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Original Research

Nonlinear regression for the characterization of peristaltic pumps, an alternative in the control of biological fluids

Regresión no lineal para la caracterización de bombas peristálticas, una alternativa en el control de fluidos biológicos

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Abstract

This paper presents a modeling approach to characterize two peristaltic pumps using nonlinear regression. Accuracy tests were performed by varying the height level of the pump with respect to the vessel, and it was found to have no effect on the flow rate. Filling data was recorded for 300 ml considering the voltage applied to the pumps and the filling time. A least squares curve fitting was performed with the recorded data. The exponential model was determined to be the most accurate for the two pumps, and using a simple rule of three, the equation for each desired volume was found. Finally, filling tests were performed to compare the model data with the real data. The coefficient of determination of the model for the first pump was 0.9875 and for the second pump was 0.9956. It can be concluded that the models are accurate, which is also confirmed in the comparative filling tests, where an assertiveness of more than 99% was demonstrated in all the tests performed. It is proposed to extend the studies on the use of this mathematical method as an alternative in the non-invasive control of fluids whose instruments must be handled in a sterile manner.

Resumen

Este artículo presenta un modelamiento para la caracterización de dos bombas peristálticas utilizando regresión no lineal. Se realizaron pruebas de precisión variando el nivel de altura de la bomba respecto al recipiente y se concluye que esto no influye en la rapidez del flujo. Se tomaron datos de llenado para 300ml teniendo en cuenta el voltaje aplicado a las bombas y el tiempo de llenado. Con los datos registrados se realizó ajuste de curvas por mínimos cuadrados determinando el modelo exponencial como el más acertado para las dos bombas y aplicando regla de tres simple se halló la ecuación para cualquier volumen solicitado. Finalmente se realizaron pruebas de llenado para comparar los datos del modelo con datos reales. El coeficiente de determinación del modelo de la primera bomba fue de 0,9875 y para la segunda fue de 0,9956 concluyendo que los modelos son acertados, lo cual se reitera en las pruebas de llenado comparativas donde se evidencia un asertividad superior a 99% en todas las pruebas realizadas. Se sugiere ampliar las investigaciones en el uso de este método matemático como alternativa en el control no invasivo de fluidos cuyos instrumentos requieran un tratamiento estéril.

Keywords: Nonlinear regression, peristaltic pumps, Characterization pumps, Engineering

Palabras clave: Regresión no lineal, bombas peristálticas, Caracterización de bombas. Ingeniería.

How to cite?

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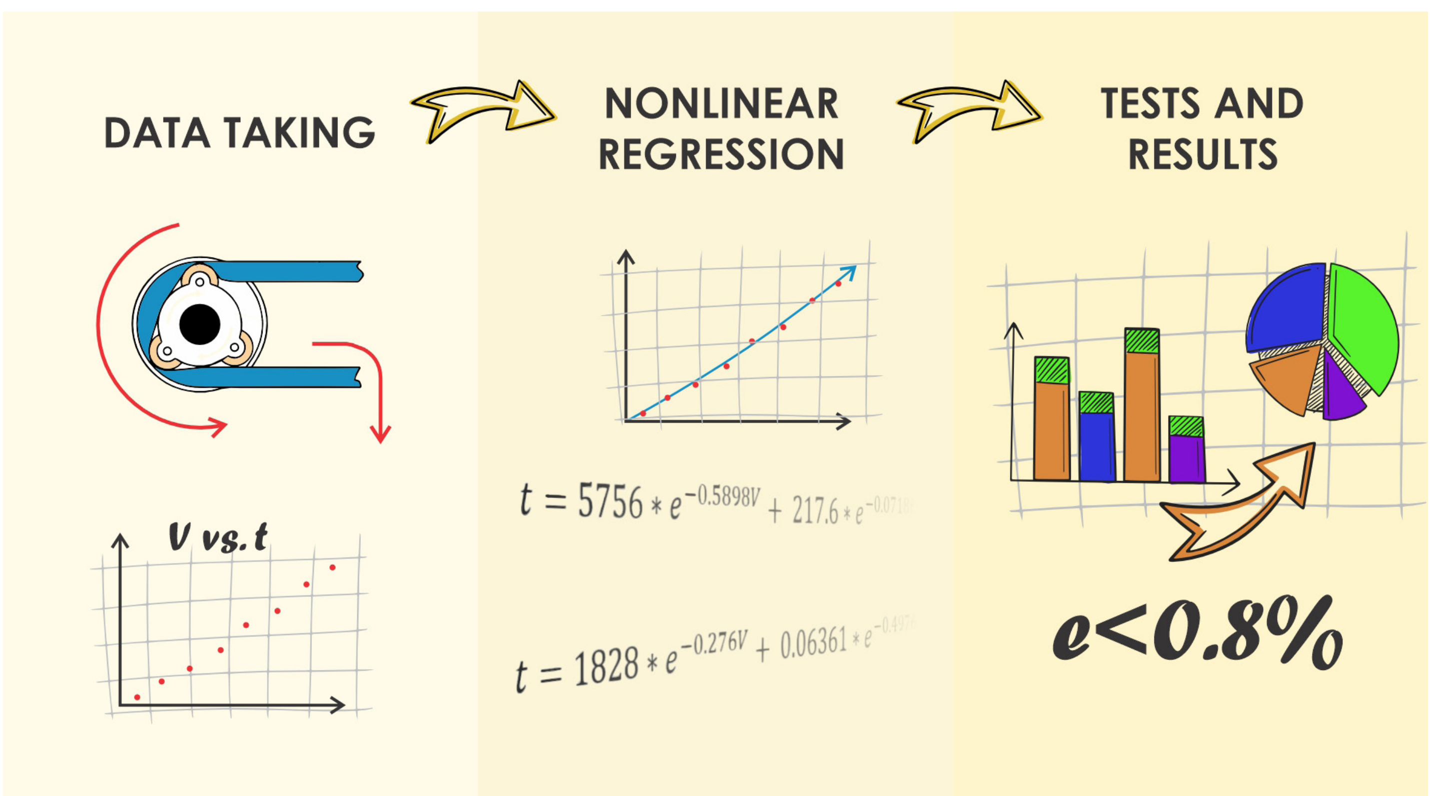
Why was the study carried out?
The research arose from the need to have an alternative for the non-invasive control of fluids whose instruments must be treated sterilely.

