

**THE SELF ACTUATED TENIM HAND: THE CONVERSION OF A BODY-DRIVEN PROSTHESIS TO AN ELECTROMECHANICALLY ACTUATED DEVICE**

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**ABSTRACT**

Users of body-driven prostheses often abandon their prostheses due to overexertion of their shoulders and a lack of features. The aim of this study was thus to design an electromechanical hand prosthesis that meets the functional and grasping requirements of prosthesis users.

To this end, the Self-Actuated Tenim Hand (SATH), a functional electromechanically actuated prosthesis, was developed. The SATH, based on the novel body-driven Tenim Hand, incorporated design refinements that improved on its predecessor's grasping capabilities. An electromechanical actuator and a wrist supination and pronation mechanism were integrated into the SATH thereby improving its functional capabilities.

The Anthropomorphic Hand Assessment Protocol (AHAP) was used as a design validation tool to assess the functional capabilities of the SATH. The SATH performed satisfactorily in AHAP and achieved results that are comparable to scores obtained by a more advanced prosthesis.

Keywords: Prosthesis design, upper limb prostheses, 3D printed prostheses, Tenim Hand, Anthropomorphic Hand Assessment Protocol

**1. INTRODUCTION**

An estimated 2.4 million people with upper-limb amputations live in lower to middle-income countries (LMICs)[1]. In these countries, upper-limb amputees are generally limited to the use of body-driven prostheses. Yet users of body-driven prostheses often abandon their prostheses due to the overexertion of their shoulder [2]. These devices often lack features that amputees find useful for completing ADLs such as wrist pronation and supination[3]. The aim of this study was thus to design an electromechanical hand prosthesis that meets the functional and grasping requirements of prosthesis users.

The Tenim Hand was an attempt at addressing the need for a cost-effective prosthetic solution that would provide more functionality than that of traditional body-driven prostheses[4]. However, while versatile in its grasping capabilities, the hand was not always able to perform the required grasp without intervention from the healthy limb of the user. This would result in the healthy limb being encumbered while grasping an object. Additionally, the Tenim Hand, despite being force transfer efficient, still required excessive exertion of the user's shoulder. Intuitively these factors would greatly reduce the usability of the device. Nevertheless, the notable features of the Tenim Hand lends the hand to be a promising starting point for the development of a prosthesis suitable for those living in LMICs.

**2. MATERIALS AND METHODS**

**2.1 Design of The Self actuated Tenim Hand**

The Tenim Hand was selected as a basis off which to develop an electromechanical hand prosthesis that meets the functional and grasping requirements of prosthesis users.

The first step taken to achieve that goal was to address the design deficiencies of the original prototype. These deficiencies included the inability to perform certain grasp types without additional intervention from the able limb. The phalanges of Tenim Hand were subsequently modified to incorporate a larger number of grasps. The improvement in grasping performance, illustrated in Figure 1, was achieved by adjusting the strength of the springs in the springloaded phalangeal joints and increasing the tolerances between the phalangeal joints and the joint pins to allow for a smoother and more natural closing trajectory of the phalanges. The new phalanges were manufactured using an SLS 3D printer and the springs were commercially sourced.

A wrist mechanism was appended to the redesigned Tenim Hand to enable rotation of the prosthesis when worn. As shown in Figure 2, the wrist mechanism allows the prosthesis to

be pronated, supinated or positioned neutrally. The wrist mechanism was also manufactured using an SLS 3D printer.

To alleviate the strain caused by shoulder exertion for amputees an electromechanical actuator was incorporated into the new prosthesis. The actuator, shown in Figure 3, comprised an electric motor (DAGU Wild Thumper Motor 75:1), a gearbox, bearings and a lead screw and nut set. The actuator can produce activation forces of up to 280N on the modified Tenim Hand's input cable. The gears and housing of the gearbox were manufactured using SLS and FDM 3D printing respectively. The remaining components of the actuator were commercially sourced.

