Modern Myoelectric Intelligent Hand Prostheses

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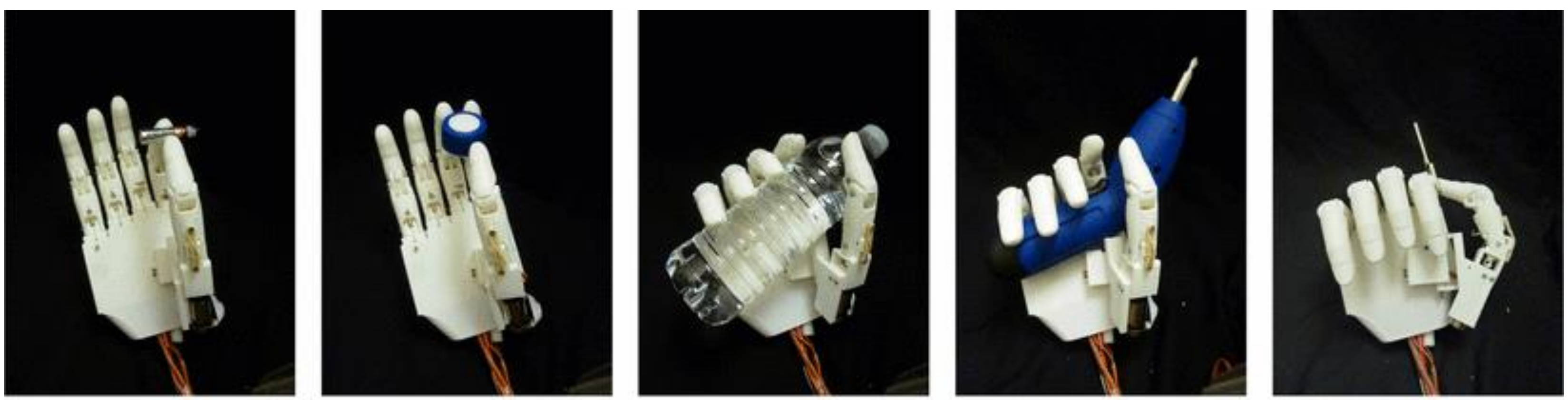
Outline

- Motivation and Challenges
- Overview of Hand Prostheses
- Comparison of Hand Prostheses
- Conclusion

Motivation

- Why myoelectric hand prostheses?
  - Make a normal life possible for amputees
  - Enable users to perform different grasps for activities of daily living (ADLs)
  - Allow the user to control the hand through muscle contraction (with EMG)
  - Electric actuators are rather small, quiet and have good precision and controllability



(a) (b) (c) (d) (e)

Motivation

- Desired properties:
  - comfortable (lightweight, small)
  - many different grasps possible
  - High finger forces / fast joint speed
  - easy to use
  - high durability (robust, easy to repair)
  - low-cost
  - intelligent functions (sensor-feedback, grasp adaption)

- Desired properties are contradicting ⇒ trade-offs are mandatory

Challenges

- *„Even state-of-the art devices lack a combination of high functionality, durability, adequate cosmetic appearance, and affordability"*

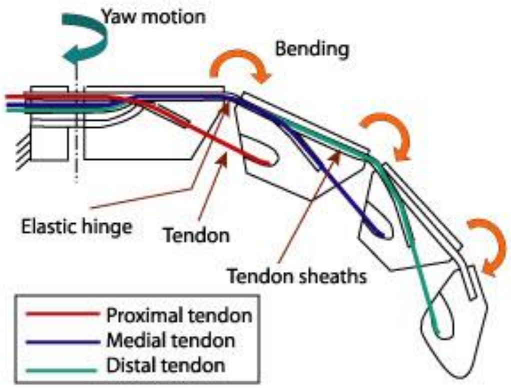
  \- Joseph T. Belter, 2013

- Total weight should be below $500g$ (human hand: $\sim 400g$)
  - ⇒ lightweight materials, small and low number of actuators
  - ⇒ transmission systems that allow for many different grasps
- Finger tip force in precision grasp should be $65\ N$ (human hand: $\sim$ 95 N) and joint speed should be $230\ {}^{\circ}/s$ (human hand: $> 2000^{\circ}/s$)
- Finger kinematic designs should be simple and robust

