UBTECH
Dream With Robots

深圳市优必选科技有限公司

仿人机械手及其设计

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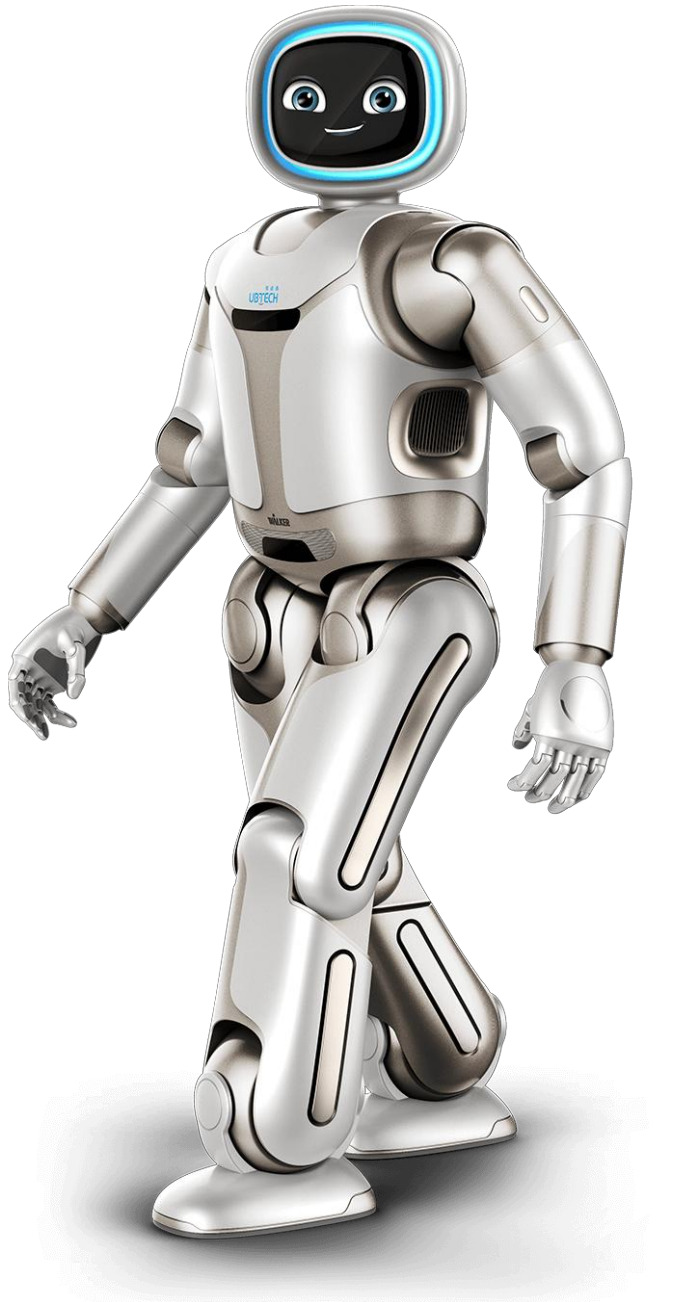
优必选研究院

2019年4月12日



内容目录

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Walker大型仿人服务机器人

Walker机器人的问世是优必选为实现“让机器人走进千家万户”这一目标迈出的坚实一步。Walker 新一代具备 36 个高性能伺服关节以及力觉、视觉、听觉、空间知觉等全方位的感知系统，可以实现平稳快速的行走和灵活精准的操作。Walker 新一代具备了在常用家庭场景和办公场景的自由活动和服务的能力，开始真正走入人们的生活。

