision. It is the most commonly electro-medical device use to infuse drugs in solution or other parenteral fluids to the patient for therapeutic purposes. [1] [2] [3] It is a very efficient, accurate and rapid method [2] to administrate high concentrations of medications for long stretches of uninterrupted time, therefore the infusion pump became an indispensable device in anesthesia and intensive therapy, cardiac and diabetes units of hospitals. [4] The main routes of parenteral administration provided by the infusion pump are intravenous, subcutaneous, epidural and enteral administration. . [1] [3]

There are four main types of infusion pumps: gravity infusion devices [5], volumetric pumps [6], patient-controlled analgesia pumps [7], and syringe pumps. [8]

The gravity infusion pump uses gravity to infuse fluid. It was the first infusion pump used. It has been in use since the late 1960s. The system has two main advantages: the simplicity of mechanism and low production cost. However, these infusion devices are difficult to use precisely because the infusion rate is depending on the viscosity of the fluid. [5]

Volumetric pumps are used to infuse large amounts of medication. Typically, these pumps are more advanced, with many smart modules such as sensitive alert systems. However, this method is not always accessible, because the medical personnel needs specialized training. [6]

Patient-controlled analgesia pumps are infusion systems that allow patients to control their dosage as necessary. These pumps are designed for specific drugs such as analgesics (painkillers) or antiemetics in long-term, consistent treatment. Typically, they are more safety systems put in place for preventing overdosing. [7]

Syringe pumps deliver small doses of high concentration medications for a long period. The flow control may be volumetric or non-volumetric. [8]

Volumetric flow control sets the volume infused per time (ml/h), independent on the type of liquid. [1] [2] In a non-volumetric control, the pump controls the number of drops per time (drops/min). In this case, velocity depends on temperature, viscosity, and density of the fluid. . [2] [8] Similar to volumetric pumps, these are also often difficult to use and require specialized training to be implemented. [1] [8]

Nowadays syringe pumps become an indispensable medical device, more than 90 percent of surgical patients and one-third of non-surgical patients receive some form of intravenous therapy while in the hospital. [9]

Other necessary medical devices in hospitals are drainage suction pumps used for evacuation of post-operative accumulated liquids or in the drainage of intracavitary fluids in acute or chronic diseases, such as refractory ascites (in hepatic failure syndrome). [10]

The system proposed in this paper allows the movement of syringe plunger in both directions of the motion axis. Thus, the system can be used for infusing drugs, aspirating intracavitary fluids or taking biological samples.

In this work, it is desired to design an infusion system using: an Arduino board, a bipolar stepper motor 42shdc4043z-22b, an Arduino LCD keypad shield 1602, an end-stop limit switch, a buzzer, a green LED, a red LED.

This paper contains the following sections Section II: State of the Art; Section III: System Description; Section IV: Calculation Report; Section V: Observations and Conclusions.

II. STATE-OF-THE-ART

Researchers originally developed infusion pumps for controlled drug delivery. The first infusion pump was invented by Christopher Wren and Robert Boyle in 1658. [11] Throughout their experiments, Wren, Boyle, and other investigators primarily used bladder based pump type syringe and unit gravity feeding of liquid through a quill into blood vessels, veins in generally. Further developments, it was continued only in the 20th century.

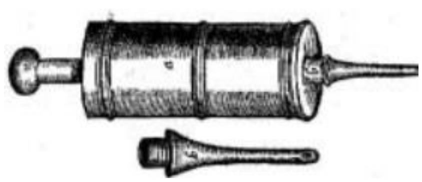

Figure II.1. - First infusion pump [11]

In 1967, J. M. Schwartz developed a new mechanism for a syringe pump based on a rack-pinion mechanism. [12] This mechanism will be present in the following figures.

