<u>**Actuation and Mechanisms**</u>

Problem: current actuation technologies fail to provide efficient, high power density actuators (Power per unit of weight W/Kg)

Most robotic hands are actuated by brushed or brushless electric motors, because they ensure the best performance. Examples:

SmartHand

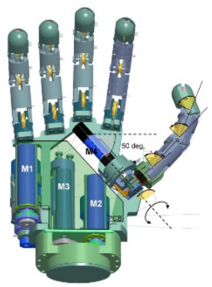
Speed Hand and Michelangelo by Ottobock

Stanford JPL

Okada

Belgrade

Barrett



Advantage: The ability to store electrical power in small batteries

Disadvantage: the lowest power to weight ratio

Pneumatic actuators

Advantage: a lightweight solution with high power

Disadvantage: low stiffness, because of gas compressibility, which is an advantage in terms of safety during human-robot interaction but, since it is difficult to modulate, it becomes a disadvantage during the execution of precision tasks.

To overcome the disadvantage of the low stiffness hydraulic actuation is used.

Advantage: In this the working fluid is liquid (instead of gas) and the compliance can be modulated by means of servo-valve control.

Disadvantage: the high working pressure (about 30 MPa) and the consequential high stress that parts are subjected to.

Shape memory alloy (SMA)

Advantage: are particularly promising for the design of artificial hands.

Disadvantage: Although electrical heating can be achieved rapidly, cooling is the main limitation on operating frequency, and additionally SMA usually present a relatively low efficiency

<u>Transmission</u>

Tendons, linkages, gear trains, belts or flexible shafts

Important design goals are to minimize friction, backlash and inertia while trying to maintain small overall size and weight.

The most commonly implemented transmissions are flexible tendons running into sheaths, in analogy with tendons in the human hand.

Advantage: It allows actuators to be located remotely from joints, reducing the dimensions and weight of the fingers.

Disadvantage: friction between tendon and sheath that occurs in curves introduces non-linear effects and reduces efficiency

Examples: Hands driven by Teflon-coated cables in flexible conduits

Stanford JPL Hand

DIST Hand

LMS Hand

SmartHand

Vanderbilt Hand

Advantage: Effects of friction can be drastically reduced by replacing sheaths with idle pulleys at the expense of system and control complexity or by flat bends instead of tendons in order to increase the strength and stiffness of the transmission system, as in the Utah/MIT  Hand

Disadvantage: An immediate drawback of flexible cables or flat bend transmission is that they can only be used to pull, so in order to achieve the active two-way control of a generic joint a pair is required (hence increasing the complexity).

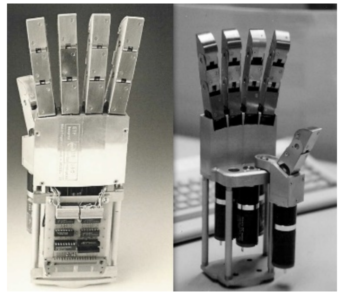
Moreover, if a high stiffness is required, flexible cable must be constantly pre-loaded, inducing dangerous pre-stress on the components.

Linkages or trains of gears

Advantage: they give the best stiffness proprieties to the transmission, low maintenance is required, and they allow bidirectional control of the joint.

Disadvantage: Their employment substantially increases the weight, complexity and sometimes dimensions of the hand.

Example: Belgrade/USC Hand



Gear train transmission can be found in the DLR/HIT Hand and in the Gifu Hand

Sensors

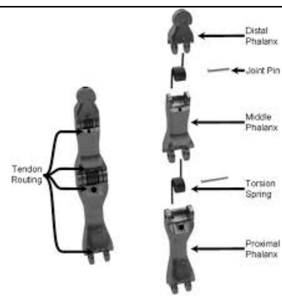
In general sensors should be lightweight, robust, small, with low drift, and low power consumption.

