A PRELIMINARY STUDY ON ARTERIAL STIFFNESS ASSESSMENT USING PHOTOPLETHYSMOGRAPHIC SENSORS

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INTRODUCTION

In recent years, statistical studies have highlighted an increase in the incidence of cardiovascular diseases. Therefore, detecting and diagnosing these conditions in advance is crucial to ensure appropriate treatment and prevent further complications. Since the elastic properties of arteries change with aging or in the presence of diseases, **arterial stiffness** is a key indicator of vascular health [1]. A parameter used to estimate arterial stiffness is the **Pulse Wave Velocity (PWV)**, the speed at which the pressure wave propagates along a blood vessel.

To study the relationship between PWV and arterial stiffness, an experimental *in vitro* system was created to simulate the cardiovascular apparatus. Four different silicone models, each with distinct mechanical properties, were used to simulate blood vessels in terms of geometry and mechanical characteristics. Two **photoplethysmographic (PPG) sensors**, employed to measure PWV, were positioned at three specific distances along the four phantom models to determine the optimal distance for detecting arterial stiffness.

EXPERIMENTAL SETUP

The main components of the experimental setup (Fig. 1) are:

1) A pulsatile pump to generate flow and simulate the diastolic and systolic phases of the cardiac cycle (90 bpm)
2) A compliance chamber for simulating arterial compliance
3) An electromagnetic flowmeter (5 l/min)
4) A pressure transducer (70-120 mmHg)
5) A silicon phantom model (50 cm in length)
6) Two PPG sensors placed on the surface of the phantom model
7) An adjustable valve to regulate peripheral resistance
8) A fluid collector containing distilled water (3 liters, 24 °C)