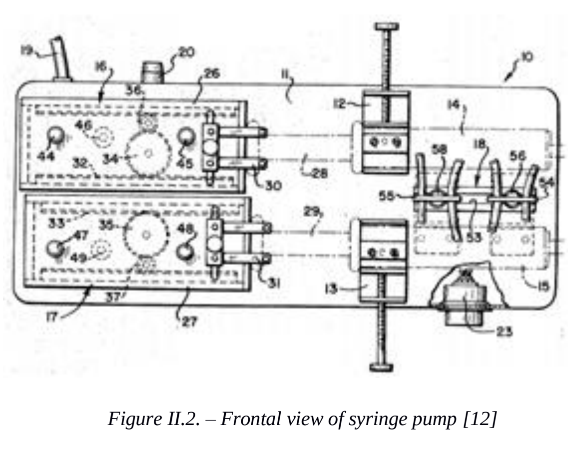

Figure II.2. – Frontal view of syringe pump [12]

The driver mechanism (16) has two separately drive carriages (26) (27), . The plunger (28), (29) of syringe (14),(15) are secured by adjustable plunger clamps (30),(31). The drive carriages (26) comprises a box-like structure, having a longitudinally extending rack (32) which are engaged by drive pinions (34). The idler gears (36) are disposed on the other side of each drive carriage (26,27). As shown in the figure, the drive pinion (35) of drive carriage (27) is driven through a reduction gear train (39) by a reversible, variable-speed motor (41). [12] When the motor is moving, the drive carriage with the racks drive

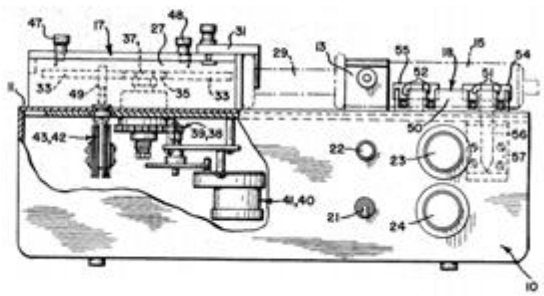

Figure II.3. – Longitudinal section view of syringe pump [12]

in the direction of fluid infusion and generate the moving of plunger in the direction of fluid infusion. [12]

In 1989, Alexandre Tsoukalis designed a syringe infusion pump that includes a lead screw mechanism for changing the rotational movement of a drive motor into a linear movement. The carriage is guided parallel to the axis of the lead screw and generates the moving of the plunger of the syringe. The carriage is disengageable from the lead screw for permitting the exchange of a syringe. [13] Syringe infusion pump mechanism will be present in the following figure.

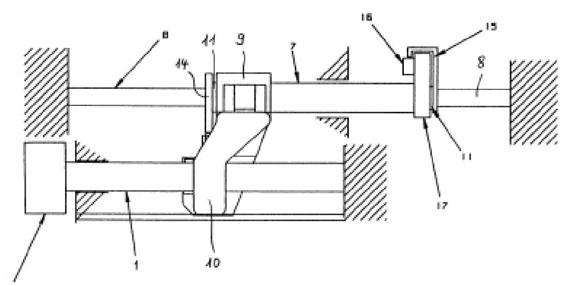

Figure II.3. – Kinematic diagram of syringe pump [13]

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he mechanism comprising a lead screw mechanism for translating rotational movement of a drive motor (18) into linear movement of a carriage (9) guided in parallel to the axis of the lead screw (1) The external thread of the lead screw (1) is driven by the drive motor (18), and an actuating mechanism (11, 14) controlling a brake (3; 3a, 3b) for normally arresting rotation of the worm wheel (2; 2a, 2b) in both directions for transmission of linear movement, and for 20 releasing the worm wheel (2; 2a, 2b) for free rotation in both directions and disengaging the transmission of linear movement. [13]

The mechanism and the operating principle of the Alexandre Tsoukalis injection have been preserved over the years. The only changes that have been made are at the sensors and alarm systems level. These changes were implemented because industry reports indicate an estimated 400,000 drug-related injuries occur in hospitals annually generating S3.5 billion in extra medical costs. [15] In the five years between 2005 and 2010 the MHRA investigated 1,085 incidents involving infusion pumps alone in the UK. In 68% of the reports no cause was established, 21% were attributed to user error, including maintenance, damage and contamination problems and 11% of incidents were due to device-related issues such as performance problems, degradation, inadequate quality assurance and design and labelling. [1]

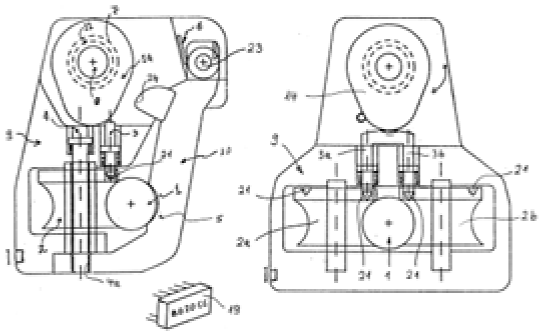

Figure II.3. – Lateral view of syringe pump [13]