开启机器人智能服务新时代

复杂地形灵活行走

自平衡调节 适应干扰

手眼协调操作

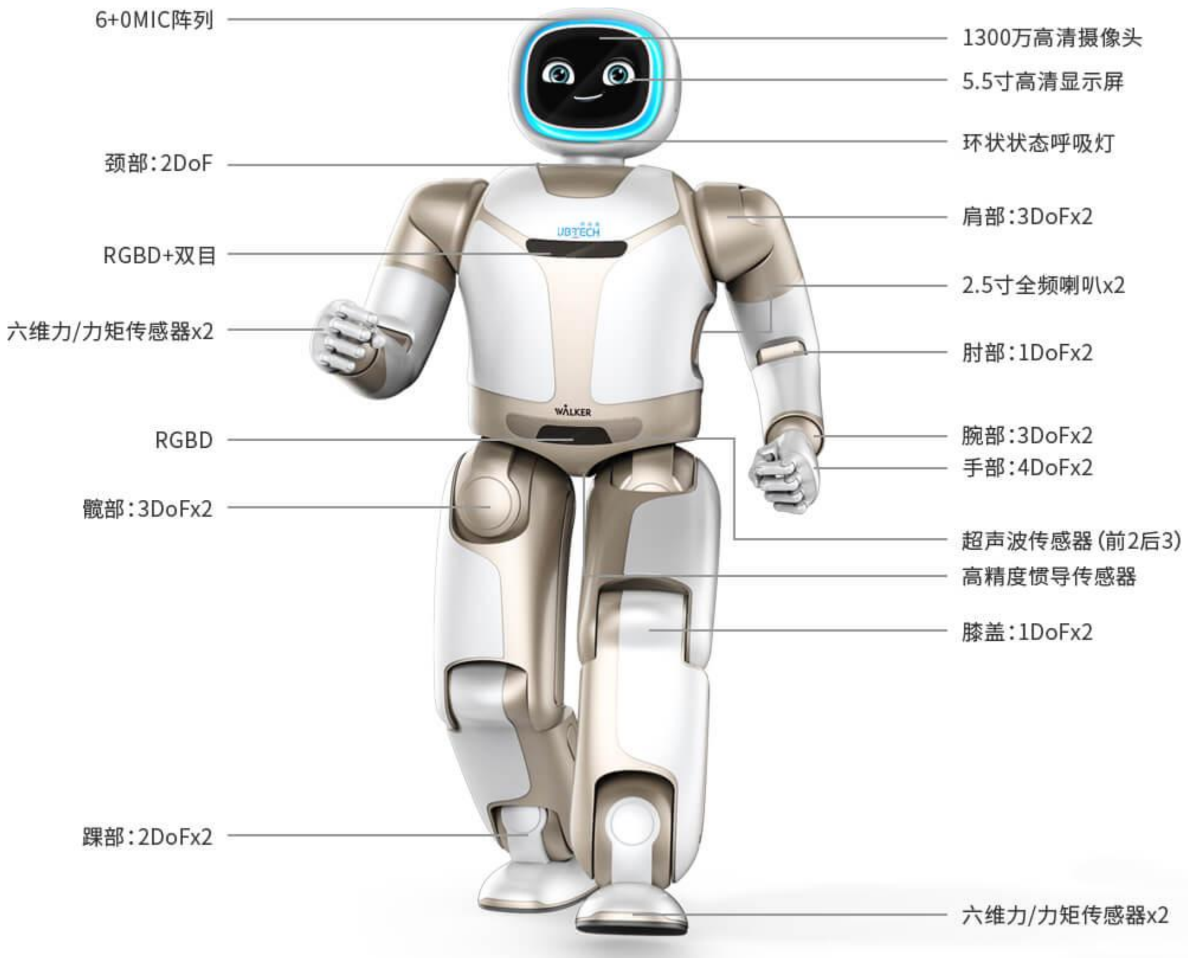
全身柔性 安全交互

U-SLAM导航避障

人脸/物体/场景识别

多模态交互

智能家居控制



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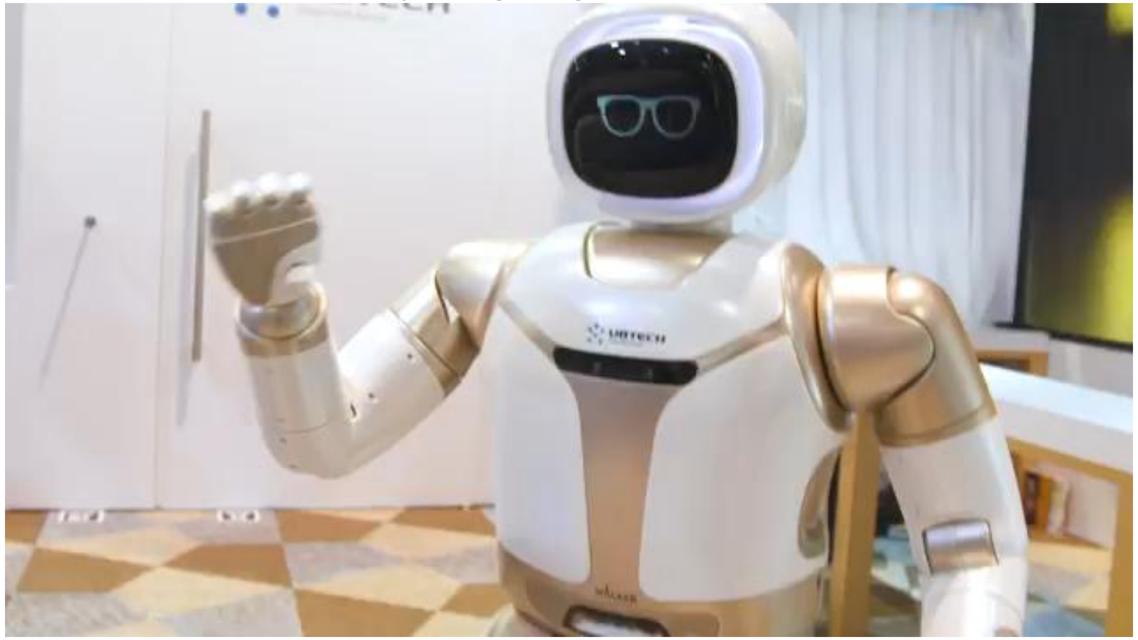
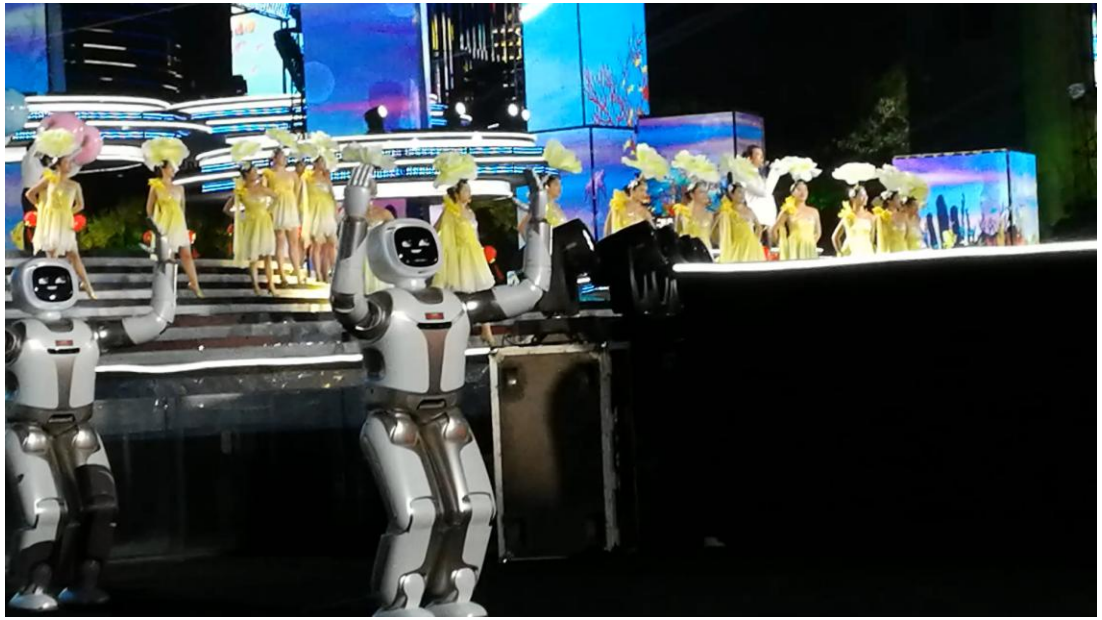
Walker大型仿人服务机器人

Hands-on video by Engadget At CES 2019



2019央视春晚深圳分会场



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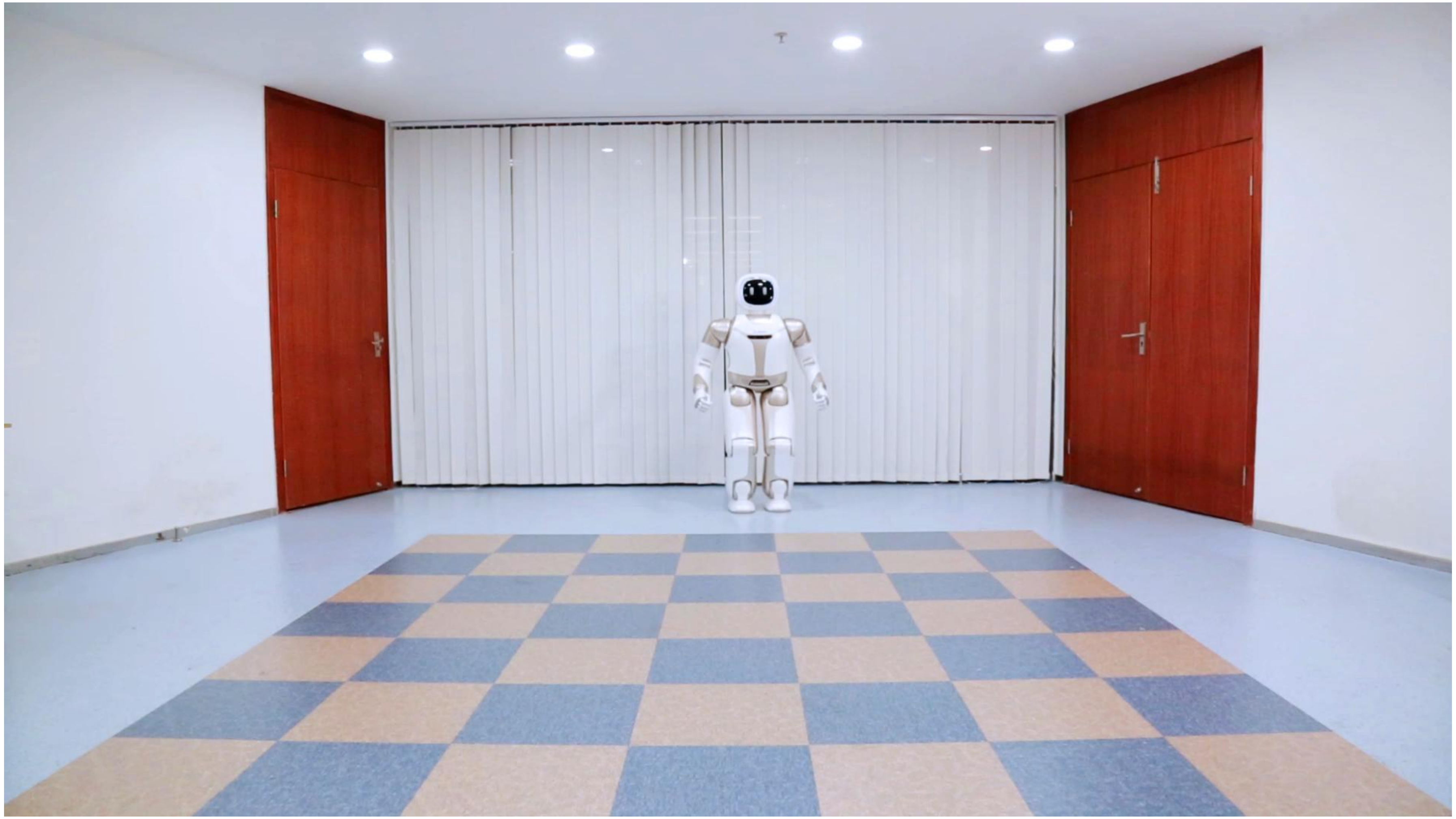
Walker 灵巧手功能展示

