

BULETINUL INSTITUTULUI POLITEHNIC DIN IAȘI

Publicat de

Universitatea Tehnică „Gheorghe Asachi” din Iași

Volumul 69 (73), Numărul 3, 2023

Secția

CONSTRUCȚII DE MAȘINI

DOI:10.2478/bipcm-2023-0029



## TESTING A NEW CONCEPT OF A SELF-ADAPTIVE TRANSTIBIAL PROSTHESIS

BY

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Received: December 21, 2023

Accepted for publication: December 30, 2023

**Abstract.** A considerable number of prosthetic medical devices for amputees are known. These devices do not fully replace the biological functions of the lost limb following lower amputations. In the case of pediatric patients, the problem is even more serious, as they are growing, it is necessary to regularly adjust the height of the prosthesis. Otherwise, a discrepancy occurs in the length of the limbs, that changes the center of gravity of the body of the prosthesis wearer, leading to related and sometimes serious pathologies. Currently, there are only classic, passive modules for adjusting the height of the prosthesis, but which are adjusted manually with low precision and extensive work. The present work contains the method of digital control of the prosthesis that can ensure the motorized height adjustment of the patient's lower limb. The results obtained from the experimental tests are presented, which indicate that this type of concept is feasible from a biomechanical point of view and can be a technical advance in the market of prosthetic medical devices addressed to the pediatric area.

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**Keywords:** prosthesis, leg length discrepancy, self-adaptive prosthesis, growing prosthesis.

## 1. Introduction

Over time, several lower limb prostheses have been developed with a role in fulfilling the functions of the lost biological limb. Some of these prosthetic devices with applicability in transtibial prostheses have been inventoried and classified according to several criteria such as the fields in which they are used, the mechanisms generating flexion and extension movements (Fodor and Seghedini, 2022).

A current problem present in the field of prosthetics is *leg length discrepancy* (LLD) which refers to the inequality in the measurements of the lower limbs, a phenomenon that determines a misaligned musculoskeletal system. Most clinicians issue different critical values of limb length discrepancy. They consider any leg difference greater than 10 mm to be pathological, requiring intervention (Pereiro-Buceta *et al.*, 2021). The findings of some authors suggest that an LLD of less than 20 mm should not be ignored (Pereiro-Buceta *et al.*, 2021). Several methods (classical and clinical procedures) of leg length discrepancy (LLD) assessment and the disadvantages of these methods in the assessment of *anisomelia* can be found in the literature (Vrhovski *et al.*, 2019).

Detection of LLD, especially in the case of children who have been amputated from the lower limbs, is particularly important for their physiological development. For example, total hip arthroplasty surgery usually results in mild postoperative LLD that could subject the prosthesis to greater pressures. This phenomenon could reduce the success of surgery. Because of the potential for mechanical stress on the prosthesis, the patient's healthy joints and the mechanisms of the prosthesis can suffer. All of these can contribute to patient dissatisfaction even when the intervention appears to be a success (Pereiro-Buceta *et al.*, 2021).

At this moment, a height adjustment of the prostheses can be ensured, but these adjustments are possible by means of classic, passive, and manually operated devices (Lenka *et al.*, 2008; Padhi *et al.*, 2022; Kadhim *et al.*, 2023; Össur, 2023; Vanguard, 2015). Thus, these devices can be elongated or compressed depending on the LLD detected by the prosthetist. Thus, the prosthetic pediatric patient and his family are put in a position to travel long distances from home and at regular time intervals for the adjustment of the artificial limb to the prosthetist. In this paper, an extendable prosthetic module that is driven by a DC motor was tested. The adjustment of the prosthesis takes place in order to compensate for the LLD detected by the prosthetist.

In the following parts of this paper, the materials used, the applied testing methodology, and the obtained results are described.

## 2. Materials and methods

In our research work the following actuation system was employed: a microcontroller was used to control the actuator within the height-adjustable prosthesis, which is functionally connected to a computer (Fig. 1). Via the PC interface, the microcontroller is powered and the functions of the entire system are controlled based on the input from the prosthetist. Thus, the prosthesis will not be manually adjusted by the prosthetist but will be self-adjusted by the automatic system based on the DC motor and the microcontroller connected to a PC. The power supply of this system can be provided from a 12 V and optionally a 5 V source. In the last configuration, the PC interface is no longer mandatory because the 5 V power supply and the microcontroller control will be independent of the growing prosthesis actuation system.