What were the main results?
Two peristaltic pumps were characterised using non-linear regression for flow modelling. When performing comparative tests for filling control, all errors were below 1%.

What are the benefits of these results?
These results open up a range of possibilities in the control of fluids that require sterile handling, increasing accuracy and avoiding the use of expensive sensors and instrumentation.

Graphical Abstract



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Introduction

Peristaltic pumps are hydraulic. They pump fluids by displacement through flexible tubes or hoses located inside the pump housing. These pumps are used for transporting biological fluids, pumping substances such as acids, creams, emulsions, in laboratories and processes with small flow rates (1). There have been several studies on this subject. López (2), for example, developed a peristaltic pump based on stepper motors. Díaz (3) characterized two peristaltic pumps controlled by a DC motor and a stepper motor, as well as a diaphragm pump, and Moraes (4) developed flow control for peristaltic pumps using an Arduino platform and a flow sensor. Several investigations have been carried out in the mathematical modeling of peristaltic pumps (5-8). Several investigations have been carried out in the mathematical modeling of peristaltic pumps (5-8). Peristaltic pumps require sterile tubing in most cases due to the fluids being transported. Therefore, characterization of peristaltic pumps using nonlinear regression (9), a least squares curve fitting method, is presented as an alternative. The application of this mathematical modeling has yielded excellent results in several studies. Velasquez (10), for example, used three nonlinear regressions to predict Mackey-Glass time series. Cobos et al. (11) compared the results of heuristic techniques ABC Artificial Bee Colony and PSO Particle Swarm Optimization used for parameter estimation of nonlinear regression models. Galeano and Cerón (12) modeled of Lohmann LSL chicken growth using neural networks and nonlinear regression models. Vera et al, (13) used nonlinear regression in modeling a solar panel. Finally, it is important to note that it was one of the mathematical methods used to study the pandemic caused by Covid-19 (14–18).

Materials and methods

A descriptive and applied methodology was used to develop the research, as shown in Figure 1.

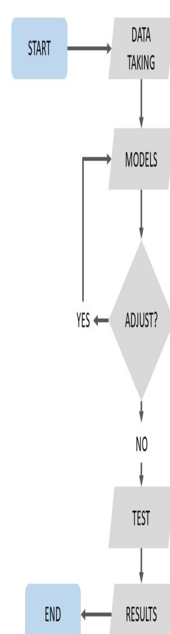

Figure 1. Methodology used in the project

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Peristaltic pumps are used that have potentiometers for voltage variation which modifies the flow intensity. Data collection begins with a precision test that varies the vertical position of the pump with respect to the fill tank, as shown in Figure 2.