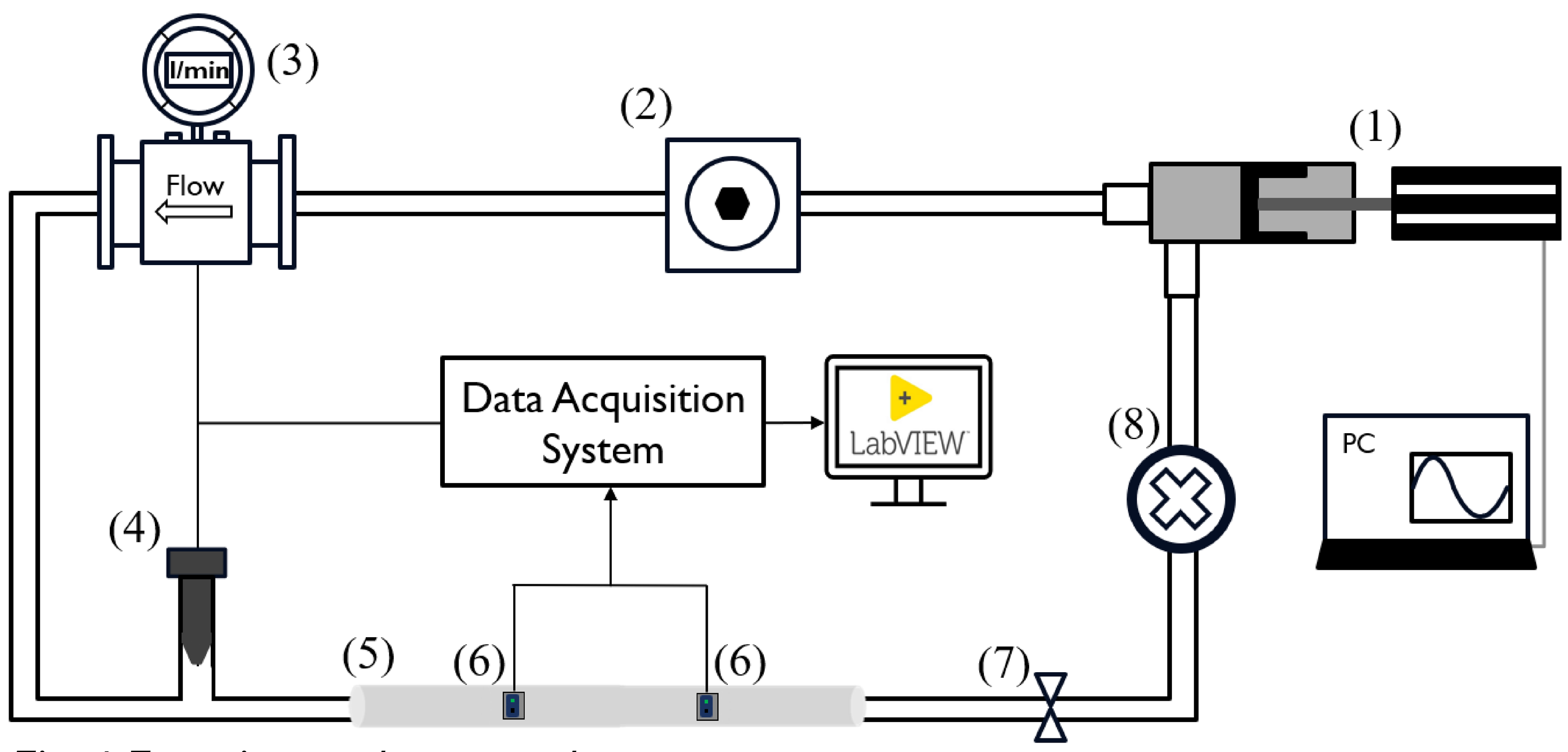

Fig. 1 Experimental setup scheme.