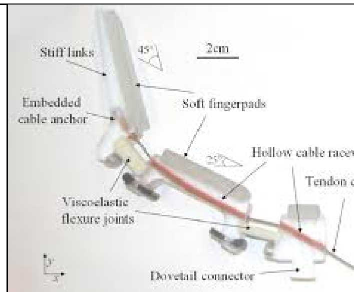
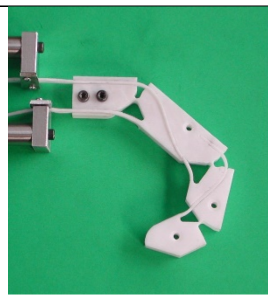
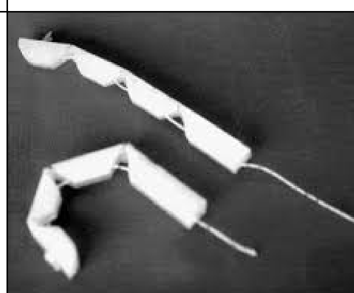
Most force sensors are developed using strain gauges mounted on a deformable structure. (Stanford/JPL Hand)

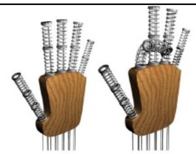
Mateials and Manufacturing

Problems: The design and fabrication of robotic hands by traditional machinery techniques is rather a long and expensive process.

Possible solutions: Rapid prototyping techniques provides several advantages on manufacturing by the traditional techniques like the chance to develop parts with complex geometry.

Name/Year	Picture	Method	Advantages	Disatvantages
Won et al. 2000		**Selective Laser Sintering (SLS)**	**joints are manufactured in one step, no need for assembly.**	**- lack of mechanical properties (stiffness and strength). - fails when dimension tolerances are narrowed**
Dalley et al. 2009		**high-strength, nickel-coated thermoplastic using an additive directly incorporated during the manufacturing process.**	**combines the flexibility of the rapid technique with the strength/stiffness of the metallic material**	**- low fatigue resistance -poor surface finish - poor geometrical tolerance - often requires remachining by traditional methods**

Dollar and Howe 2010		**polymer-based Shape Deposition Manufacturing (SDM)**	**- integration of sensors, electronics, and actuation - possibility of simultaneously creating rigid links and compliant joints of the fingers - number of components are avoided (such as pulleys, axis, torsion springs, and so on) - the ability to embed the extension system, disguised as releasing springs, in the structure thus resulting in a reduction in joint size.**	
University of Bologna 2002				
Stanford 1998				
Genoa 2004				

Scuola Superiore Sant'Anna 2005				
University of Iowa 2004				

- Investigating materials with proprieties close to the human skin. Human finger layers have different mechanical properties:

    - the skin: the sense of touch and in the mechanics of contact

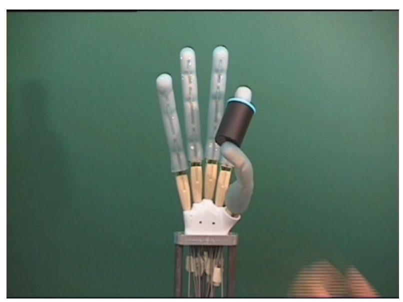
    - the soft tissue: responsible for strain dissipation during force interaction so to reduce wear and possible damage

    - the bone: the stiff core of the finger

    - the nail: suppresses excessive deformation of soft tissue and enlarges the range of the possible friction coefficient

Examples of bio-inspired fingertips for robotic hands:

UB Hand 3 (University of Bologna 2005)



<u>Future Trends</u>

- Use of lightweight, low cost, compact and high precision actuator arrays.

- Security and comfort are important issues to consider.

- Soft and compliant materials will often prevail when the hand is used to interact with humans

- Development of artificial skins with denser spatial resolution and a multitude of sensor modalities.

- Sensors employed in smartphones will be employed by the artificial hands driving costs down and increasing reliability.