ARTIFICIAL LIMBS
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HUMAN-MACHINE INTERFACES FOR ROBOTIC HANDS

HMI is a physical system at interface between human's body and prosthesis, usually used to control this one. They are efferent, when it is used for control, afferent when provides a sensory feedback; they are bidirectional, when it provides both functionalities.

HMIs can be non-invasive, mid invasive and invasive. Non-invasive ones are based on control signals of human body (superficial EMG, cortical BCI, although this last is not feasible for limbs), five senses of human perception, and not natural ones (speech, tongue, foot, EOG). Mid-invasive causes slight modification of human body, like displacement of human parts, since an insertion in not critical parts of human body is expected. Examples are TMR and implantable myoelectric sensors. Invasive ones involve ~~on~~ the nervous system with for direct control and feedback. They can affect the CNS or PNS. Common challenges are decoding intention, encoding sensation and physical interface with the source of the signal.

MUSCLE → SURFACE EMG → PROCESSING (amplification, filtering, sampling) → ANALYSIS (segmentation, extraction, classification) → CONTROLLER → PROSTHESIS

SENSING TRANSDUCTION → DECODING ALGORITHM → ENCODING ALGORITHM → ACTUATING TRANSDUCTION → BODY

Here, there are the scheme of efferent and afferent part of the HMI.

HAND PROSTHESIS

Main components are mechanism design, integration of sensors and intelligent control. About the first one, something important to ther mechanism is not to be back-drivable, motion has to be transmitted only from input to output and not viceversa. This allows a stabler

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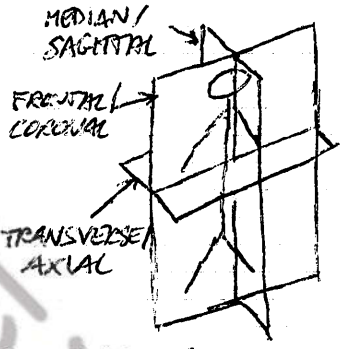


more stable control of prosthesis and possibility to switch off motors when a grasping has been performed. The mechanism should be adaptable for each type of grasping. This is done to mimic behavior of human hand, with 21 DoF, by reducing the complexity of the mechanisms.
Prosthetic hands are subdivided between active and passive. Passive ones are cosmetic prosthesis, with no actuation, very cheap.
Active ones are subdivided between body-powered and myoelectric. Body-powered prosthesis exploit residual movement of body after amputation, to control the actuation.
Myoelectric prosthesis use linear envelop of EMG muscles from antagonistic muscles and filter, amplify and process their difference to control the electric. This device must be supplied by a local battery. All device must reside inside the socket (SELF-CONTAINED/SUSPENDED)

HISTORY OF ROBOTIC HANDS
First powered hand, in 1915, was a compressed gas powered hand. First electric one was built in 1919. First myoelectric hand was built in 1943 and was based on vacuum tubes. In 1950, pneumatic sensors were installed. First portable version appeared in 1959. A proportional control was inserted in 1965. First self-contained/suspended version appeared in 1970.
In Italy, INAIL started this research line in 1964. In 1973, 1000 people in Italy had prosthesis. The device was then acquired by Otto Bock.
In 2005, DARPA launched a challenge on upper limb prosthesis. In 2008, first arm with 22 DoF was invented. In 2007, a hand of 5DoF-like research started at SSSA. Since tens years, three main brands on artificial are present: iLimb, BeBionic and Michelangelo

Challenges in design are high power-to-weight ratio, human inspired sensory system, dependence of context, proper physical interfaces for appropriate control system and sensory feedback. It is also important to reach the impact society is expecting.

MOVEMENTS OF THE UPPER LIMB



Upper limb has three main articulations: shoulder, elbow and wrist. Movements performed with shoulder are:

- extension (up to 45°-50°) and flexion (up to 180°)
- adduction, possible only if combined with flexion or extension;
- abduction (up to 180°); this movement, combined with flexion, is the most common movement, used to put hand before mouth; from 90° to 150°, movement of scapula is needed; from 150° to 180°, movement of column is needed, instead

The 4 joints contribute to basic movement of shoulder

The elbow has following movements:

- flexion: when active it reaches up to 145°, 160° when passive;
- pronation (up to 85°) and supination (up to 90°)

Wrist has as movements ulnar and radial deviations (30°/55°, 15° respectively), flexion and extension (85° both)

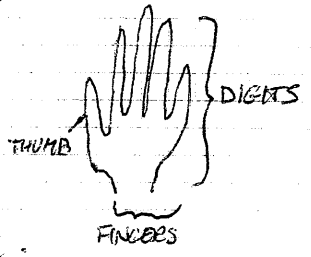
Hand is able to be completely open and extended. In that case, fingers' axis converge in a same point of the hand; it also works, when fingers are closed, but the point is different.

The hand can be flattened, but when it grasps something, it forms three arches:

- transverse (wrist concavity)
- longitudinal (wrist - index / middle finger);
- oblique (thumb - index)

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About MCP joints, flexion is 90°, extension is 30°-40° when active, up to 90° when passive. Index is ~~goon~~ MCP joint has greatest range of movement. Regarding PIP and DIP joints, flexion is greater than 90° in PIP, less than 90° in DIP. Extension is null in PIP, up to 30° in DIP.
A relevant aspect of hand is the thumb
To achieve alignment of planes
between thumb and index, 5 dofs
are needed:



- three for coincidence of contact points;
- two for full coincidence of planes

Trapezo-metacarpal joint performs all types of movements. MCP of thumb has flexion, medial displacement, pronation and supination. IP joint (in thumb, there is only one phalangeal joint) makes active flexion up to 75°-80°, passive up to 90°. Extension is up to 5°-10° if active, 30° if passive

BONES

Skeleton is divided in two parts: axial, which includes head, column and thorax, and appendicular, composed of superior and inferior limbs. Upper limb has 7 dofs plus those ~~of~~ over of the hand.
Hand has 8 carpals, 5 metacarpals, and 14 phalangeal bones (5 proximal, 4 intermediate, 5 distal). Central bones of hand are fixed, for an overall of 21 dofs.

BASIC FEATURES OF SKELETAL MUSCLE

Skeletal muscles move from a bone to another one, but only one bone moves. Point of contact between muscle and movable joint is called insertion, the other one origin. Muscles are only able to deliver force in traction. So for an opposite movement control, a system of antagonist muscles is needed. Co-contraction of muscles allow increase of stiffness of the limb.

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