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BEBIONIC PROSTHETIC DESIGN

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INTRODUCTION

The *bebionic* hand by RSLSteeper is a fully articulating myo-electric hand with multiple pre-programmed grip positions. Increased function and hand flexibility provides design engineers with challenges in maintaining reliability and meeting increasing user demands. This paper will discuss the technical attributes, key design elements and the philosophy of their selection and evolution, as well as thoughts for the future. Special attention will be paid to thumb and digit design, feedback loop, material and hardware selection.

The hand is controlled in a similar way to other myo-electric hands by controlled muscle contraction. Electrodes measure electrical changes on the skin covering the control muscles, and instruct the five individual actuators within the hand to provide the desired movements.

The hand incorporates five high speed/force motors and is designed for low power consumption. The naturally compliant fingers and thumb of the bebionic hand provide a secure platform to perform everyday tasks using common grip patterns.

TECHNICAL INFORMATION

Principal Dimensions

Table 1: Principal Dimensions of *bebionic* Hands

Principal Dimensions	Large Hand	Medium Hand
A Middle Finger Tip to Hand Base	200mm	190mm
B Thumb Tip to Hand Base	125mm	121mm
C Max Chassis Width (no glove)	92mm	84mm
D Diameter of Chassis at Wrist	50mm	50mm
Palm Circumference (no glove)	220mm	204mm
Maximum Opening width Tripod Grip	105mm with glove	105mm with glove
Thumb Swing Through Angle	68°	68°
X EQD only	5mm	5mm

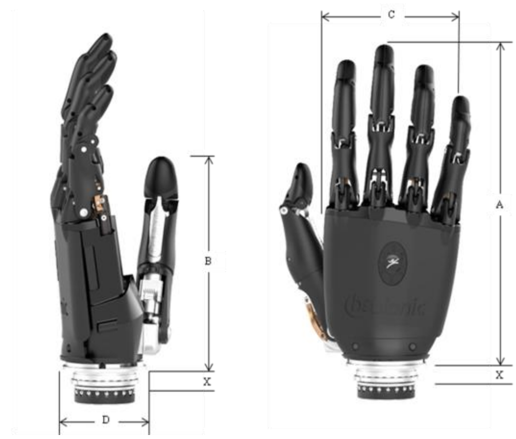

Figure 1: *bebionic* v2 Hand

Performance Specification

Table 2: Performance Specifications of *bebionic* Hands

	Large Hand	Medium Hand
Maximum Power Grip	16.8 ft lbs (75N)	16.8 ft lbs (75N)
Maximum Tripod Grip	7.6 ft lbs (34N)	7.6 ft lbs (34N)
Minimum Time to Close – Tripod Grip	0.4 Seconds	0.4 Seconds
Minimum Time to Close – Power Grip	0.9 Seconds	0.9 Seconds
Minimum Time to Close – Key Grip	0.9 Seconds	0.9 Seconds
Maximum Static Load – Hook Grip	70.5 lbs (32kg)	70.5 lbs (32kg)
Maximum Load Individual Finger – Hook Grip	35.2 lbs (16kg)	35.2 lbs (16kg)
Finger Tip Extension Load	13.2 lbs (6kg)	13.2 lbs (6kg)
Maximum safe vertical load taken through knuckles	198.4 lbs (90kg)	198.4 lbs (90kg)

KEY DESIGN FEATURES

The *bebionic* hand has many sophisticated design features providing flexibility for both user and practitioner.

Finger Design

The *bebionic* hand features individually powered, articulated digits each driven by and linked to its own 6V actuator. The actuators are positioned within the palm to provide a beneficial solution for weight distribution.

The actuators are assembled with individual separately programmed PCB's with onboard microprocessors. These are coded to constantly track the placement of each digit and provide precise control. This ensures accurate grip sequences and digits performing synchronized movements together every time.

An aluminum lead screw nut attaches the actuator to its individual finger proximal through carefully designed foldaway links. Made of nylon (Technyl A218V30) these foldaway finger links allow the fingers to flex freely and naturally, as well as allow the user to push up to 90kg through the hand to aid in standing from a seated position, a feature especially useful for the bilateral amputee.