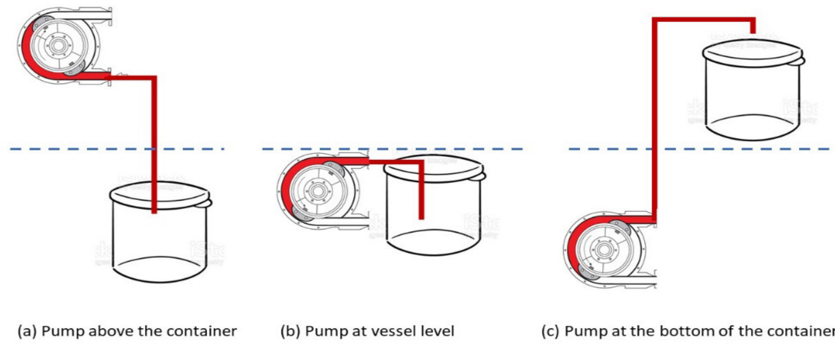

Figure 2. Pump levels for precision testing

The purpose of this test is to analyze the effect of this variation in fluid velocity to determine if this changes the performance of the pumps and if so, to include this variable in the mathematical analysis.

The pump is placed above the level of the vessel as shown in Figure 2(a), then at the same level as shown in Figure 2(b), and finally, the pump is placed at a lower level than the vessel, as shown in Figure 2(c).

Data were collected for filling 300 ml of water with the two pumps by changing the voltage and recording the time in seconds. With this data, we proceed with mathematical modeling using nonlinear regression. Curve fitting is performed and the modeling is repeated until the best results are found. Exponential, polynomial, potential, and Gaussian models were developed, with the exponential model being the most successful. Filling tests are performed with the obtained models and the model times are compared with the real times.

Results and discussion

The accuracy test shown in Figure 2 indicated that the height of the pump with respect to the container did not change the behavior of the liquid. We then plotted the data for 300 ml by plotting the voltage against time, as shown in Figure 3.

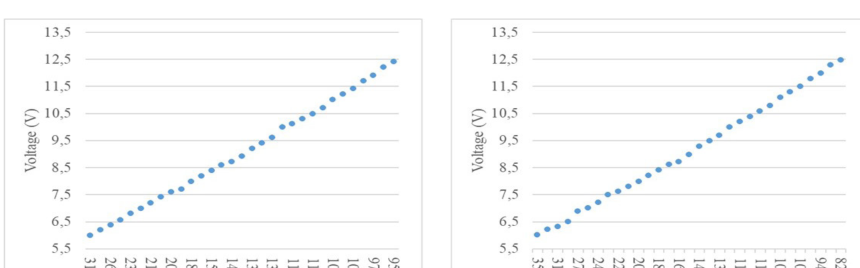

Figure 3. Voltage versus time data acquisition

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With the above data, a nonlinear regression model is developed using academic software. Exponential, Gaussian and quadratic modeling is performed, with the exponential model yielding the best results. Figure 4 shows the model developed for each pump.

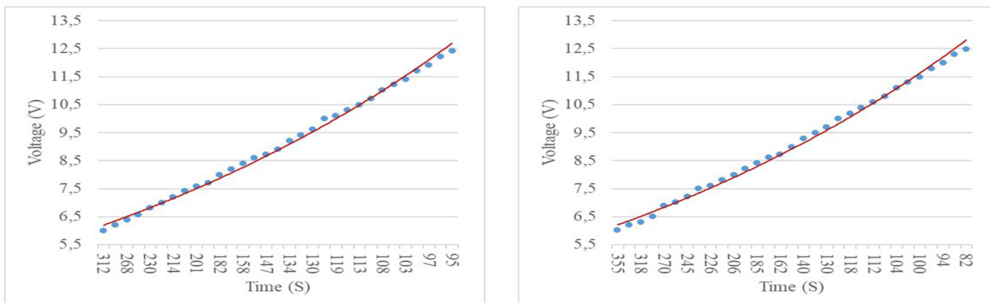

Figure 4. Modeling using nonlinear regression

The purpose of the study is to determine the time required for each pump to fill a certain amount of volume according to the applied voltage. After performing a dimensional analysis [19], the dependent variable is time (t) and the independent variable is voltage (v).