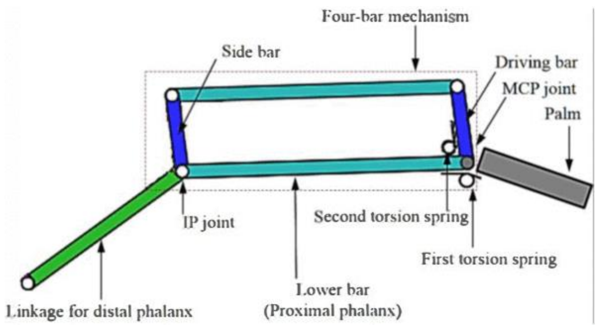
- User should be able to move the hand without concentrating
- User should get sensor feedback from the hand

Transmission systems

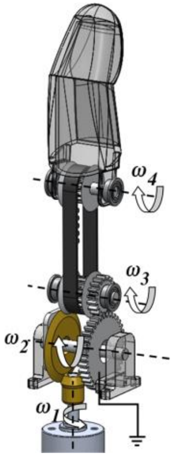
- Tendons



- Four-bar linkage



- Gears/belts



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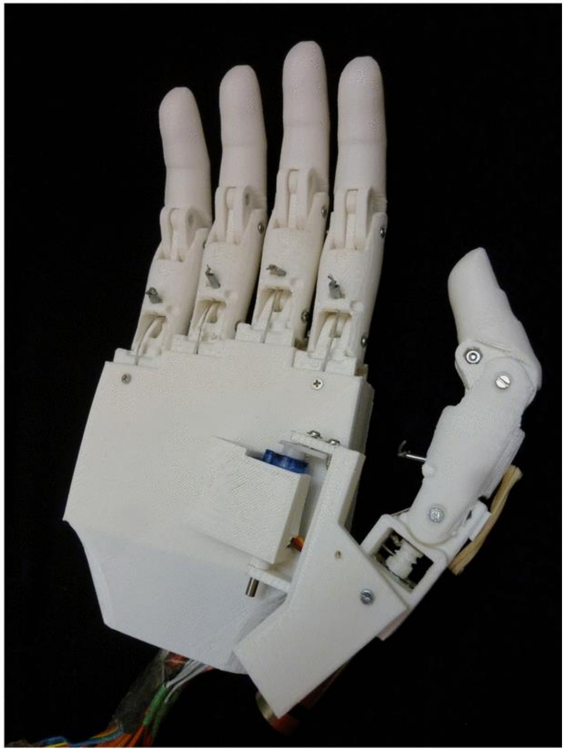
Tact

Year	Mass (g)	Joints	DoF	Actuators	Transmission
2015	350	11	6	6	Four-bar linkage

- Special feature:
  - Matches performance of other myoelectric prosthetic hands,