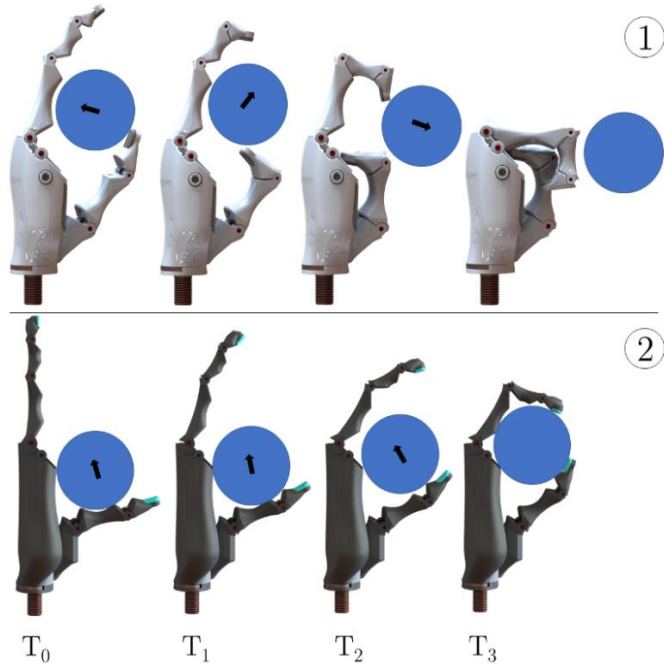


FIGURE 1: AN ILLUSTRATION SHOWING THE IMPROVED GRASPING PERFORMANCE OF THE MODIFIED TENIM HAND (2) WHEN COMPARED TO THE TENIM HAND(1).

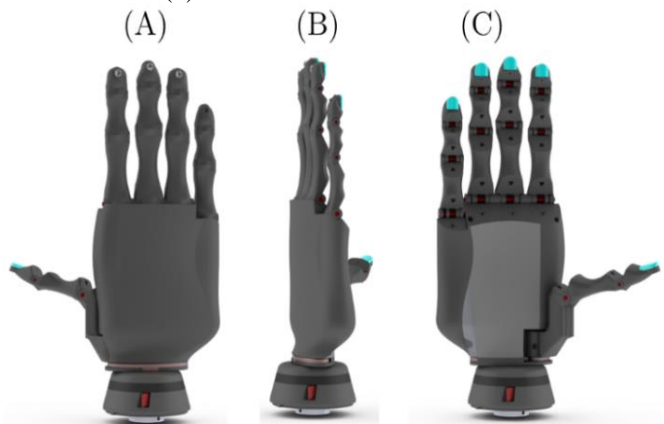


FIGURE 2: THE MODIFIED TENIM HAND IN THE PRONATED (A), NEUTRAL (B) AND SUPINATED (C) POSITIONS.

A simple trigger mechanism was designed to activate the actuator. The trigger mechanism is in essence a spring-loaded single pole triple throw switch that has been designed to fit under the able limb of the user. The trigger mechanism is activated by the user pressing the trigger with the underside of their able limb. Depending on which side of the trigger the user activates, the prosthesis extends or flexes. When the user is not applying an input, the hand will maintain its current grasp. The trigger mechanism was manufactured using an FDM 3D printer and pushbutton switches.

Electronic components including a motor driver and microcontroller were used to control the actuator. The microcontroller (Arduino Nano) and the motor driver (Monster Moto Arduino shield) were selected for their relatively compact size and ease of development. A battery, a power switch and wiring were also incorporated into the device. The electronic components that make up the actuator system are shown in Figure 5.

The modified Tenim Hand when combined with the addition of the wrist and actuation systems form the Self Actuated Tenim Hand (SATH). The SATH, the specifications of which are listed in Table 1, has improved grasping capabilities when compared to its predecessor. The inclusion of new features, such as wrist rotation and electromechanical actuation, should respectively assist amputees in performing their ADLs and prevent overexertion of the shoulder. However, the addition of these features adds considerable length to the prosthesis and may prevent the device from being prescribed to amputees with longer forearm stumps. The assembled SATH, shown in Figure 6, was equipped with an attachment that made testing the device possible for a non-amputee.