In the event of mechanical overload it is important to protect the unit. The design accomplishes this with a shear pin fitted as part of the finger linkage. The shear pin is made from peek and is designed to fracture under a predetermined extension load, thus preventing damage to the finger and motor. The shear pin can be replaced locally by the clinical team.

The finger proximal moulds are shared between the index, middle and ring finger and are of an extremely robust construction utilising high impact thermoplastic, Hostaform C9021 GV3/20 (POM). All joint connections are locked with titanium fixed fasteners and square extension return springs. These materials maintain a high degree of strength and durability whilst reducing weight. Each finger also has tip mounted soft pads made from silicone. The palps are moulded in halves and shared between the index and ring finger.

Field replacements of individual digits can be done by carefully removing the shear pin, closing the hand slightly to lower the lead screw nut and then removing the hex screw from the knuckle base.

<u>Thumb Design</u>

The thumb also utilizes its own actuator and can be manually placed in one of two positions, opposed or non-opposed to the fingers. Located at the base of the thumb motor is a nylon (Derlin AF) trunnion nut which fits directly into the aluminum (AL-LM25TF) thumb bracket. A wishbone link, made from silicone brass, attaches the back of the bracket to the actuator to provide stability and allow movement towards and away from the palm.

The thumb bracket is attached to the chassis base through a fitted lower cam, mounting bolt and spring assembly. This robust assembly allows for continual manual movement of the thumb with a 68 degree range of baseline adjustability. The cam design allows the thumb to lock into an opposing or non-opposing position. This prevents the patient from wasting time aligning the thumb and allows for fast selection of grip patterns through the feedback loop (read switch). Also, when the thumb is locked it cannot back away under load, for example if the finger-object is hitting off center.

A read switch is located on the rear chassis near the outer side of the thumb bracket and works in conjunction with a small magnet located in the same vicinity on the bracket. When the thumb is in a non-opposing position the magnet is in close enough proximity to enable the read switch causing the non-opposed hand grips to be facilitated. With the thumb in opposed position, the magnet cannot enable the read switch and therefore the opposed set of grips are used.

Thumb alignment adjustment has been added to the design to allow clinical staff to reposition the thumb for additional grips or realign strike points as required by patient need. The thumb includes a medial-lateral adjuster to reposition contact with either the index and middle fingers or with the index finger alone. A slotted screw is fitted within the thumb pivot assembly and acts to adjust the friction on the internal clamp. To loosen requires turning two complete turns then pushing the screw inward. With the clamp slackened the thumb position can be manually re-positioned. The assembly must be retightened before electrically driving the thumb.

Another adjuster, located under the thumb base, is integrated to alter the baseline position of the thumb. This moves the thumb either towards the palm or away from the palm in order to optimize the contact point of the thumb tip against the opposing finger(s). Using a flat bladed screwdriver the adjuster should be turned clockwise to move the thumb towards the palm and counter-clockwise to move the thumb away from the palm. The effect will only be observed after resetting the hand (turning the battery switch off/on), not whilst making the adjustment.

<u>Chassis Architecture</u>

The rear chassis provides attachment of the thumb through the bracket, lower cam, mounting bolt and spring assembly. The selected *bebionic* wrist type is attached to the base of the rear chassis and held in place with three M3 x 8 SKT cap screws. The chassis is uniquely designed to conform to the shape of the palm PCB which is slid in and held in place with an M2 x 6 PAN POZI thread forming screw.

The front chassis design conformably houses the four finger actuators and a gear cover, while providing attachment and placement for the knuckles. The gear cover (ABS material) protects the finger actuators from dust particles while also providing a shield for the palm PCB and wiring. Attachment of the front chassis to the rear chassis is done in three places. An M3 16 PAN POZI thread forming screw located in the outer palm of the front chassis attaches it directly to the rear chassis. An M3 x 16 SKT head cap screw below the first finger on the front chassis attaches it through the rear chassis thumb bolt. This also holds the thumb bolt/bracket assembly in place. The third connection point is located on the back of the hand and includes a chassis link, T-bolt and M3 x 12 SKT head cap screw assembly that also contributes to further stabilizing the palm PCB.

