Towards a soft articulated bionic hand for pediatric users

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***Abstract*—The present work develops a pediatric soft prosthetic hand, based on the technologies of the Pisa/IIT SoftHand. The mechanical design is the result of a parametrization of variables of the existing device. The hand has shape and dimensions similar to the one of children between 6 and 9 years. Fingers are based on a modular structure that allows scaling the Pediatric SoftHand Pro, to follow the growth of the user. The soft technology ensures to obtain a robust and versatile device. Moreover, the softness allows grasping firmly objects of different sizes.**

***Index Terms*—Robotic Hand, Soft Robotics, Pediatric Prosthesis.**

I. Introduction

According to neuroscientists and occupational therapists [1], the age of first fitting of a prosthetic hand in a pediatric patient is a relevant factor. The application of an active prosthetic device in an early stage may obtain functional benefits since the developing motor scheme and control can incorporate the prosthesis. Many clinicians encourage early fitting, as a basis for normal neural development of children and as means of prevention of possible ensuing syndromes [2]. Differently from cosmetic and body/powered devices, whose management is widely accepted, the proper age for fitting myoelectric devices is a controversial topic in literature. [3] indicates the tendency in the United States towards an application at 10-15 months, while [4] shows no advantages in a fitting before 30 months, indicating 4 years as the preferential age.

The rate of rejection of myoelectric devices in young patients is high, up to 25% [5]. One of the principal causes is the unintuitive control strategy of these devices [6]. Additionally, they show low durability, due to the fragility of their components. This makes necessary continuous assessment and assistance for the device, which in turn increases its final cost. Another important factor for the price of pediatric prostheses is the need for adaptation to rapid child growth. Sockets may require adjustments every 3 to 6 months, while the replacement of the entire prosthesis is necessary every 1-2 years [7].

Existing myoelectric hands can be divided into grippers and anthropomorphic hands. On one side, grippers are 1 Degree of Freedom (DoF) devices, covered with cosmetic gloves, that roughly reproduce the movement of the hand. However, they are lightweight and can reach dimensions for 6-12 months old users. On the other side, anthropomorphic myoelectric hands are complex multi-DoF and multi-Degrees of Actuation (DoA) devices, able of dexterous movements, but heavier, expensive, and suitable starting from 8-10 years.

Fig. 1: Starting from the left, the Robotic Pisa/IIT SoftHand, the Adult SoftHand Pro and the Pediatric SoftHand Pro.

The hand, here presented, tries to integrate the advantages of both the concepts of myoelectric hands. The Pisa/IIT SoftHand [8], applied in robotics and as prosthesis for adults [9], inspired the design of this new device; it is an underactuated hand, in which a single DoA pulls a tendon that moves the entire hand, reproducing the first synergy of the human hand [10].

In the next section, a detailed description of the architecture of the Pediatric SoftHand Pro is done. Fingers are designed with custom-made elements to achieve sufficiently low sizes. Dimensioning of the path of the tendon and of motor group considers the replication of the first synergy. Grasping tasks successfully performed with the prototype are shown. Future works are presented in the conclusions.

II. Mechanical design of the Pediatric SoftHand

The Pediatric SoftHand Pro is an underactuated hand, with 5 fingers moved by a single electric motor. The pull of the motor shaft is transmitted to all the soft joints of the hand. Dimensions of the pulleys and stiffness of the tendon and elastic elements of joints are set so that the kinematics of the Pediatric SoftHand Pro reproduces the first synergy of human pediatric grasping.

The presented prototype, shown in Figure 2 has shape and dimensions that can fit 6-9 years old children (Table I). A comparison between three different versions of the SoftHand (Robotic, Adult, and Pediatric prosthetic) is visually proposed in Figure 1. The weight of the pediatric version is around 170g, significantly less than any existing anthropomorphic version [1].

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[1]https://www.ossur.com/

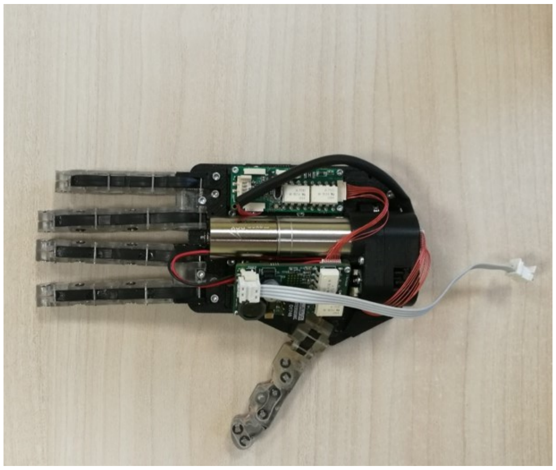


Fig. 2: Prototype of the Pediatric SoftHand Pro.

Hand	Palm [mm]	Middle f. [mm]	Little f. [mm]
6 yo child [11]	76	74.5	54.5
Pediatric SH Pro	80	61.5	56

TABLE I: Comparison between significant lengths of a mean 6 year old child hand and of the Pediatric SoftHand (SH) Pro.

A. Design of fingers

Fingers are assembled connecting a proximal to two medial and a distal phalanges, whilst the thumb has only one medial phalanx, as in the human anatomy (see Figure 3). They are composed of two 3D printed symmetrical elements. Two sizes of medial phalanges are designed (see Figure 3), a ”short” and a ”long” one, for ensuring the modularity of the device. By combining different sizes of phalanges, the length of every finger can be adapted to the growth of the user. The prototype for 6-9 years old users applies long phalanges in the index, the middle, and the ring fingers, which are identical, and short ones in the little finger and the thumb. The thumb has a proximal phalanx that ensures an autonomous opposable movement during the closure of the hand.