Daily tasks：
- 弹琴
- 倒水
- 写字



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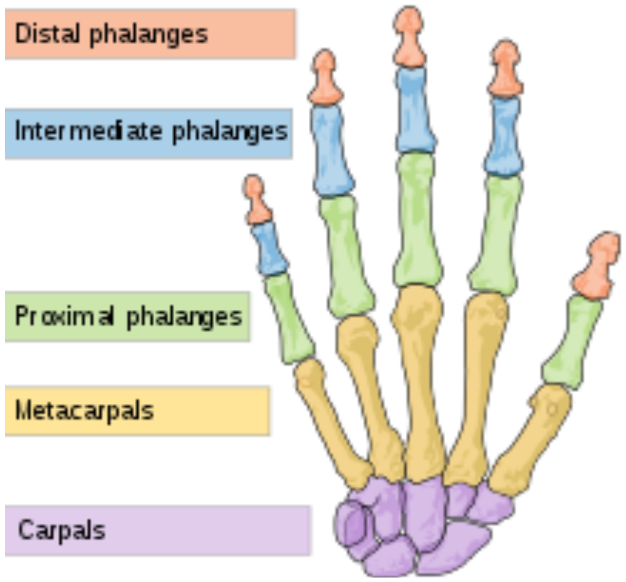
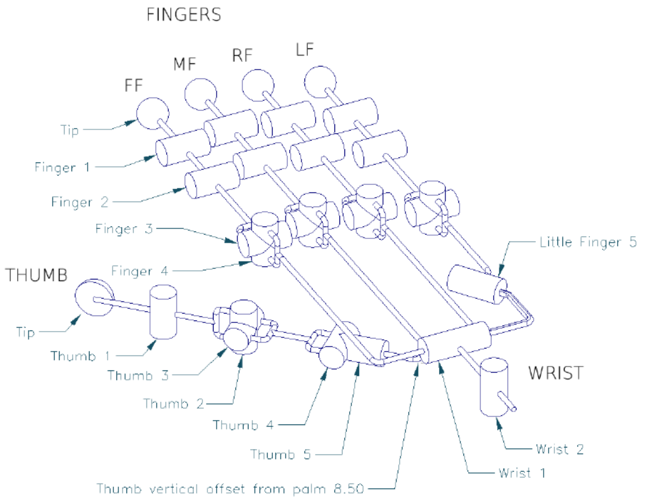
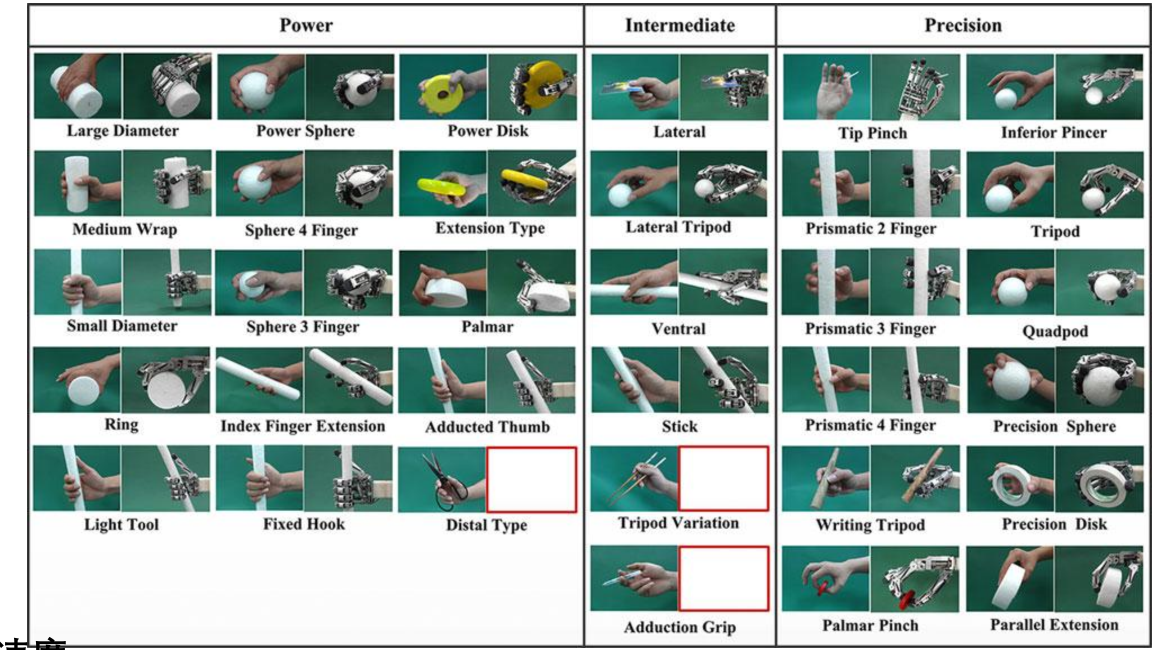
人手基本功能指标





人手典型抓握动作和手势

Grasps can be grossly classified as either precision or conformal types. The most common precision grasps are the **tip, tripod, and lateral pinch grasps**, while the most common conformal grasps are the **hook, spherical, and cylindrical grasps**. Note that the purpose of a precision grasp is generally to provide dexterity, while the purpose of a conformal grasp is generally to provide stability.