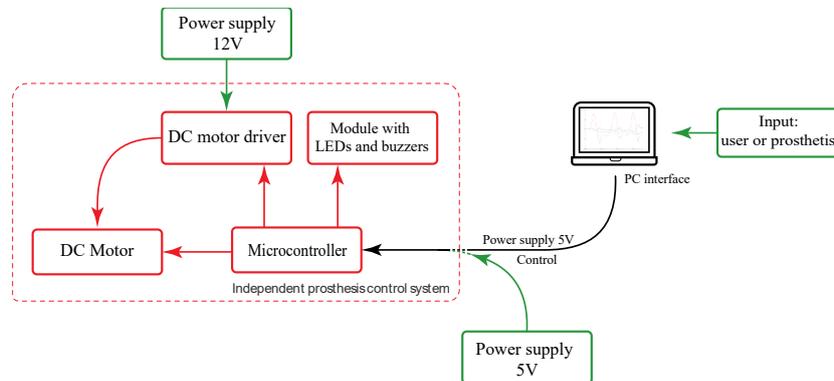


Fig. 1 – Block diagram of prosthesis control during experimental tests.

A driver connected to the microcontroller was used to control a DC motor mounted in the adaptive prosthesis. A 12 V power supply is used to power the DC motor control driver. The 12 V supply is provided from a socket with a voltage of 220 V, through a power source (input: 220 V, output: 12 V). Also, a light indication module is managed by the microcontroller to easily observe the status of the prosthesis (advancement in progress or retraction in progress).

The ATmega328P microcontroller included in the Arduino Nano development board, which is a small-sized platform, was used (architecture – AVR; operating voltage – 5 V; flash memory – 32 KB of which 2 KB used by bootloader; clock speed – 16 MHz; analog IN Pins – 8; digital IN Pins – 14; input voltage – 7-12 V; power consumption – 19 mA;). This platform uses a mini-USB plug to connect to the PC (Arduino, 2023).

An L298N type motor driver module was also used which is a high-power module for driving DC and stepper motors (driver chip – double H bridge L298N; motor supply voltage (maximum) – 46 V; motor supply current (maximum) – 2 A;

logic voltage – 5 V; driver voltage – 5-35 V; driver current – 2 A; logical current – 0-36 mA; maximum power (W) – 25 W). This module consists of an L298 IC (integrated circuit) and a 78M05 5 V regulator. The L298N module can control up to 4 DC motors or 2 DC motors with directional and speed control (Handsontec, 2023).

A CHR-GM25-370-12V DC motor was used to drive the prosthesis, which has the following technical specifications: torque – 1,4 g·cm; continuous current – 200 mA; commutation – brush; output power – 12 W max. (DC 12 V).

To determine the displacement of the prosthesis, the measurement of the increase and decrease in length from the plantar surface of the manikin to the upper end of the prosthesis during the controlled change in the length of the prosthetic lower limb was considered.

The schematic diagram of the equipment used for data determination and measurement is composed of a multi-channel amplifier (Spider 8, Höttinger Baldwin Messtechnik®), inductive displacement transducers type W1/10 (Höttinger Baldwin Messtechnik®), and a PC interface (Fig. 2).

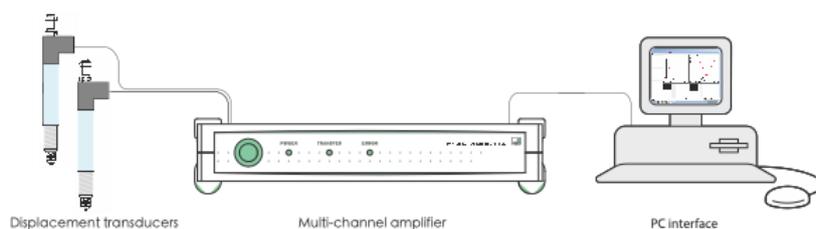


Fig. 2 – Schematic diagram of the equipment used for data acquisition and measurement (Chitariu, 2018; HBM®).

The multi-channel amplifier (Spider 8, Höttinger Baldwin Messtechnik®) has a number of 8 channels (4 basic and 4 optional channels through SR55 modules) through which data acquisitions can be made simultaneously. The channels have analog-to-digital converters, and the sampling frequency for each channel (data acquisition rate) is in the range of 1-9600 Hz. The Spider 8 amplifier and computer are interfaced via Catman Easy/AP® v.2.2 software. The software allows the configuration of customized interfaces, depending on the transducers, the number of channels used, etc. (Chitariu, 2018).

The displacement transducers used are inductive W1/10 mm type, Höttinger Baldwin Messtechnik®, and have the following technical characteristics: nominal displacement – 10 mm; nominal output span – 80 mV/V; nominal signal at starting point: -40 mV/V; nominal signal at end point – 40 mV/V; zero signal – the output signal is zero when the plunger or probe is at the midpoint of the measuring range; linearity deviation – 0.2%; operating temperature range: -20 ... +80 (Chitariu, 2018; HBM®).