    while being very cheap ($ 250)
  - Easy to manufacture with 3D-printer

    and of-the shelf parts
  - Open-source



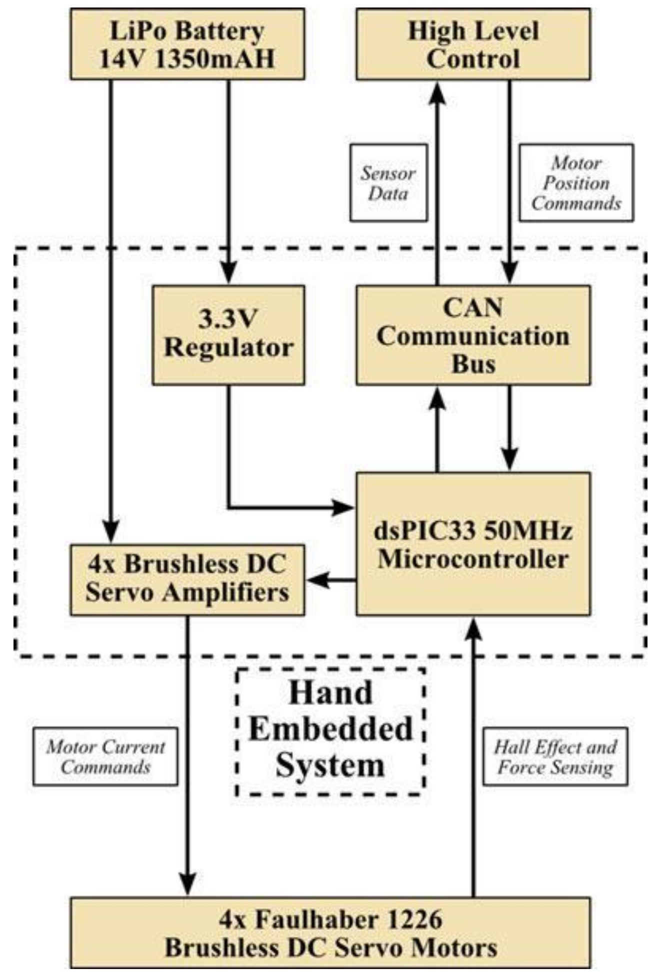
Hand of Bennett et al.

Year	Mass (g)	Joints	DoF	Actuators	Transmission
2015	546	12	12	4	Tendons

- Special feature:
  - Four motor units in unique configuration:
    - 2 for thumb and 1 for index (fully actuated)
    - 1 for other fingers (underactuated)
  - Embedded control system that enables self-contained control of hand movement

Hand of Bennett et al.

- Embedded system:
  - Consists of a single , four-layer circuit board
  - Accepts and executes motion/force commands from a high-level controller
  - Returns processed position/force information



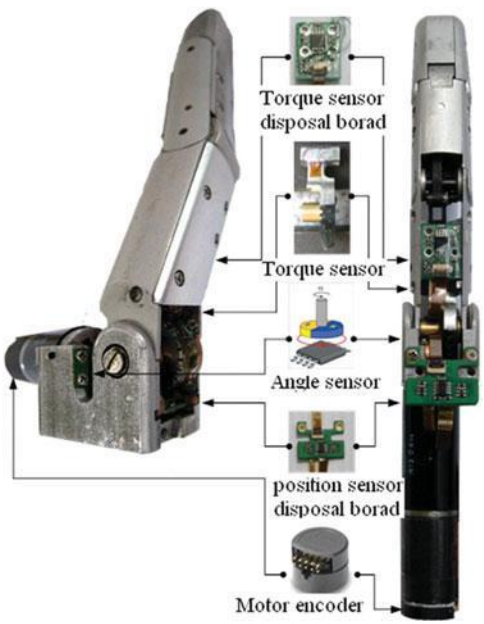
Hand of Zhang et al.

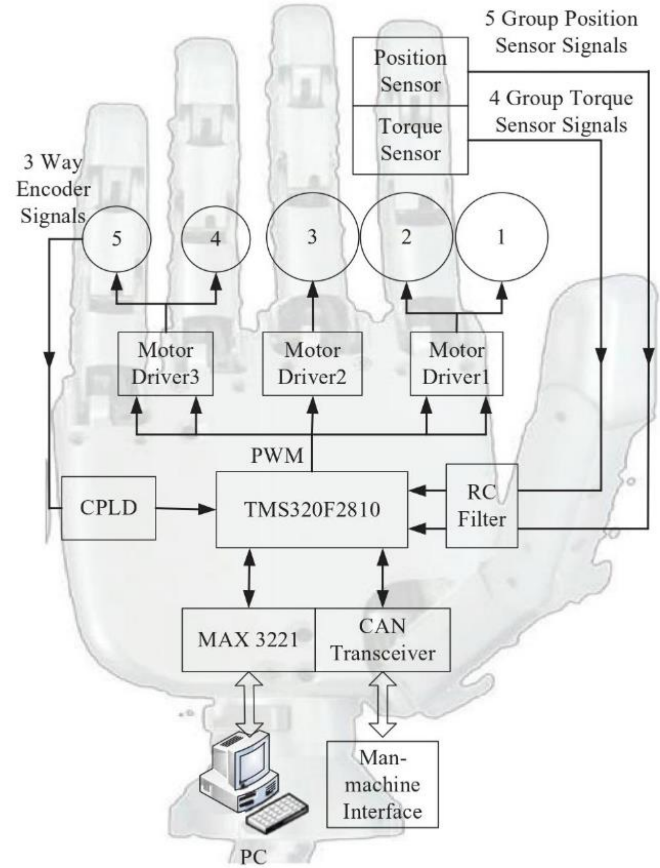
Year	Mass (g)	Joints	DoF	Actuators	Transmission
2015	420	15	5	5	Four-bar linkage