手指的力和速度

Paper I：A Multigrasp Hand Prosthesis for Providing Precision and Conformal Grasps
the digits associated with precision grasp (digits I and II: the thumb and forefinger) should be capable of at least **11 N**, and ideally up to 25 N; the composite force exerted by digits III–V (the middle, ring, and little fingers) should be at least 14 N; and the digits should be capable of joint angular velocities of at least **4 rad/s.**

Paper II：RoboRay hand: A highly back drivable robotic hand with sensorless contact force measurements
more than **40N lifting force and 10N fingertip force** are required. The maximum finger joint speed is greater than **500 deg/sec.**

Paper III：Design of a Highly Integrated Underactuated Finger towards Prosthetic Hand
The goal of the **fingertip force is 12 N, and the grasp speed is 120 deg/s .**

假肢机械手

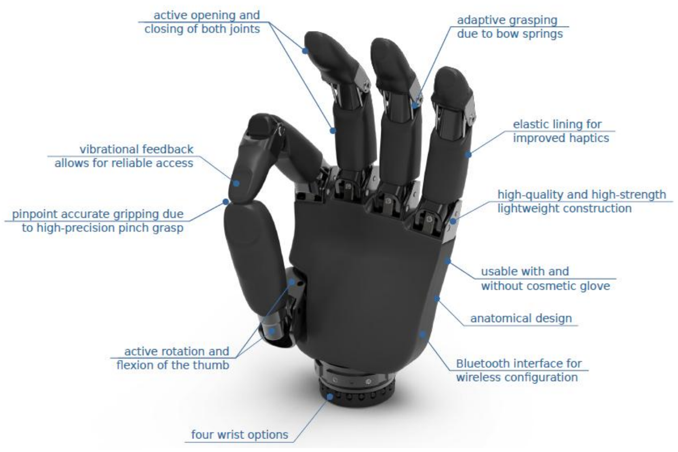
假肢机械手轻巧，紧凑，功能比较简洁，通过人的感知和肌肉信号来控制功能，静态承载力较大。

Be Bionic

具备5自由度，机械自锁，载荷大

iLimb ultra revolution

Vincent evolution 3



iLimb和Vincent都使用蜗轮蜗杆传动，具备机械自锁，电机位于手指中，适用人群更多

Johns Hopkins' Applied Physics Lab: Modular Prosthetic Limb

使用模块化设计，快拆接口。设计了外置和内置手掌驱动电机的方案，最终采用了内置方案，整合度更高，适用人群更广。

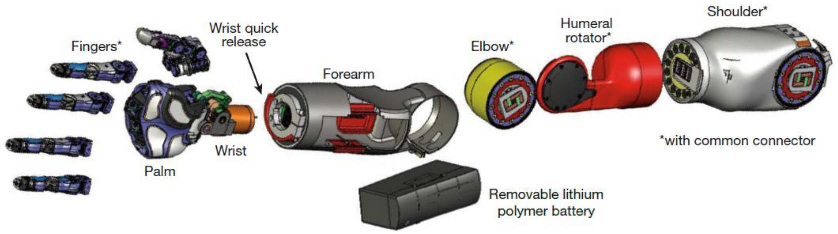


Figure 9. Modular components of the MP

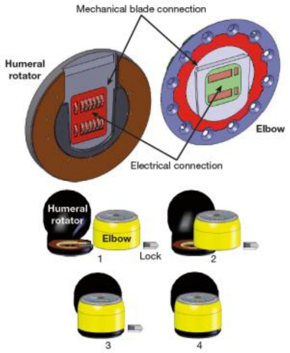
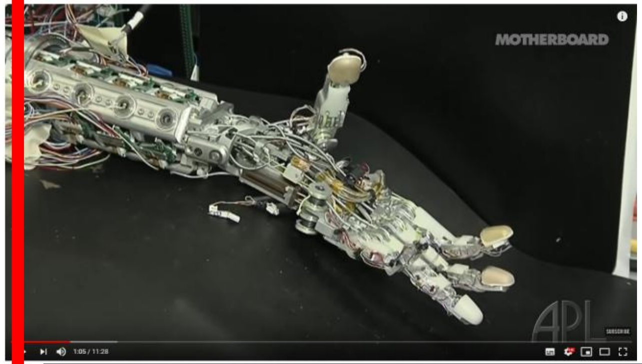
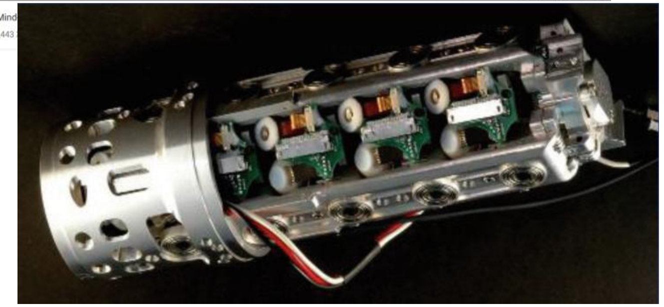


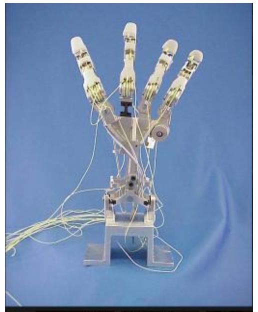
Figure 12. Modular upper arm interfaces combine mechanical