During experimental work the contact method was used to determine the increase and decrease in length of the prosthesis. The sensitive element of the transducer which is a mobile core made of ferromagnetic material and is integrally one of the prosthetic components that perform translation in the advancement or retraction of the prosthesis. When the ferromagnetic core moves through a cylindrical coil in the transducer, the inductance of the coil changes (that is, the current absorbed by the coil), so the displacement is directly proportional to the indicated current. The displacement transducer connects to the multi-channel amplifier on the Wheatstone half-bridge principle (Chitariu, 2018).

Fig. 3 shows the schematic representation of the experimental stand for measuring the stroke that the prosthesis makes over time, to increase/decrease the length of the lower prosthetic limb. The growing prosthesis attached to the abutment of the manikin can be seen. A rigid element has been attached to the mobile component of the prosthesis containing the DC motor, which moves simultaneously with the advancement of the prosthesis. Two transducers with a nominal stroke of 10 mm each were used to be able to measure a maximum total extended displacement of the prosthesis of 20 mm. The transducers ( $T_1$  and  $T_2$ ) were positioned in the same direction, and  $T_1$  is extended and  $T_2$  is compressed.

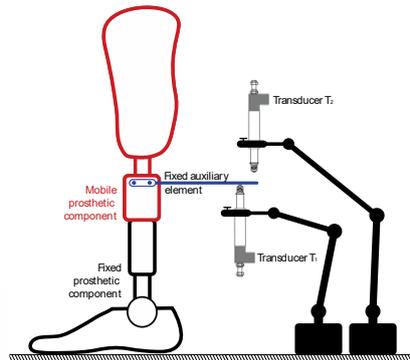


Fig. 3 – Schematic representation of the test stand.

### 3. Results and discussions

Fig. 4 shows the interface created in the Catman Easy/AP<sup>®</sup> program that was used for the acquisition of data related to the stroke that the prosthesis performs when the DC motor is powered. Thus in Fig. 4 the displacements perceived by each sensor is described. Data is recorded at a sampling rate of 25 Hz.

Different phases of the data records are visible in the Catman Easy/AP<sup>®</sup> program during prosthesis advancement (corresponding to increasing the length of the manikin's lower limb) and during prosthesis retraction (corresponding to decreasing the length of the manikin's lower limb).

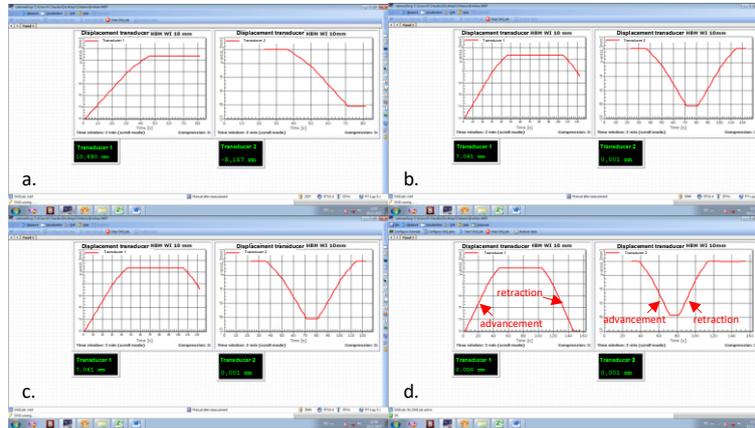


Fig. 4 – Screenshot of experimental results regarding displacement (mm) measured during advancement and retraction of the self-adaptive prosthesis (CatmanEasy/AP®).

Fig. 5 shows a total stroke of the advance of the prosthesis. The red curve was obtained by merging the green signal (recorded with  $T_1$ ) with the blue signal (recorded with  $T_2$ ) at a data acquisition rate of 10 Hz. To make this possible, the negative data recorded with  $T_2$  was converted to positive data.

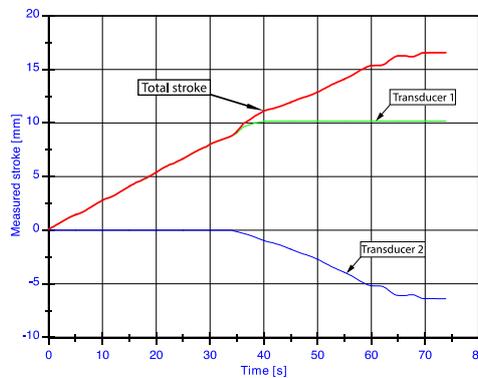


Fig. 5 – Evolution over time of the advance of the prosthesis according to the actuation time of the actuator.

The segment with overlapping signals (data recorded simultaneously with  $T_1$  and  $T_2$ ) was removed from the total stroke curve. This phenomenon is necessary to have a real continuity in the translation of the moment when the exchange of transducers takes place so that there are no interruptions in the recording of the 20 mm stroke that the prosthesis can achieve. This can be avoided by using a displacement transducer with a nominal stroke of 20 mm.