- Special feature:
  - Fingers are equipped with numerous torque and position sensors
  - Integrated motion control system consisting of a motion control subsystem and several sensory subsystems
  - New concept for sensory feedback system based on an electrical stimulator

Hand of Zhang et al.

- Sensor system:
  - Equipped with 18 proprioceptive and exteroceptive sensors



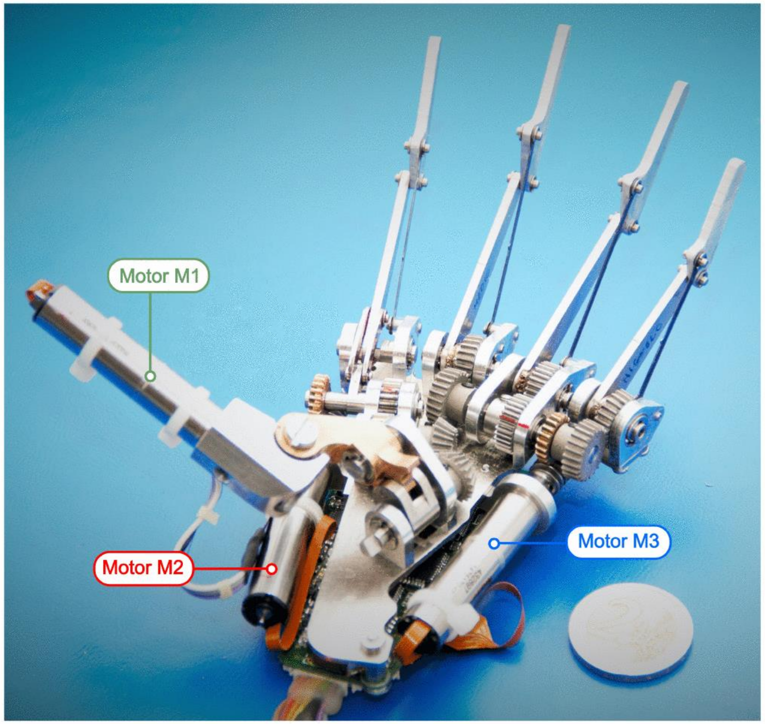


- Embedded system:
  - Consists of a motion control subsystem and several sensory subsystems