The implementation of joints developed in [8] allows the connection of phalanges. They are composed of tendon and elastic elements, one phalanx rolls on the flat cam of the successive one. They are dislocatable and elastic, ensuring robustness and softness, features that particularly adapt to careless and active children. The tendon is wrapped around 4 pulleys in long phalanges and 3 in the short. Bearings are custom-made, to have dimensions that satisfy the kinematic of the Pediatric SoftHand Pro. The tendon closes each finger when it is pulled by the motor. Elastics are placed in the dorsal side of fingers and tensioned so that they can restore the open hand position when the motor pull is released. To have a stiffness that allows reproducing the first synergy of human grasping, elastic dimensions are customized for this prototype.

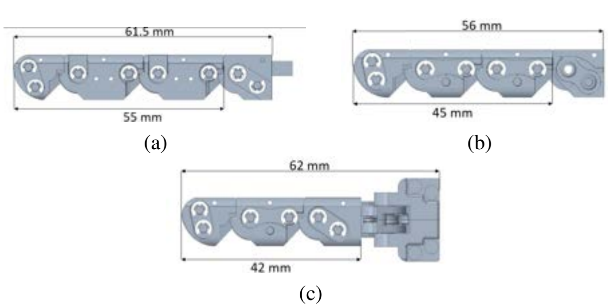


Fig. 3: Figures show the CAD representation of the index, middle and fore finger 3a, little finger 3b and thumb 3c.

B. Design of the palm

The palm hosts the motor group, pulleys for the kinematic architecture of the hand, and the electronic elements. The proximal phalanges of fingers are directly and firmly connected to it. In this prototype, the abduction-adduction of fingers is not present, this choice is motivated by the necessity of adapting dimensions to pediatric application. The palm is divided into two semi-planes with a relative constant inclination equal to 6°. This angle causes a convergent movement of fingers towards the opposable thumb. Electronic components are specifically designed to match dimensions that can be reached by the Pediatric SoftHand Pro. They are split into a logic board and a power board, arranged on the two sides of the motor placed on the palm (see Figure 2).

C. Design of the motor group

The design of the motor group for the Pediatric SoftHand Pro has considered both the performances, in terms of torque and speed, and the volume, length, and weight. Dimensions have to be compatible with the palm of a 6 years old child. After a meticulous survey among the suitable commercial solutions, the DCX 16S-12V motor has been selected, coupled with a GPX16HP gearbox, with a transmission ratio of 138:1, composed of 3 stages of reduction. The electric motor has an efficiency of 77.3%, while the commercial gearbox has 65%. The motor group provides a pull on the tendon that allows closing the hand in 1 s, and tension in the tendon of 100 N, to obtain a firm grasp of objects of everyday use (for further details see Section III).

III. EXPERIMENTAL GRASPING

Pediatric SoftHand Pro has been tested in grasping different objects of everyday use, to verify the feature of adaptivity. The hand is fixed on a table and the objects are placed in the grasp. Table II shows pictures of grasping 5 objects of different shapes (a sphere, a tube, scissors, a screwdriver, and a card). They are successfully grasped by the Pediatric SoftHand Pro, with a power or a tip grasp. In Table II, a comparison with grasps of the same objects performed with a 6-year-old child is proposed. This helps for highlighting the similarity between the grasping shape of the human hand and the Pediatric SoftHand Pro. The introduction of the inclination of the palm in the Pediatric SoftHand Pro enhances the wrapping around objects. The grasp of the sphere, which is large if compared to the hand, is performed in a proper way by the device, thanks to the inclined palm.

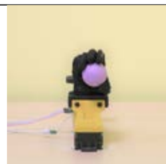
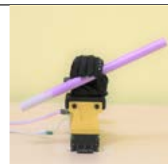
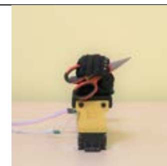
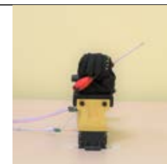
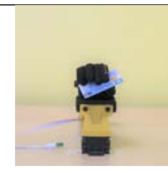
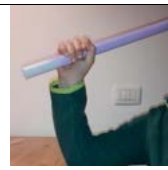
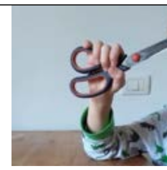
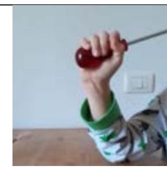
Hand	Sphere	Tube	Scissors	Screwdriver	Card
Pediatric SH Pro					
6 yo child					

TABLE II: Visual comparison between grasping of a sphere, a tube, scissors, a screwdriver and a card performed with the Pediatric SoftHand (SH) Pro and a 6 year-old child's hand.

IV. Conclusions and Future Work

The presented Pediatric SoftHand Pro tries to fill the lack of research and commercial pediatric myoelectric devices. It results in an anthropomorphic and lightweight hand, that can fit children of 6-9 years old. The modular structure of fingers allows scaling the Pediatric SoftHand Pro, to follow the growth of the user, avoiding the complete and expensive substitution of the device. The prototype reproduces the first synergy of the human hand and it allows grasping firmly a large variety of objects, of different shapes and dimensions, thanks to the adaptability ensured by soft technologies. It is validated experimentally through grasping tests and grasping force measurements.

The next steps of the development process for this prototype will be focused on clinical trials with pediatric users. It will allow validating the design in terms of safety, efficacy, and usability of the hand. Joint work with neuroscientific scientists is also planned, to understand how the early fitting impacts the motor abilities of the child. The effect on the rate of rejection, if any, will be analyzed.

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