Fig. 6 shows the signals recorded at a sampling frequency of 25 Hz for the evolution of the advancement and retraction of the prosthesis with a green color for  $T_1$  and a blue color for  $T_2$ .

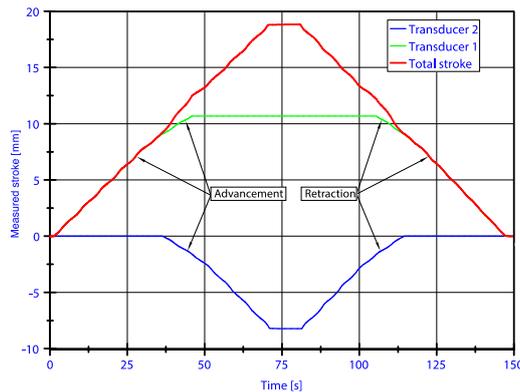


Fig. 6 – Evolution over time of the advance and retraction of the prosthesis depending on the actuation time of the actuator.

Fig. 7 shows the stroke (red signal) that was obtained by combining the two signals (25 Hz), for the advance and the retraction of the prosthesis. This was performed three times to see if the movement of the prosthesis was repeatable.

Slight deviations are observed between the three curves which may be caused by noise or the fact that the screw-nut drive mechanism has not smoothed out long enough and the moving contact surfaces of the parts have not yet been adjusted.

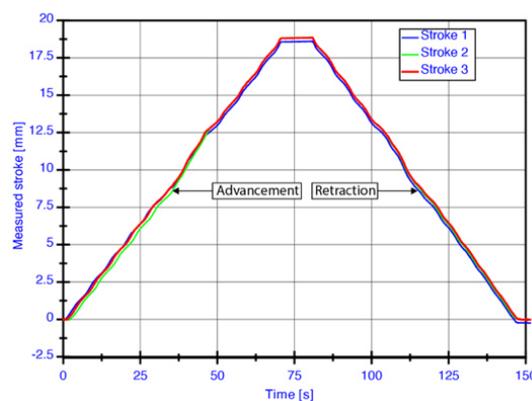


Fig. 7 – Evolution over time of the advance and retraction of the prosthesis depending on the actuation time of the actuator (stroke 1, 2, and 3).

#### 4. Conclusions

The paper includes a description of the main problems faced by pediatric unilateral transtibial amputations. It was found that these devices do not fulfill the essential biological functions lost after lower limb amputations, such as the automatic height adjustment of the artificial limb. In the case of pediatric patients, regular height adjustment of the prosthesis is necessary. Otherwise, the limb leg discrepancy may appear, which changes the center of gravity of the prosthesis wearer's body, leading to related pathologies.

Thus, preliminary experimental results were obtained regarding the stroke that the height-adjustable prosthesis can achieve, regarding its advance (increasing the length of the prosthetic lower limb what makes this prosthesis self-adaptable) and its withdrawal (reduction in the length of the prosthetic lower limb). Experiments were carried out with a multi-channel amplifier (tip Spider 8, HBM®) to analyze the total stroke that the prosthesis can perform over time. The performed work also contains the method of digital control of the growing prosthesis that can ensure the motorized height adjustment of the patient's lower limb. Also, the experimental results obtained from the tests are presented, which show that such a concept is feasible from a biomechanical point of view and can be an advance in the market of prosthetic medical devices addressed to the pediatric area.

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## TESTAREA UNUI NOU CONCEPT DE PROTEZĂ TRANSTIBIALĂ AUTOADAPTABILĂ

(Rezumat)

Este cunoscut un număr considerabil de dispozitive medicale protetice care se adresează amputaților. Aceste dispozitive nu suplinesc în mare măsură funcțiile biologice pierdute în urma amputațiilor de membru inferior. În cazul pacienților pediatrici, problema este și mai gravă, deoarece aceștia fiind în creștere, este necesară ajustarea regulată a protezei pe înălțime. În caz contrar, își face apariția discrepanța de lungime a membrelor care modifică poziția centrului de greutate a corpului purtătorului de proteză ducând la patologii conexe, uneori grave. La momentul actual, există doar module clasice, pasive pentru reglarea înălțimii protezei, care se reglează cu o oarecare subiectivitate. Lucrarea de față conține modalitatea de control digital a protezei care poate asigura reglarea motorizată pe înălțime a membrului inferior al pacientului. Sunt prezentate rezultatele experimentale obținute în urma testelor care arată că un astfel de concept este fezabil din punct de vedere biomecanic și poate fi un avans tehnic pe piața dispozitivelor medicale protetice adresate zonei pediatrice.