SSSA-MyHand

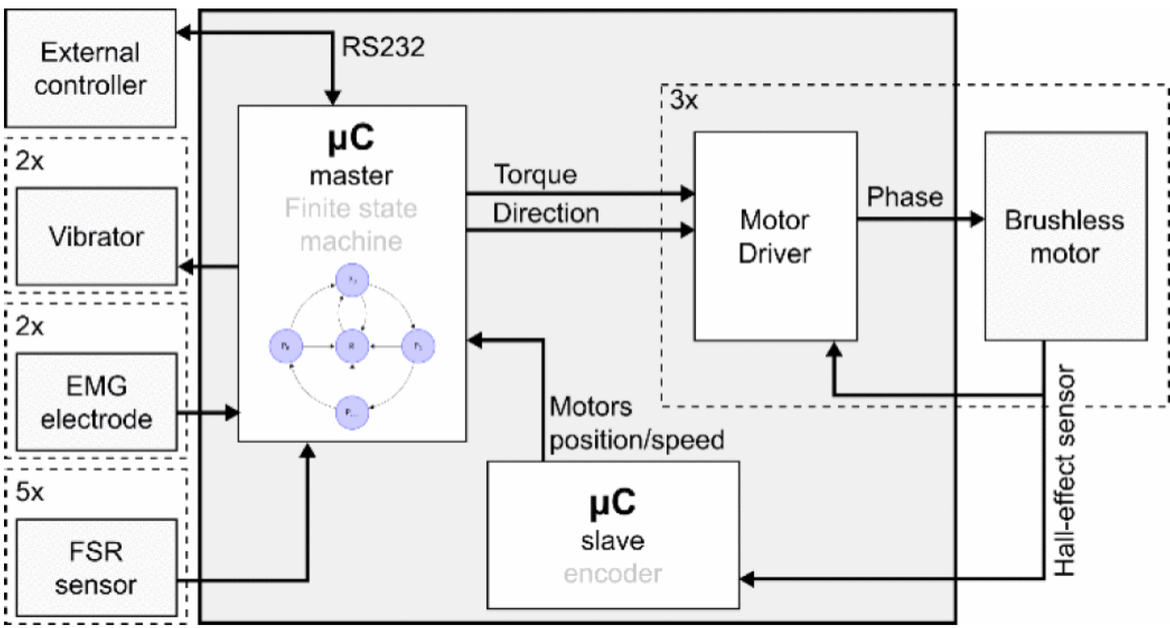
Year	Mass (g)	Joints	DoF	Actuators	Transmission
2016	478	10	4	3	Four-bar linkage, Geneva drive

- Special feature:
  - Only three actuators
  - Abduction/adduction of the thumb and flexion/extension of the index with single actuator via Geneva drive
  - Embedded controller and sensory system with force/position sensors and automatic grasp control



SSSA-MyHand

- Embedded system:
  - Master-slave configuration based on a pair of 8-bit microcontrollers
- Supports:
  - Identification of external commands
  - Implementation of automatic motor functions
  - Real time processing of the internal sensors
  - Potential delivery of sensory feedback

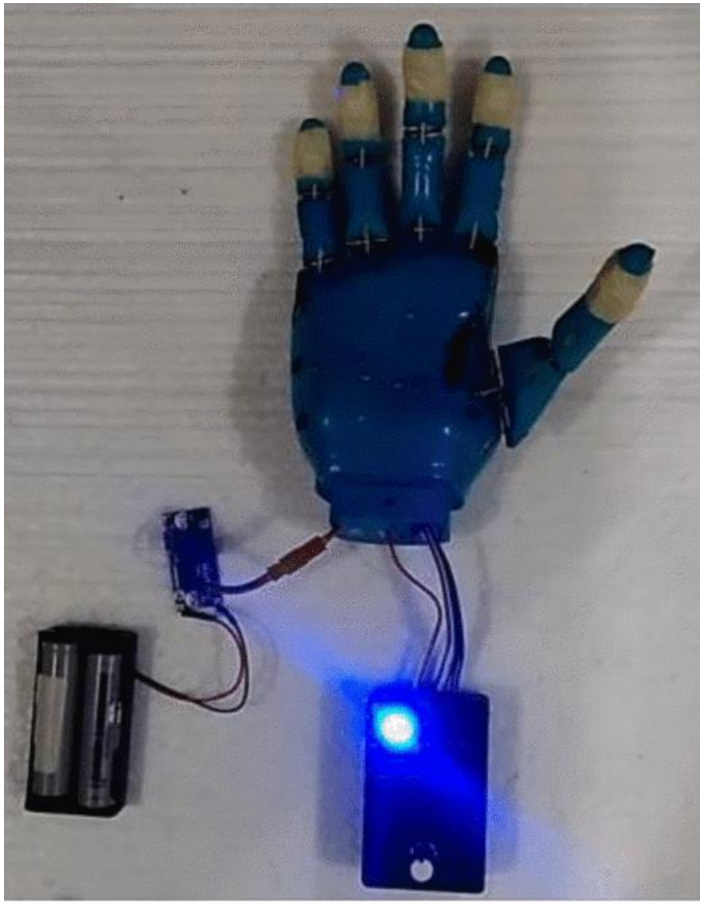


AstoHand v.1

Year	Mass (g)	Joints	DoF	Actuators	Transmission
2016	261	10	5	5	Tendons

- Special feature:
  - Low-cost
  - Very lightweight
  - Built with 3D-printed material
    (easy to manufacture and maintain)