外置驱动电机方案

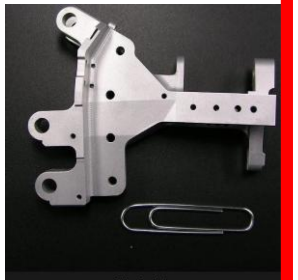




DARPA Phase I Hand

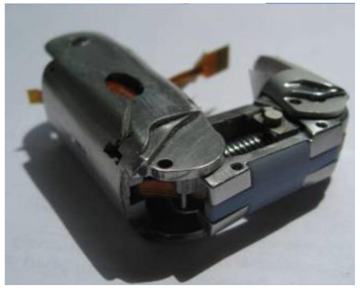


Extrinsically actuated hand



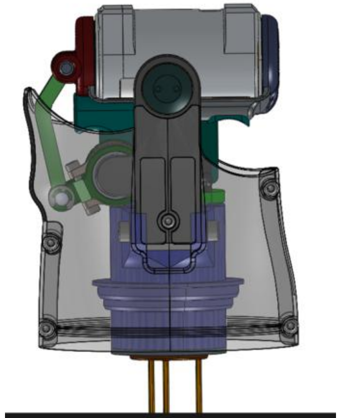
robotic palm structure

内置驱动电机方案

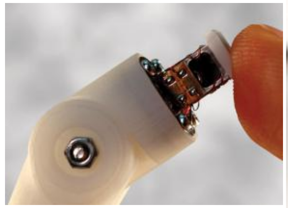


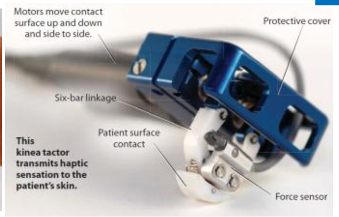
Robotic hand, mechanical engineering

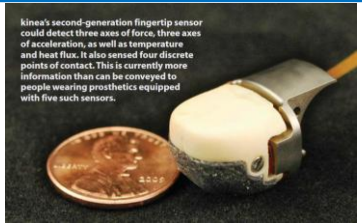
DARPA RP2009 MPL Hand



MPL Wrist







SPECTRA FIBER

Honeywell Spectra® fiber
patented gel-spinning pr

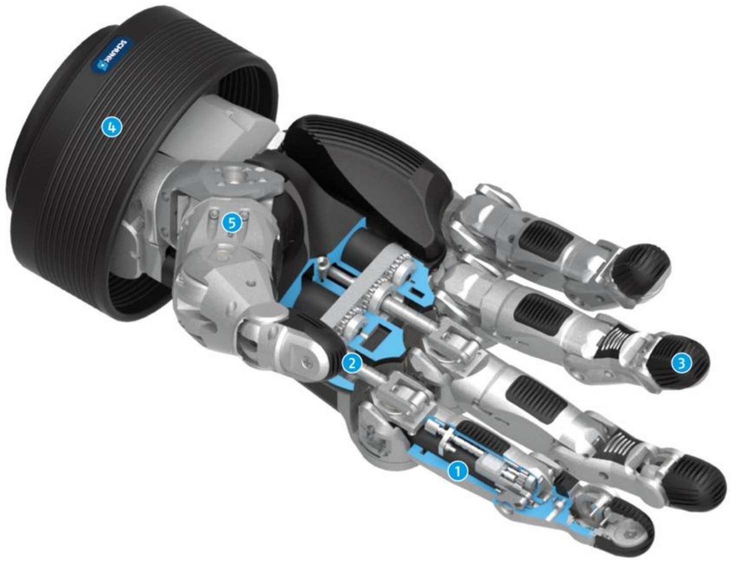
- A bright white polyethy
- Stronger than steel anc
- Capable of withstandin

机器人灵巧手

灵巧手用于机器人上。因为机器人的感知能力与人相比有较大差距，灵巧手需要更多的信息提供给机器人，例如关节转过的角度和指尖受到的压力，用于精确的控制手指的动作和位置，完成抓握，拾取等动作。因此灵巧手设计往往较为复杂，系统集成度更高。功能更加全面。

Schunk

市面上集成度最高的灵巧手，具备9个自由度，指尖能输出6N。价格昂贵。



Elu2-Hand
24-2-10
(speed and torque data subject to change)

1a Thumb Opposition
max speed 164 (deg/s)
max torque 0.76 (Nm)
--coupled to palm 'cupping'--

1b. Thumb Adduction
(Carpometacarpal Joint - CMJ)
max speed 83 (deg/s)
max torque 1.66 (Nm)
--coupled from a single actuator—(OR)
1b. Thumb Adduction
(Proximal Interphalangeal Joint - PIPJ)
max speed 83 (deg/s)
max torque 1.66 (Nm)

2a. Index Finger Flexion
(Metacarpophalangeal Joint - MCPJ)
max speed 183 (deg/s)
max torque 0.57 (Nm)
mechanically backdrivable

2b. Index Finger Flexion (PIPJ)
Max speed 112 (deg/s)
Max torque 0.20 (Nm)
mechanically backdrivable

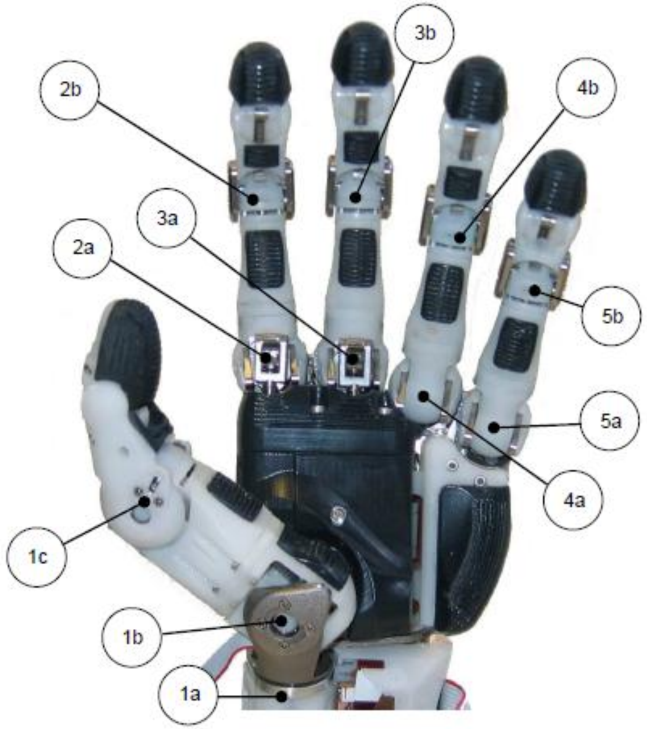
3a. Middle Finger Flexion (MCPJ)
max speed 183 (deg/s)
max torque 0.57 (Nm)
mechanically backdrivable

3b. Middle Finger Flexion (PIPJ)
Max speed 112 (deg/s)
Max torque 0.20 (Nm)
mechanically backdrivable

4a. Ring Finger Flexion (MCPJ)
max speed 76 (deg/s)
max torque 0.30 (Nm)
--coupled from a single actuator— (OR)
--both mechanically backdrivable--
4b. Ring Finger Flexion (PIPJ)
Max speed 112 (deg/s)
Max torque 0.20 (Nm)

5a. Small Finger Flexion (MCPJ)
max speed 76 (deg/s)
max torque 0.30 (Nm)
--coupled from a single actuator— (OR)
--both mechanically backdrivable--
5b. Small Finger Flexion (PIPJ)
Max speed 112 (deg/s)
Max torque 0.20 (Nm)

6. Spreading Digits 2-4-5 (not indicated)
max speed 162 (deg/s)
max torque 0.55 (Nm)
compliant spring in series with actuator



Speed ratings are based on nominal motor speed ratings for all motors used.

Torque ratings are based on a 1A input current for movements labelled; 1a, 1b, 1c, 2a, 3a, 6; and a current input of 0.5A for the movements labelled; 2b, 3b, 4a, 4b, 5a, 5b.