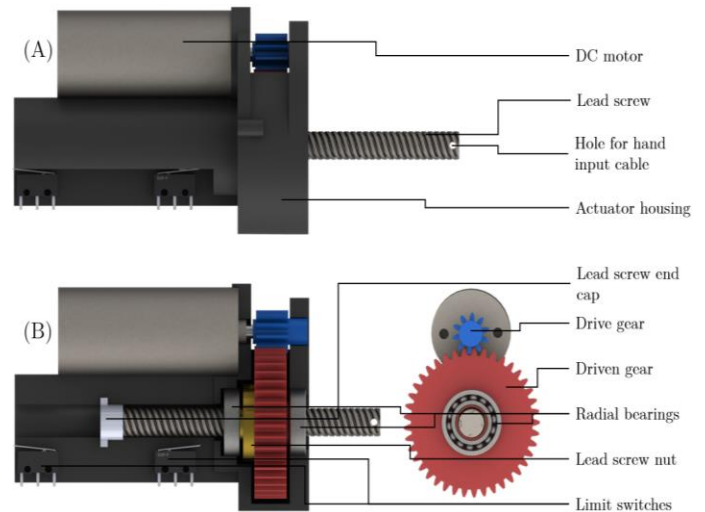
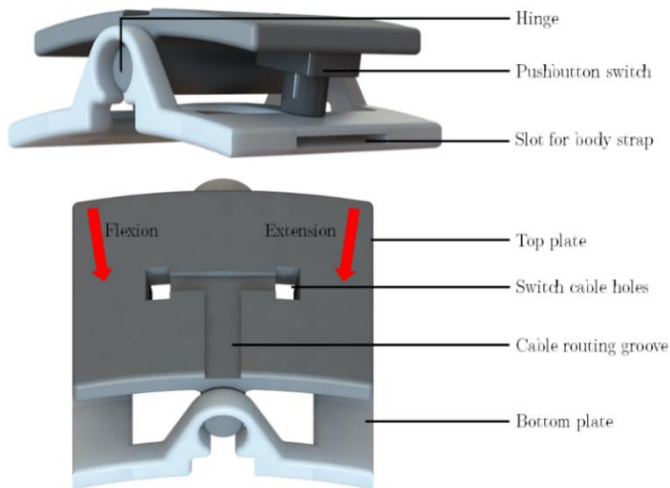


FIGURE 3: THE ELECTROMECHANICAL ACTUATOR USED IN THE SELF ACTUATED TENIM HAND (A) AND A SECTIONED VIEW SHOWING THE INTERNAL COMPONENTS OF THE ACTUATOR (B).

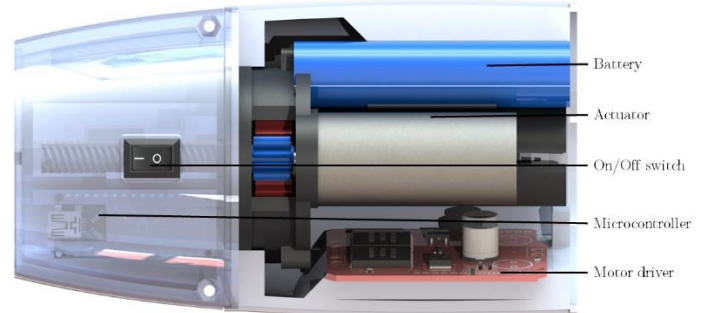


**FIGURE 4:** THE TRIGGER MECHANISM USED IN THE SELF ACTUATED TENIM HAND

**TABLE 1:** THE SPECIFICATIONS OF THE SELF ACTUATED TENIM HAND AND ITS SUBCOMPONENTS.

Component	Manufacturer and Model	Specification	Value
SATH	Custom Made	Cylindrical Grasp Force [N]	175*[4]
		Hand Mass [kg]	1.6
Gearbox	Custom Made	Gear Ratio	4.1
DC Motor	DAGU Wild Thumper 75:1	Motor Torque [kg.cm]	7.4
		Stall Current [A]	3.4
		Voltage [V]	6.0
		Gear Ratio	75:1
Battery	Ansmann 7.4V Li-ion battery	Nominal voltage [V]	7.4
		Nominal Capacity [mAh]	2600
		Max. Discharge current [A]	5
Lead Screw	TR8x8 Lead Screw	Major Diameter [mm]	8
		Pitch [mm]	2
		Lead	8

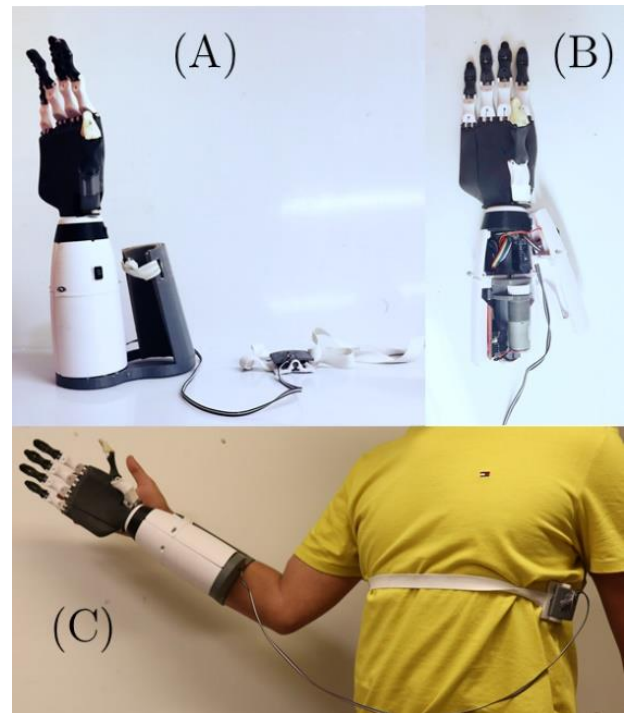
\*Due to there being only minor adjustments made to the force distribution mechanisms of the hand, the maximum cylindrical grasp force was assumed to be approximately equal to that of the unmodified Tenim Hand.