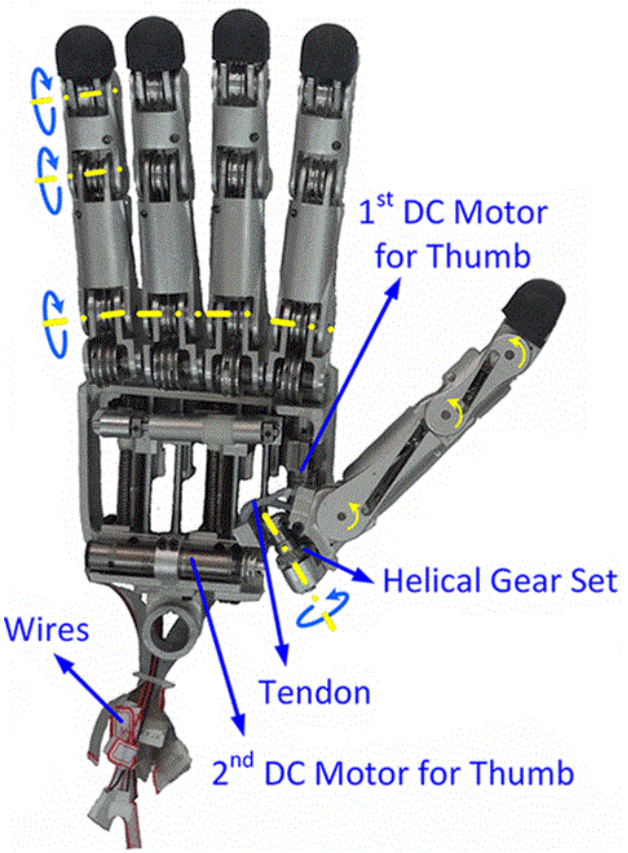
- Embedded system:
  - Arduino Nano microcontroller
  - Control algorithm developed in Simulink
  - Digital input is used for selecting one of seven grip patterns



X-Hand

Year	Mass (g)	Joints	DoF	Actuators	Transmission
2016	-	16	4	4	Tendons

- Special feature:
  - Anthropomorphic grasping ability via special motion distribution mechanism structure
  - Can replicate almost all natural movement of the human hand while using few actuators



Six-DOF-Hand

Year	Mass (g)	Joints	DoF	Actuators	Transmission
2016	584	10	6	6	Gears/Belts

- Special feature:
  - Inexpensive
  - Open source
  - Independent finger movements
  - Actuators with encoders for motor position feedback

Bionic Hand

Year	Mass (g)	Joints	DoF	Actuators	Transmission
2016	-	24	24	13	Tendons

- Special feature:
  - Hybrid actuated with Brushless DC motors and Shape Memory Alloy (SMA)
  - Close replication of the human hand (with all structures, joints and tendons)
  - 24 degrees of freedom

SoftHand Pro-D

Year	Mass (g)	Joints	DoF	Actuators	Transmission
2016	-	19	19	1	Tendons

- Special feature:
  - Strongly underactuated softhand
  - 19 joints with only one single actuator
  - Can move along two different synergistic directions to perform either precision or power grasp
  - Decoding of movement intensions using the dynamic frequency content