The applied exponential model obtained a coefficient of determination of 0.9875 for pump 1 and 0.9956 for pump 2. The model for pump 1 is described by Eq (1).

$$t = 5756 * e^{-0.5898V} + 217.6 * e^{-0.07186*V} \quad (1)$$

The model of the second pump is described by Eq (2).

$$t = 1828 * e^{-0.276V} + 0.06361 * e^{-0.4976*V} \quad (2)$$

Finally, for each model, a simple rule of three was used to find an Eq (3) for each desired filling volume, as follows:

$$t(v) = v * t(300ml)/300 \quad (3)$$

$t(v)$ is the time for any volume v, and t(300ml) is the filling time of 300 ml found with the developed exponential models. Applying Eq (1) and Eq (2) in Eq (3), we have Eq (4) and Eq (5), for each pump respectively.

$$t(v) = v * (5756 * e^{-0.5898V} + 217.6 * e^{-0.07186*V})/300 \quad (4)$$

$$t(v) = v * (1828 * e^{-0.276V} + 0.06361 * e^{-0.4976*V})/300 \quad (5)$$

Considering that the peristaltic pumps used have variable voltage, the flow rate will be variable and is defined by Eq (6).

$$Q = v/t \quad (6)$$

Applying Eq (4) and Eq (5) to Eq (6), we have Eq (7) and Eq (8) for the flow rate of each pump as a function of applied voltage.

$$Q = 300/(1828 * e^{-0.276V} + 0.06361 * e^{-0.4976*V}) \quad (7)$$

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$$Q = 300/(1828 * e^{-0.276V} + 0.06361 * e^{-0.4976*V}) \quad (8)$$

By performing fill tests for different volumes and comparing the time required with the model time, the errors in each test were calculated. The average errors for all tests were then calculated and the results shown in Table 2 were obtained.

Table 2. Average errors in all tests

Volume Pump 1(v)	Average error (%)	Volume Pump 2(v)	Average error (%)
200ml	0,52	200ml	0,79
400ml	0,43	400ml	0,59
800ml	0,64	800ml	0,38
1000ml	0,63	1000ml	0,78
1200ml	0,74	1200ml	0,29
1400ml	0,53	1400ml	0,67
1600ml	0,72	1600ml	0,34
1800ml	0,82	1800ml	0,52
2000ml	0,99	2000ml	0,41

Average errors of less than 1% are evident in all tests.

Conclusions

The accuracy test showed that varying the pump head with respect to the container does not change the fluid velocity. This facilitates modeling by not having to include another variable in the analysis. The measures of determination showed accurate modeling for the two peristaltic pumps, with the exponential model being the most accurate. The models had an assertiveness greater than 99%, as the average errors were less than 1% in all tests. Nonlinear regression is an effective mathematical model for characterizing peristaltic pumps whose use does not require sterile flow sensors, which can be expensive. Clarification of the formula using the simple rule of three to determine the filling time of any volume, with modeling performed only for 300 ml, shows that the filling volume is a variable that varies linearly and proportionally to the models developed. It is proposed to expand research on the use of nonlinear regression as an alternative for the control of biological fluids when the use of sterile instruments is required.

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References

1. Luna, Hector & Valderrama-Rincon, Juan & Martínez, Andrés & Rincón J. Bomba peristáltica con cabezal tipo rodamiento y portamanguera para desgaste reducido. Rev SayWa [Internet]. 2020. Available from: https://www.researchgate.net/publication/332553328_Bomba_peristaltica_con_cabezal_tipo_rodamiento_y_portamanguera_para_desgaste_reducido
2. C. López García. Diseño y fabricación de bomba peristáltica basada en motores paso a paso [Internet]. Universidad de Sevilla; 2015. Available from: https://idus.us.es/handle/11441/36281
3. A. F. Díaz Viloria. Diseño y caracterización de un sistema de control preciso de dosificación y frecuencia de riego para el ensayo de estrategias de fertirriego en un banco de pruebas hidropónico [Internet]. Universidad de los Andes; 2018. Available from: https://repositorio.uniandes.edu.co/handle/1992/39535
4. Luis de Moraes D. Desenvolvimento de um Sistema de Controle e Medição de Vazão para Bombas Peristálticas. UniversidadeFederaldeOuroPreto - UFOP; 2016.
5. Díaz-Montes E, Martínez-Hernández J, Cerón-Montes G, Vargas-León E. Transferencia de calor en el contenedor de alimentación de un secador por aspersión. Pädi Boletín Científico de Ciencias Básicas e Ingenierías del ICBI. 2022 ;10(19):84–93. Available from: https://repository.uaeh.edu.mx/revistas/index.php/icbi/article/view/8896
6. Rojas-Meza E, Recalde-Dicado K. Implementación de un módulo IoT hidropónico NFT semiautomático con alimentador de nutrientes por control difuso. Universidad Politécnica Salesiana [Internet]. 2023 Available from: https://dspace.ups.edu.ec/handle/123456789/24134
7. Rivera-García J. Modelado y caracterización hidrodinámica de celdas de flujo redox con electrodos tridimensionales para su aplicación en sistemas de almacenamiento de energía. Centro de Investigación y Desarrollo Tecnológico en Electroquímica, S. C. [Internet] 2023. Available from: https://cideteq.repositorioinstitucional.mx/jspui/handle/1021/514
8. Herrera-Baños E. Modelación matemática y simulación de un sistema enfriador-calentador, mediante el uso de un enfriador termoeléctrico (TEC). ESPOL. FIEC [Internet]. 2023 Available from: https://www.dspace.espol.edu.ec/handle/123456789/57631
9. S. Chapra y R. Canale. Métodos numéricos para ingenieros. Interamericana MG-H, editor. México, D. F; 2007.
10. David J, Vel´ V, Henao V. Pronóstico de la serie de Mackey-Glass usando modelos de regresión no lineal. DYNA. 2004;71(142):85–95.
11. de-los-Cobos-Silva S, Gutiérrez-Andrade MA, Rincón-García EA, Lara-Velázquez P, Aguilar-Cornejo M. Colonia de abejas artificiales y optimización por enjambre de partículas para la estimación de parámetros de regresión no lineal artificial. Rev Matemática Teoría y Apl [Internet]. 2014. 21(1):107–26. Available from: http://www.scielo.sa.cr/scielo.php?script=sci_arttext&pid=S1409-24332014000100007&lng=en&nrm=iso&tlng=es