**FIGURE 5:** THE ELECTRONIC COMPONENTS OF THE ACTUATOR SYSTEM.

## 2.2 Validation Methods

To assess the grasping ability of the SATH, the Anthropomorphic Hand Assessment Protocol (AHAP) was used as a design validation tool. AHAP is a quantitative hand function assessment protocol used for evaluating the ability of prostheses to perform grasps frequently used in ADLs[5]. Although AHAP is a relatively new protocol and more widely utilized assessments such as the Southampton Hand Assessment Protocol exist, AHAP was selected for this early validation as the objects used in the protocol have well-defined specifications in the Yale-CMU-Berkeley (YCB) object set[6]. The objects used for this validation were independently sourced and selected to match the specifications listed in the YCB object set. This allowed for rapid preliminary validation and modifications to be made before the device is to be scrutinized more thoroughly.



**FIGURE 6:** PHOTOGRAPHS OF THE SELF ACTUATED TENIM HAND SHOWING: THE TESTING ATTACHMENT(A), THE INTERNAL ELECTRONICS(B), AND THE DEVICE BEING USED BY NON-AMPUTEE

### 3. RESULTS AND DISCUSSION

The SATH scored an overall GAS of 75%, scoring 100% for the platform task; 100% for the index pointing task; 50% for the pulp pinch; 83% for the lateral pinch 50% for the diagonal volar grip; 75% for the cylindrical grip, 64% for extension grip; 75% for the tripod pinch; 97% for the spherical grip; and 89% for the hook grip. These results are comparable to those of the more advanced KIT prosthetic hand P2 (KIT2) prosthesis also assessed using AHAP[5]. The SATH's and KIT2's AHAP results are presented in Table 2.

The SATH's performance in AHAP, having scored above 75% for seven of the ten grasp types and above 50% for the remaining three, is mostly satisfactory. In the grasps the SATH performed weakest in the primary reason for poor performance was slippage of the grasped object. A previous study has shown that the addition of strategically placed friction pads can decrease the likelihood of slippage and thus improve performance in AHAP[5]. It is likely that by increasing the friction between the SATH and the grasped objects, the SATH can improve its GAS.

**TABLE 2: THE RESULTS OF VALIDATING THE SATH USING AHAP COMPARED TO THE RESULTS SCORED BY THE KIT2.**

Grasp Type	SATH GAS percentage	KIT2 GAS percentage [5]
Hook (H)	89	81
Spherical grip (SG)	97	81
Tripod pinch (TP)	75	87
Extension grip (EG)	64	72
Cylindrical grip (CG)	50	89
Diagonal volar grip (DVG)	83	64
Lateral pinch (LP)	50	75
Pulp pinch (PP)	50	83
Index pointing (IP)	100	100
Platform	100	50
<b>Overall GAS</b>	<b>75</b>	<b>79</b>

### 4. CONCLUSION

The SATH is an electromechanically actuated prosthesis that adds wrist rotation and electromechanical actuation to the Tenim Hand's versatile grasping capabilities. On balance, the SATH's performance in the AHAP can be considered successful with the device only requiring minor modifications to increase its already satisfactory performance.

Once the modifications are made the device can be reassessed using amputee participants and the SATH can then be compared with commercially available prostheses.

While one of the objectives in developing the Self Actuated Tenim Hand was to provide a cost-effective solution to amputees in LMICs, it would be disingenuous at this stage of the SATH's development to accurately assess whether the device has met this goal. The cost of regulatory approval and the use of mass-manufacturing techniques such as injection moulding is yet to be accounted for and will require a detailed costing analysis. However, by using the already low-cost Tenim Hand and the addition of a relatively simple electromechanical actuation system the SATH is expected to ultimately meet this objective.

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