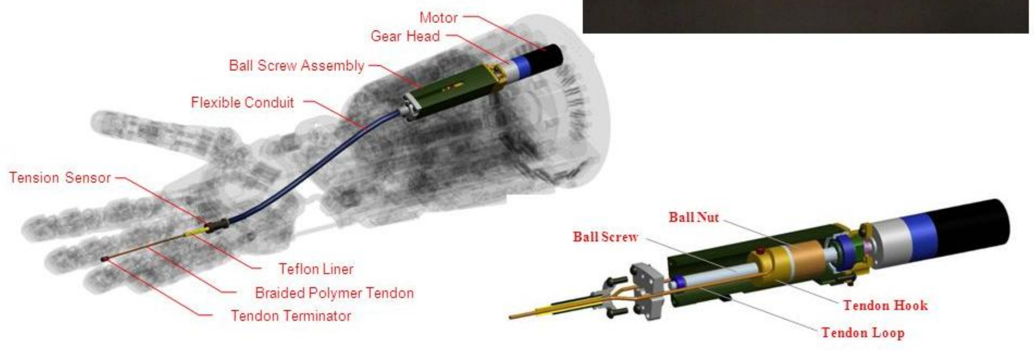
Shadow Dexterous Hand

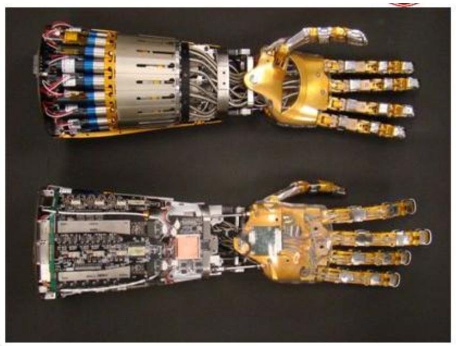
20个自由度，完全还原人手自由度。重达5Kg.

NASA Robotnaut hand

Enabling Technologies

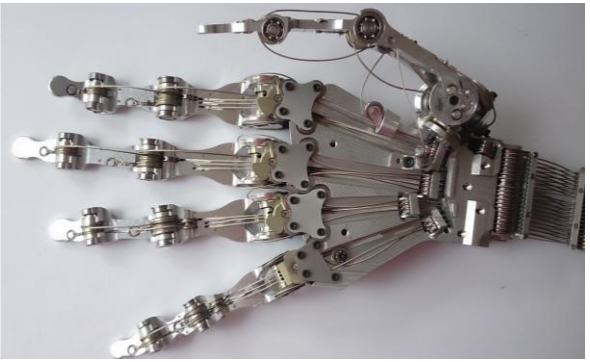
- Tendon Driven Finger Actuation System
  - Compact Remote Actuation
  - Hybrid Vectran/Teflon Tendon Material
- Capabilities Enabled
  - Human-Like Size, Strength, and Range of Travel
  - Finger Torque Control





为航天任务设计，兼具灵巧性和可靠性。

DLR_Hand Arm System



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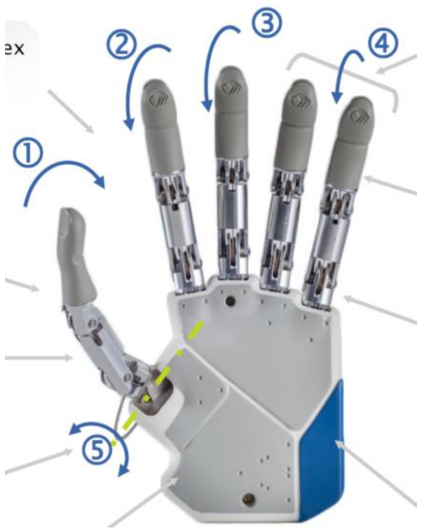
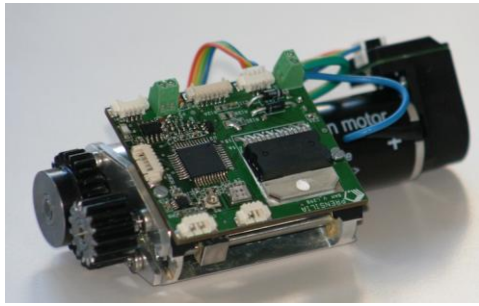
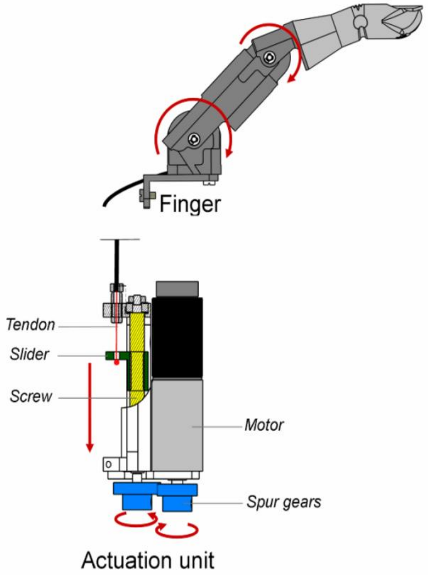
The required tendon forces are ranging from 60N for the metacarpal joint of the little finger and rising up to 350N for the DIP joint of the index finger. All joints should have a passive range of 30 degrees without tendon slack. Hence one mechanism must provide 60 degree tendon travel at the finger. Despite all these requirements the mechanism must remain compact, with low friction and minimal inertia.