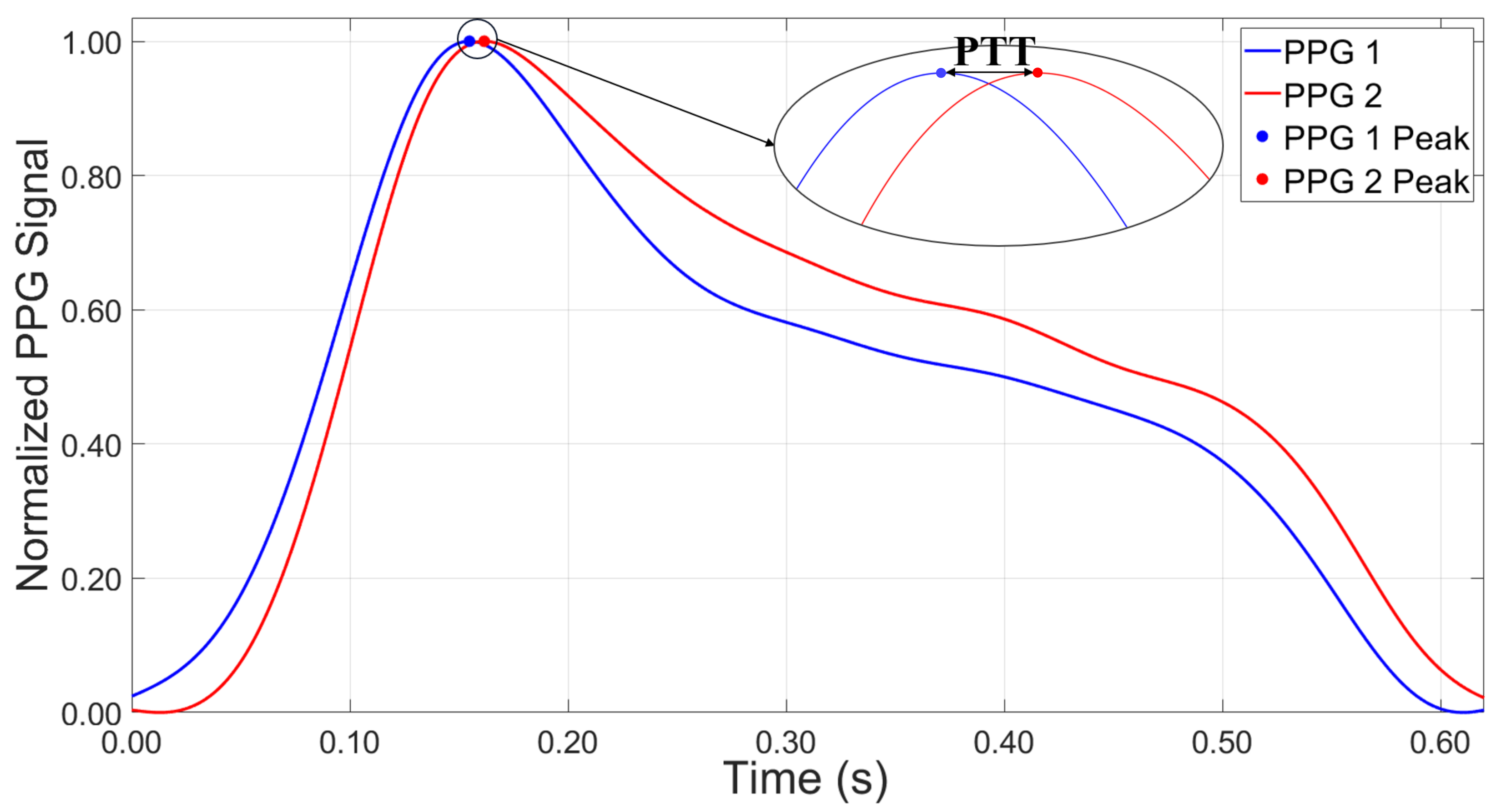

Fig. 2 PPG signals recorded from two sensors, PPG 1 (blue) and PPG 2 (red). PTT is calculated by measuring the time difference between the two PPG peaks.

MATHEMATICAL MODELS

Arterial stiffness can be estimated using the Moens-Korteweg equation [2], which correlates PWV with the mechanical and geometric properties of the blood vessel:

$$PWV = \sqrt{\frac{E\,h}{2\,r\,\rho}}$$

The PWV is estimated using the two PPG sensors by measuring the Pulse Transit Time (PTT) of the pressure wave (Fig. 2) between two sections of the phantom model, positioned at a distance Δs from each other [3]:

$$PWV = \frac{\Delta s}{PTT}$$

EXPERIMENTAL CAMPAIGN

Four models with different mechanical and geometric properties were considered to simulate various vascular health conditions. For each test condition, 10 measurements of 3 minutes each were performed. Tensile tests were conducted on samples to obtain reference values.

RESULTS AND DISCUSSION

Preliminary results (Fig. 3) show that with a PPG sensor distance of 15 and 20 cm, the measurement approach showed good accuracy (Tab. 1) in stiffness estimation, while the worst performance at 10 cm.

An increase in stiffness resulted in higher standard deviation.

The results are consistent with similar studies in the literature [4].

Future refinements will be made on improving the system both on the setup and on the calculation algorithm.

Tab. 1 Geometrical and mechanical properties of the models and experimental Young's modulus values.

Model	Dimensions (mm)		Tensile test (MPa)	Experimental Value (MPa)	
				15 cm	20 cm
1	8,60	1,30	2,10±0,23	2,04±0,15	2,00±0,19
2	15,00	1,50	2,70±0,14	2,63±0,24	2,78±0,28
3	8,00	1,00	4,00±0,29	4,04±0,51	4,20±0,58
4	16,00	2,00	5,65±0,43	5,74±0,65	6,18±0,82