The top chassis, or back cover, provides final enclosure and easy access to the finger actuators and palm PBC. An RF ID tag is placed on the inside of the cover to provide easy identification of each hand. At the top of the cover are three pins designed to slide into adjacent holes located on the front chassis beneath the back of the knuckles. The base of the cover is secured directly to the rear chassis with two M2 x 10mm trimet thread forming screw.

<u>Program Switch</u>

Located on the back of the hand is a membrane switch that utilises flexible PCB tracks to connect directly to the palm PCB. The tactile design allows the used to easily locate it beneath a glove. The switch has four functions and is integrated with selectable bleep and vibrate switch indicators, which can be activated through the *bebalance* software.

<u>Grip Patterns</u>

The *bebionic v2* hand can provide 14 selectable grip patterns / hand positions.

The thumb has two user selectable positions – opposed and non-opposed – with two grip patterns available in each position, thus providing four primary grip patterns. The user can sequence between the default and alternative grip pattern for each thumb position by applying an OPEN OPEN or co-contraction signal (depending on what setting is chosen within the *bebalance* software). To gain access to four further grip patterns, the user can alternate from the primary grip patterns, to the secondary grip patterns by pressing the program switch.

Several grip patterns – Hook Grip, Finger Adduction and Flat Hand – are achieved as partial grips of another grip pattern and therefore do not need to be actively selected. For instance, a partial close in Power Grip provides Hook Grip. A maximum of 10 out of the 14 grip patterns are therefore available to the user at any one time. Individual fingers can also be stalled manually by applying resistance, allowing further hand positions.

To achieve certain grip patterns it is necessary for the practitioner to adjust the thumb alignment so that the contact position between the finger(s) and thumb is changed. For instance, the thumb contacts on the index finger for Precision and Pinch Grip rather than the index and the middle finger for Tripod Grip.

This represents an increase of grip patterns compared with the version 1 *bebionic* hand, and demonstrates how new unique hand patterns such as MOUSE grip may easily be created.

<u>Electronic Monitoring of Digit Position</u>

The code sets a starting point for the counter when hand is first powered up. The number of revolutions of each actuator is counted in order to monitor placement of individual motors. This provides accurate and repeatable grip patterns.

<u>Auto Grip Feature</u>

Auto Grip is a selectable electronic feature that can be enabled or disabled through the *bebalance* software. It functions only with the thumb opposed and in Tripod or Pinch Grips. Once enabled auto Grip is activated by the user providing three consecutive close signals and de-activated when the hand is opened.

The rotation of the finger actuators is monitored every 50ms. Movement or slippage of a held object is detected by motor rotation. The appropriate motors are driven to prevent this movement occurring by changing finger position / grip force and therefore automatically providing a more secure grip.

BEBALANCE SOFTWARE

The hand is programmed using Bebalance software developed by RSLSteeper. Information is transmitted wirelessly to and from the system. A radio frequency transmitter / receiver module is incorporated within the hand. The software allows control parameters such as hand speed, grip force and grip selection to be individually optimized, set and stored. It also provides a range of control methods using one or two electrodes, or other inputs. The software provides real time analysis including adjustment of user signal and allows the user to practice using visual feedback. The software also allows a hand to be 'read' to determine its existing program settings.

FUTURE THOUGHTS

The *bebionic* wrist allows the patient to perform rotation, flexion and extension for either a left or right hand. It uses a single motor to accommodate both actions. The wrist provides 230 degrees of rotation, 180 degrees of which is external (rotation to palm facing up) and 50 degrees internal rotation, and 30 degrees of flexion and 30 degrees of extension. Its diameter is approximately 50mm with a total length of approximately 75mm.. The *bebionic* wrist has an EQD connection, enabling compatibility with all *bebionic* devices as well as some competitor devices.

Figure 2: *bebionic* Wrist

REFERENCES

Bebionic v2 hand and bebalance software Technical Manual. Large & Medium