Prensilia IH2 Azzurra

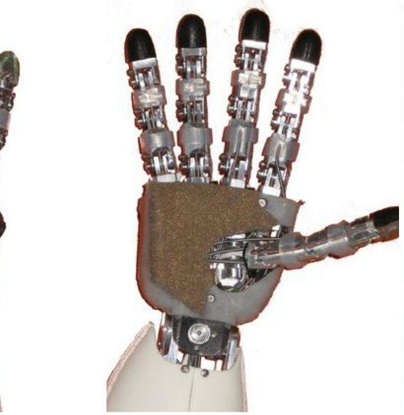


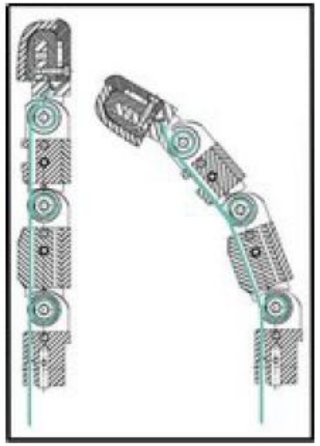


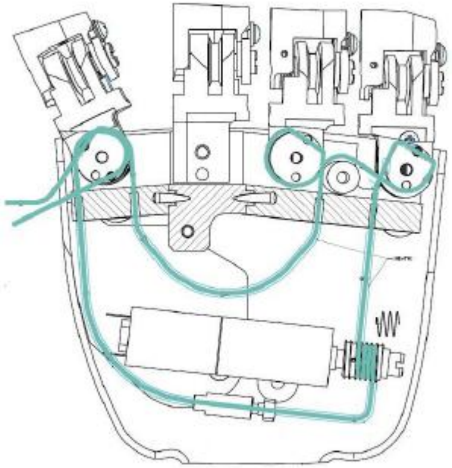


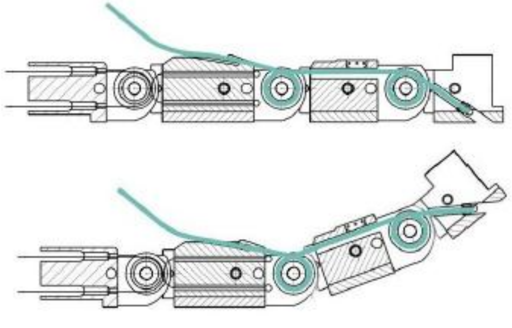
欠驱动手，结构简单，
具备自适应抓取能力。

iCub Hand









DLR Dexhand

高度集成模块化手指，
单根手指三个自由度。
无自锁传动效率高。

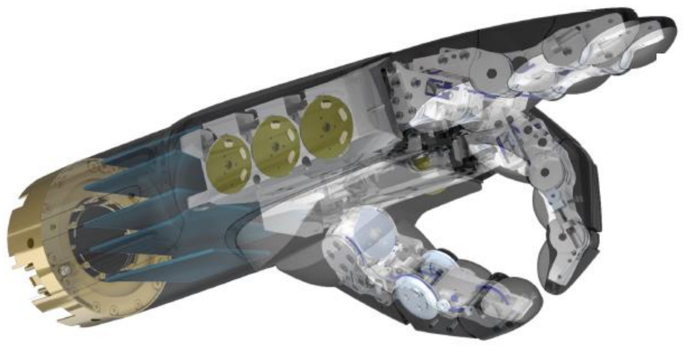


Fig. 9. Section view of Dexhand

Fig. 6. Drive unit with ILM 25 and harmonic drive gearing

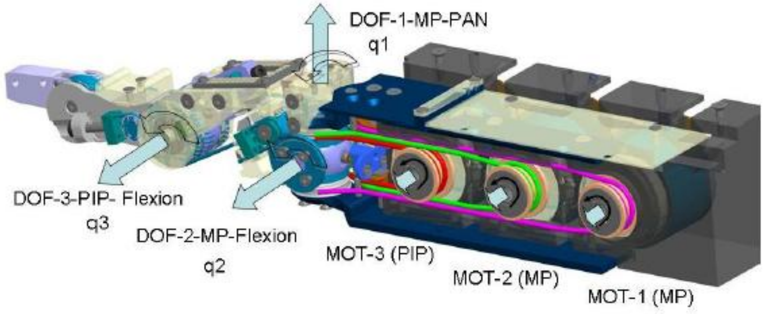
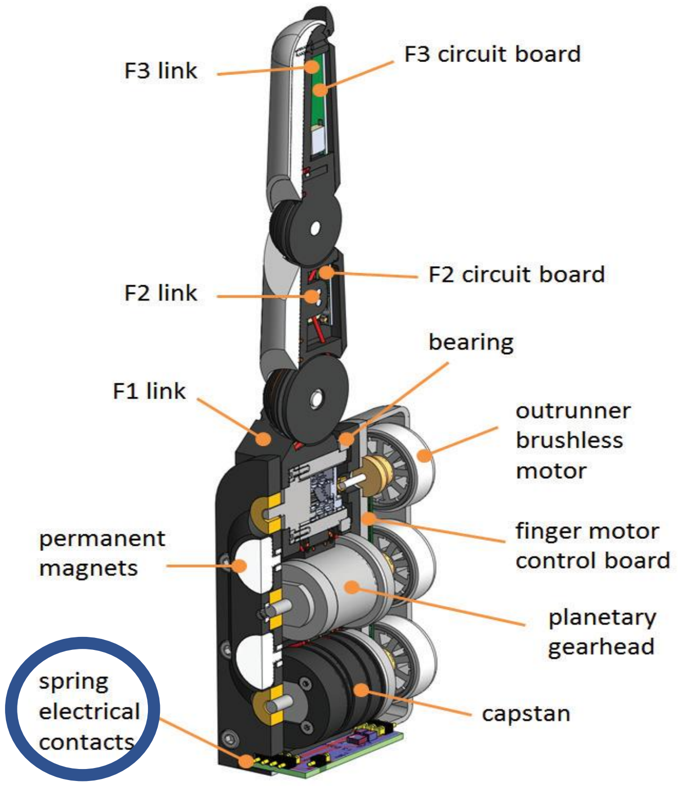
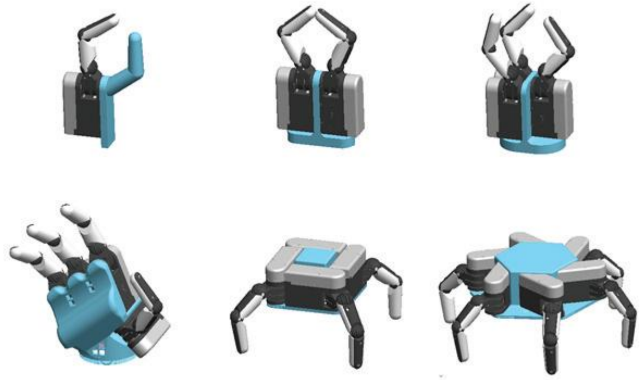


Fig. 5. Actuation principle of the fingers

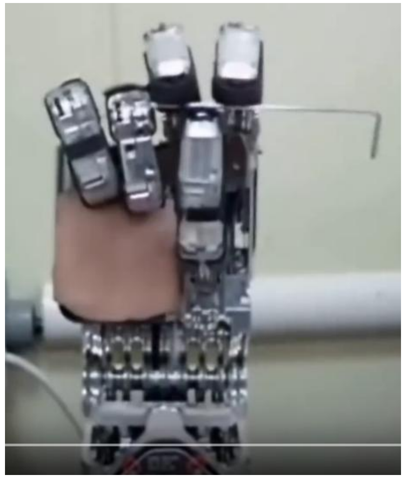
The Dexhand fingers are design to actively produce a fingertip force of 25 N (for the stretched finger it corresponds to about 3kg at finger tip1 while withstanding 100 N passively. The motor unit for Dexhand has been developed based on the DLR / Robodrive ILM 25 motor including the gearing of a harmonic drive HFUC 8 with a transmission ratio of 100:1. The whole unit fits into a cylinder of 27 mm diameter and a length of 17.5 mm with a weight of 46g (Fig. 6).

Sandia Hand





IRIM Lab Koreatech: RoboRay hand



将手指的运动分解为了指尖的pose motion，指根的grasp motion和roll motion三个自由度。使用差速机构实现手腕的两个自由度，能实现精确的动作。

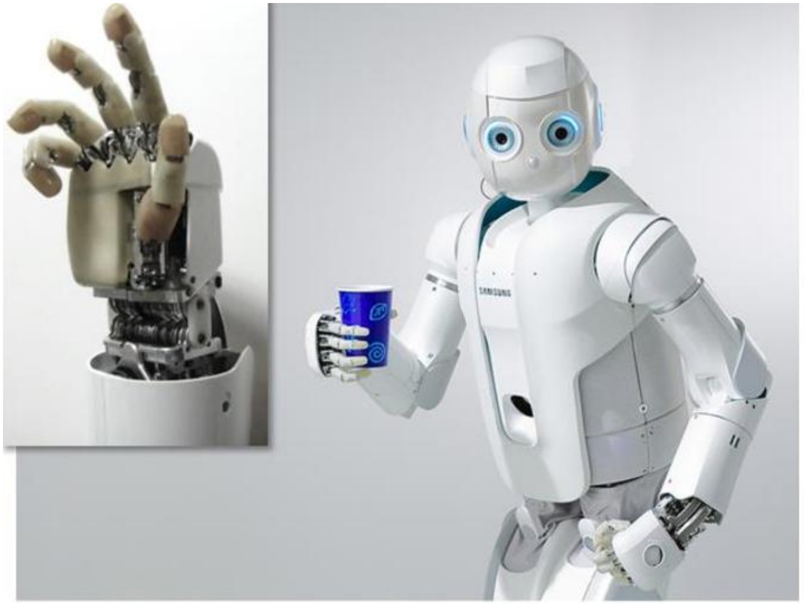


Fig. 1. RoboRay, a humanoid robot with two life-size dexterous robotic hands developed in Mechatronics Center of Samsung Electronics [9][10].