Safety software, including drug error reduction systems (DERS), has been developed to reduce medication errors, enhance quality care, and improve work flow. [9]

Drug error reduction systems (DERS) typically use a drug library editor (DLE) to develop drug libraries including protocols, rule sets, and/or pump configuration settings, which are then loaded onto an infusion pump.[9] The drug library at the infusion pump provides medication pick lists for the caregiver to select the desired therapy, medication profiles including hard and Soft limits, and pump configuration settings including but not limited to distal pressure occlusion limits, air-in-line limits, callback settings, back light display settings, etc.[12]

III. SYSTEM DESCRIPTION

In this work, it is desired to design a syringe pump for drug delivery and sampling/drainage of intracavitary fluids. The mechanism is based on a lead screw mechanism driven by a bipolar stepper motor controlled by an Arduino board. The control panel consists on a keypad, to set the infusion parameters. The data output is visualized through an alphanumeric display (Liquid Crystal Display – LCD). This display shows the information on the infusion in course, the total volume to be infused, the flow rate (ml/min).

III.1. SYRINGE PUMP 3D MODEL

The 3D model of the system purge was made in AutoCAD, using the dimensions of the standard syringes. AutoCAD is a computer-aided graphics and design environment, produced and marketed by the American company Autodesk. It is a CAD program successfully used in fields such as architecture, medicine, and technology.

Figure III.1. – 3D model of the system purge

The main advantages in the use of AutoCAD are the lower storage -space, the possibility to easily make corrections, the opportunity to save repetitive drawings to CAD library, the realization of 3D CAD drawings as realistic as possible, the connection of CAD systems to CAM machines, the use of libraries with materials and possibility of simulating the way the assembly works.

The main disadvantages of AutoCAD-assisted design are the high probability to loose drawings if the computer crashes, the possibility to hack drawings, the complexity of the program, and the need to update frequently the program.

III.2. THE OPERATING PRINCIPLE

In this work, a lead screw mechanism was used for changing the rotational movement of a drive motor into a linear movement. The mechanism has a T8 nut and a threaded rod with a trapezoidal profile, diameter 8mm, step 2mm and length 400 mm. It is driven by a bipolar stepper motor 42shdc4043z-22b. The shaft of the motor is coupled by the threaded rod through an aluminum elastic coupling with an internal diameter of 8 mm. The nut was mounted in the first bore of the 3D printed support. To prevent the rotation of the support element, it uses an aluminum rod with an outer diameter of 8mm. To reduce friction between aluminum rod and support, it was inserted a linear bearing.

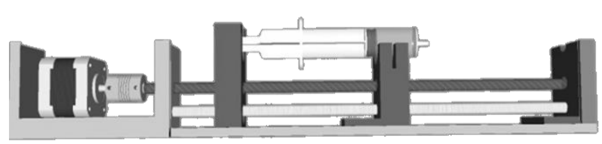

Figure III.2. – 3D model of the system purge mechanism

To engage the mechanism was used a two-phase bipolar motor with 200 steps per revolution, powered by 12V, 1A power supply. The motor is controlled by an A4988 driver.

The working parameters of the syringe pump are set using a 1602 LCD Keypad Shield for Arduino. The parameters which can be adjusted are syringe-type (10 -100 ml), flow rate (0.5 - 100 ml/min), flow direction (-1 for suction and 1 for infusion mode) and heat mode (0 not heat and 1 heat at 35*C).

Three LEDs were used: two LEDs to indicate how to use the pump (infusion, suction), and a third LED to indicate the successful completion of the command.

The syringe pump cannot recognize the type of syringe. Therefore it is necessary a system calibration for each device use. The stepper motor will rotate anticlockwise and generate a linear motion of the rod mount in the suction direction until the limit switch was touched. Then, it will calculate the number of steps until the rod mount plunger will be in a position that can permit the mount of the syringe. Afterward, it will wait for the confirmation of the operator and next will initiate the infusion or suction mode.