doi: 10.25100/iyc.v26i1.12943

12. Galeano-Vasco L, Cerón-Muñoz M. Modelación del crecimiento de pollitas Lohmann LSL con redes neuronales y modelos de regresión no lineal. Rev MVZ Córdoba [Internet]. 2013.18(3):3861–7. Available from: https://revistamvz.unicordoba.edu.co/article/view/158

13. Vera-Dávila AG, Delgado-Ariza JC, Sepúlveda-Mora SB, Vera-Dávila AG, Delgado-Ariza JC, Sepúlveda-Mora SB. Validación del modelo matemático de un panel solar empleando la herramienta Simulink de Matlab. Rev Investig Desarro e Innovación [Internet]. 2018. 8(2):343–56. Available from: http://www.scielo.org.co/scielo.php?script=sci_arttext&pid=S2027-83062018000100343&lng=en&nrm=iso&tlng=es

14. Eduardo Ramírez Carvajal L, Puerto López KC, Luciano G, Barrera L. Análisis de curvas de covid-19 en Colombia utilizando ajuste por mínimos cuadrados. Ingeniare [Internet]. 2020. (29):41–55. Available from: https://revistas.unilibre.edu.co/index.php/ingeniare/article/view/7434

15. Alejandro J, Bastidas O, Priscila A, Pita P, Nathalia L, Vargas O, et al. Importancia de los modelos de regresión no lineales en la interpretación de datos de la COVID-19 en Colombia. Rev Habanera Ciencias Médicas [Internet]. 2020. 19. Available from: http://scielo.sld.cu/scielo.php?script=sci_arttext&pid=S1729-519X2020000400014&lng=es&nrm=iso&tlng=es

16. Gómez-Rojas J, Pérez JR, Hernández MT. Análisis y estimación gráfica del comportamiento del COVID-19 en Colombia, Santa Marta y Cartagena enfocado a la letalidad. Respuestas [Internet]. 2021, 26(1):118–31. Available from: https://revistas.ufps.edu.co/index.php/respuestas/article/view/2854/4204

17. Huancachoque-Mamani L, Pérez-Paredes MGS, Nolasco-Pérez IM, Huancachoque-Mamani L, Pérez-Paredes MGS, Nolasco-Pérez IM. Análisis predictivo de casos confirmados de Covid-19 en el Perú basado en el Modelo de Regresión no lineal de Gompertz usando datos de casos fatales. Tecnia [Internet]. 2021, 31(2):48–53. Available from: http://www.scielo.org.pe/scielo.php?script=sci_arttext&pid=S2309-04132021000200048&lng=es&nrm=iso&tlng=es

18. Carrillo E, Montero M, Jiménez A, Portelles J, Otero J. Diseño y pruebas realizadas en sensores piezoelectricos TTFM para la medición de flujo sanguíneo en implantes coronarios. Revista Cubana de Física. 2020; 40 (1)

doi: 10.25100/iyc.v26i1.12943