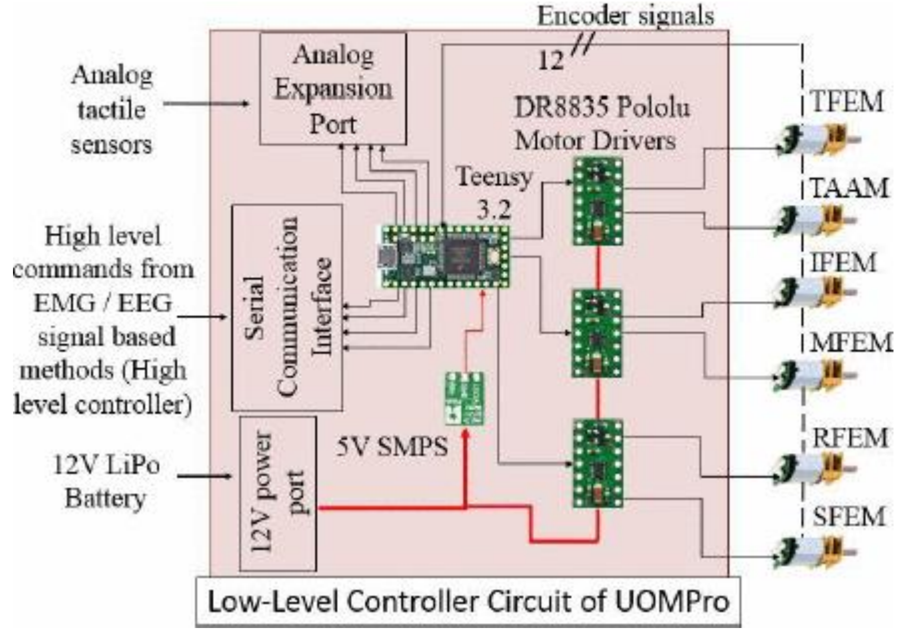
UOMPro

Year	Mass (g)	Joints	DoF	Actuators	Transmission
2017	432	10	6	6	Four-bar linkage

- Special feature:
  - Simple serial communication interface to link with high-level control methods
  - The implemented low-level controller can handle individual finger position commands or hand grip pattern commands

UOMPro

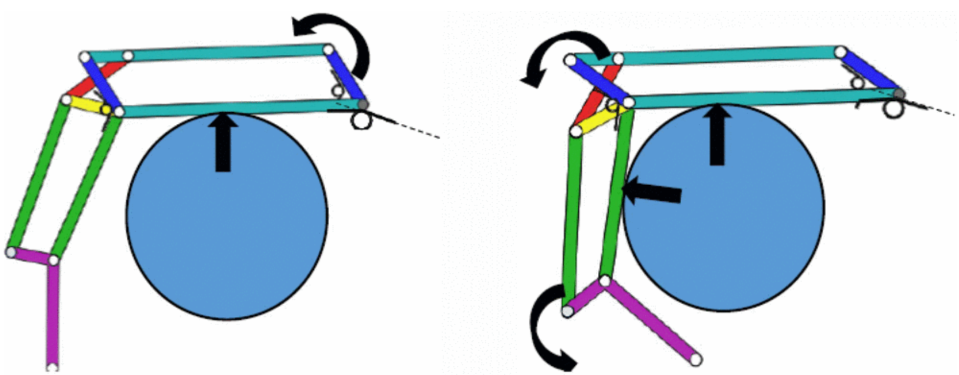
- Embedded system:
  - Low-level controller for close loop control of the motors using various control techniques
  - High-level controller to identify the motion intention



MORA Hap-2

Year	Mass (g)	Joints	DoF	Actuators	Transmission
2017	250	14	11	4	Four-bar linkage

- Special feature:
  - Self-adaption ability
  - Finger mechanism is capable of generating passively different flexion/extension angles
  - Fingers have under-actuation mechanism