The housing will be contain a light intensity control system using infrared sensor. When the infrared sensor detects an object on its proximity (a hand waving in front of it), the light will turn on and off on the following rule: short wave:the led will turn on or off, according to the current state, if the hand wave is >1s, the LED starts to decrease its intensity gradually, until a minimum value. The intensity can be increased in only one way: short hand wave which will turn off the light, followed by a short wave hand, which will turn on the light again, at its maximum intensity.

III.3. 3D PRINTING OF COMPONENTS

3D printing is an easy and fast method of transforming a complex virtual 3D model into a physical prototype. Depending on the operating mode, two main printing techniques are distinguished: by extrusion (Fusion Filament Fabrication) and by laser deposition (Selective Laser Sintering, Stereolithography, Digital light processing.

Figure III.3. – 3D Printer Tevo Tarantula

In FFF (Fused Filament Fabrication) the model is fabricated by extruding small quantities of thermoplastic material arranged in successive layers.

A 3D TEVO Tarantula, presented in the following figure, was used to print the syringe pump. Table III.3-1 illustrates the technical specifications of the 3D printer.

Specifications	
Printing Technique	FFF
Maximum volume of print	200x200x200 (mm^3)
Maximum resolution	0.1 mm
Print speed	60 mm / s
Printed surface	Aluminum heated
Filament diameter	1.75 mm
Nozzle diamete	0.4 mm
Filament Printing	PLA, ABS, PETG, PVA and flexible filament

III.4. WIRING DIAGRAM

The following figure shows the diagram of the electric circuit. To make the injection system was used a 1602 LCD Keypad Arduino Shield, 42shdc4043z-22b stepper motor connected to an Arduino MEGA 2560 board through an A4988 driver.

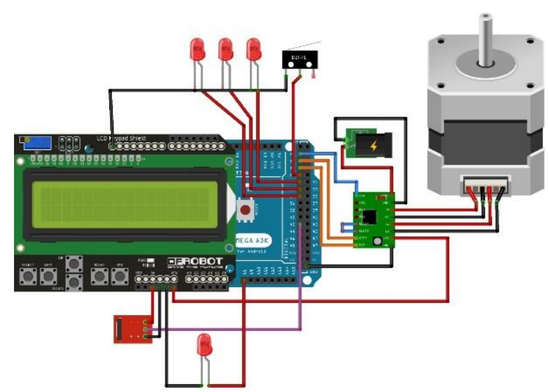

Figure III.4 – 1 Wiring Diagram of the Syringe Pump

IV CALCULATION REPORT

From the main menu, the user can select the infusion or aspiration flow rate (ml/min). The speed of rotation of the motor corresponding to the desired flow rate is calculated according to the formula:

$$\omega = \frac{Q \cdot 360°}{\pi \cdot R^2 \cdot p \cdot \partial}$$

where Q = flow rate, R = radius of cross- sectional surface, p = motor step, ∂ = step angle.

Suppose the flow rate defined by the flow of the volume of fluid V through a surface per unit time T:

$$Q = \frac{V}{T}$$

The volume of liquid pushed to a step is:

$$V = S \cdot p = \pi \cdot R^2 \cdot p$$

where S = cross-sectional vector surface

Then engine speed is:

$$n = \frac{1}{T} = \frac{Q}{V} = \frac{Q}{\pi \cdot R^2 \cdot p}$$

Suppose the engine speed defined in steps per second:

$$\omega = \frac{Q \cdot 360°}{\pi \cdot R^2 \cdot p \cdot \partial}$$

The radius of the cross-sectional surface depends on the syringe volume. The characteristic dimensions for a 10 – 60 ml syringe are illustrated in the table below.

Syringe volume	Syringe radius	Plunger length
10 ml		
20 ml		
30 ml		
40 ml		
50 ml		
60 ml		

V CONCLUSION

The developed system could be used as an infusion pump or suction pump. The device allows the setting of the basic parameters of the syringe pump.

During the experiments, it was found that the function of the stepper motor produces too much vibration in the infused or aspirated liquid so that the biological samples such as blood or lymph can not be taken. Also, due to vibration, it could not be implemented an alert system for occlusion or bubbles detection.

For future improvements, it is desired to replace the stepper motor with a DC motor coupled at a 1: 1500 reducer and to introduce an alert system in case of occlusion.

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