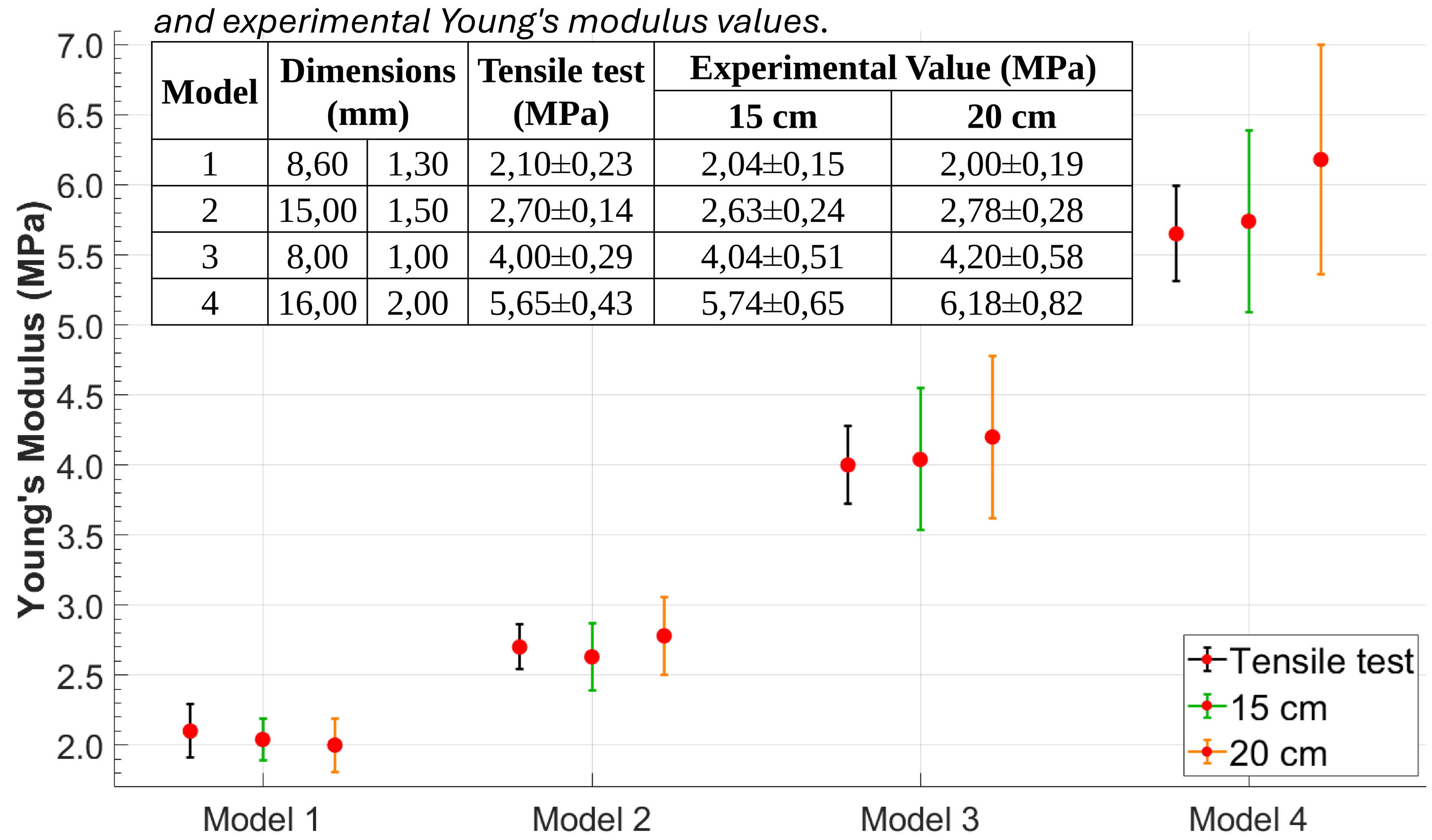

Fig. 3 Comparison between reference values and experimental values of Young's modulus.

REFERENCES

[1] Kohn JC, Lampi MC, Reinhart-King CA. "Age-related vascular stiffening: causes and consequences." Front Genet. 2015 Mar 30.
[2] Y. C. Fung, "Blood flow in arteries," in Biomechanics: Circulation, 2nd ed. New York, NY, USA: Springer-Verlag, 1997, pp. 108–205.
[3] F. Filippi, G. Fiori, G. Bocchetta, S. Sciuto, A. Scorza, "A Preliminary Comparison of Three Methods for the Assessment of Pulse Wave Transit Time in an Arterial Simulator" IMEKO TC-4 International Symposium.
[4] F. Fuiano, G. Fiori, A. Scorza, S. A. Sciuto, "A novel experimental set-up for Young Modulus Assessment through Transit Time measurements in Biomedical applications." 2021 IEEE International Workshop on Metrology for Industry 4.0 & IoT, Rome, Italy, 2021.

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ECSA-11 2024 Conference