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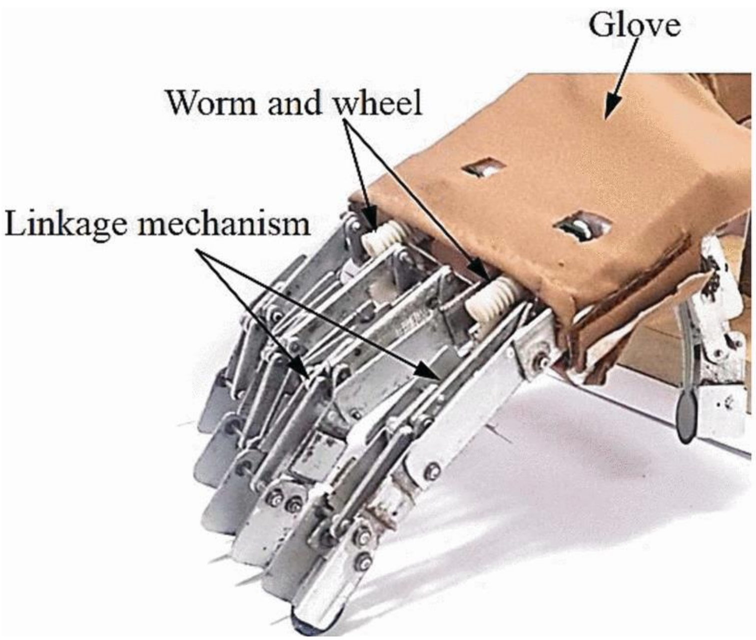

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Physical properties

Name	Weight (g)	Size (length x width x thickness in mm)
Tact	350	200 x 98 x 27
Hand of Bennett et al.	546	200 x 89 x -
Hand of Zhang et al.	420	159 x 79 x 21
MyHand	478	200 x 84 x 56
AstoHand v.1	261	180 x 85 x 50
X-Hand	-	Human hand size
Six-DOF-Hand	584	202 x 99 x 61
Bionic Hand	-	-
SoftHand Pro-D	-	-
UOMPro	432	189 x 88 x -
MORA Hap-2	250	95 (fingers) x 83 x 25

Finger Kinematics

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Name	Number of Joints	Joints per Finger		
		Thumb	Index	Others
Tact	11	3	2	2
Hand of Bennett et al.	12	3	3	2
Hand of Zhang et al.	15	3	3	3
MyHand	10	2	2	2
AstoHand v.1	10	2	2	2
X-Hand	16	4	3	3
Six-DOF-Hand	10	2	2	2
Bionic Hand	24	3	4	4
SoftHand Pro-D	19	3	4	4
UOMPro	10	2	2	2
MORA Hap-2	14	2	3	3

Actuation and Transmission

Name	Actuators	Transmission system
Tact	6	Four-bar linkage
Hand of Bennett et al.	4	Tendons
Hand of Zhang et al.	5	Four-bar linkage
MyHand	3	Four-bar linkage, Geneva drive
AstoHand v.1	5	Tendons
X-Hand	4	Tendons
Six-DOF-Hand	6	Gears / Belts
Bionic Hand	13	Tendons
SoftHand Pro-D	1	Tendons
UOMPro	6	Four-bar linkage
MORA Hap-2	4	Four-bar linkage

Grasping

- Most of the hands are capable of performing the known grasping patterns:
  - Power grasp (Cylindrical grasp)
  - Precision grasp (Pinch grasp)
  - Lateral grasp
  - Hook grasp

- The MORA Hap-2 is mainly developed for power and hook grasp
- The SoftHand Pro-D with its single actuator can perform power and precision grasps

Dynamics

Name	Individual Finger Force	Joint Speed
Tact	4.2 N	250 °/s
Hand of Bennett et al.	25-30 N	-
Hand of Zhang et al.	4.3-10 N	68-118 °/s
MyHand	12-31 N	160-250 °/s
AstoHand v.1	-	-
X-Hand	-	-
Six-DOF-Hand	4.1 N	128 °/s
Bionic Hand		-
SoftHand Pro-D	-	-
UOMPro	-	-
MORA Hap-2	-	-

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Conclusion

- There are still a lot of open problems in designing myoelectric hand prostheses
- Many research groups develop prosthetic hands with new features
- The main goal in the last years was to develop preferably low-cost protheses
- Most research groups currently focus mainly on one novel design approach in their hand design
- Only a few groups tried to incorporate intelligent functions

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Thank you for your attention!