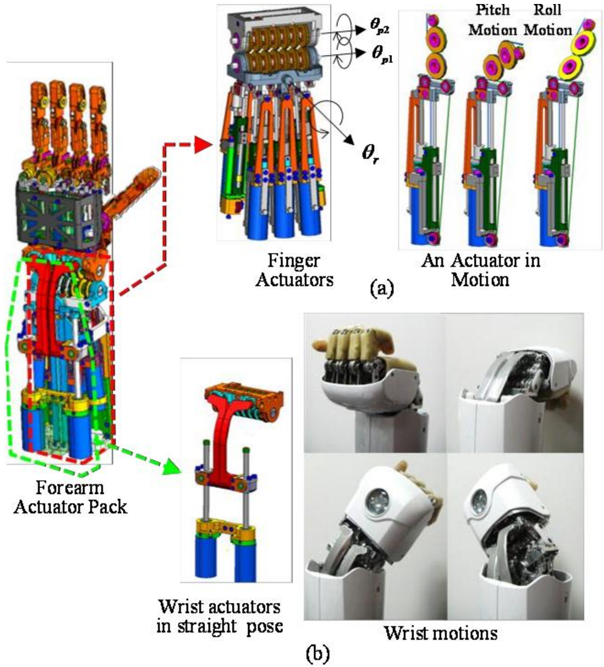


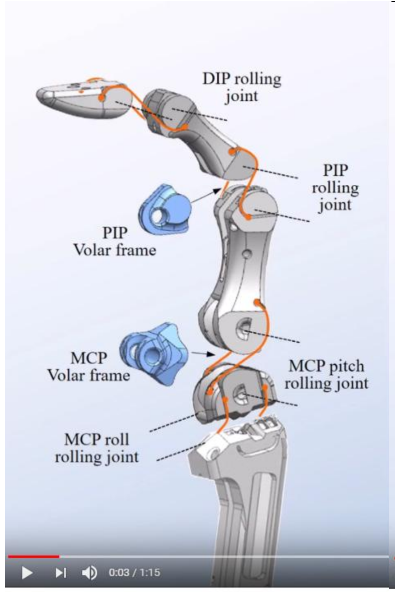
TABLE II
SPECIFICATIONS OF THE ROBORAY HAND

Items	Specifications	
Weight	1.59 kg	
Dimensions	Hand (H×L×W)	160 × 80 × 45 mm
	Forearm (H×L×W)	186× 76× 83 mm
DOF	Finger	12 DOF / 5 fingers
	Wrist	2 DOF
Payload	Peak Fingertip force	15N
Speed / Reduction ratio	MPR joint	800deg/sec, 47:1
	MPP joint	700deg/sec, 57:1
	PIP joint	450deg/sec, 82:1
Actuation	Motor, ball screw, wire and pulley	
Sensing	Minimum force sensing without Compensation : 0.735N with Compensation : 0.196N	
Motor	Pose motion	1.8Watt DC motor
	Grasp & roll motion	8Watt BLCD motor
	Roll motion	12Watt BLCD motor
Electronics	DC 12V, DSP TMS320F2812 EtherCAT communication	

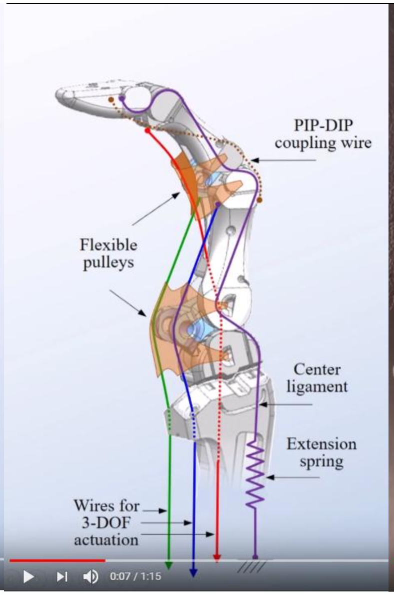
IRIM Lab Koreatech FLLEX Hand

- 3 DOF per finger
- fingertip force 40 N
- Repeatability 0.2 mm
- Impact absorbing capability

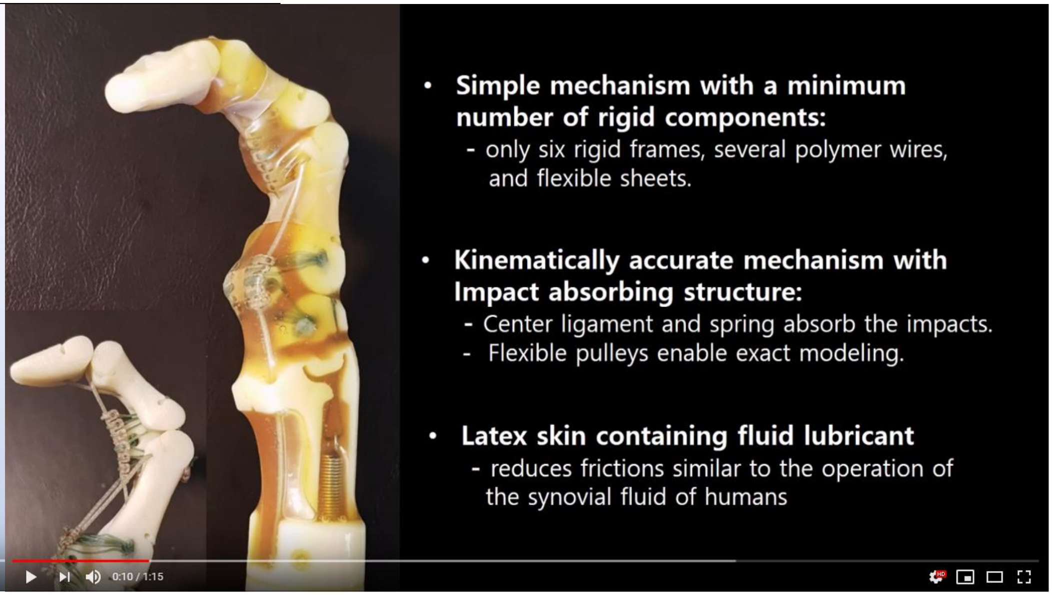
利用凸轮副构成手指关节，具有很强的抗冲击能力。



asic Concept of FLLEX Hand



Basic Concept of FLLEX Hand



Basic Concept of FLLEX Hand

DLR/HIT Hand II

DLR/HIT II 灵巧手是具有多种感知功能的、集成的5 指灵巧手，共具有15 自由度，如图1 所示。 为了实现手指的模块化设计，5 个手指完全相同。每个手指有3 自由度、4 个关节，末端的两个关节通过钢丝机构耦合运动。所有的驱动器、电路板、通信控制等都集成在手指内部。

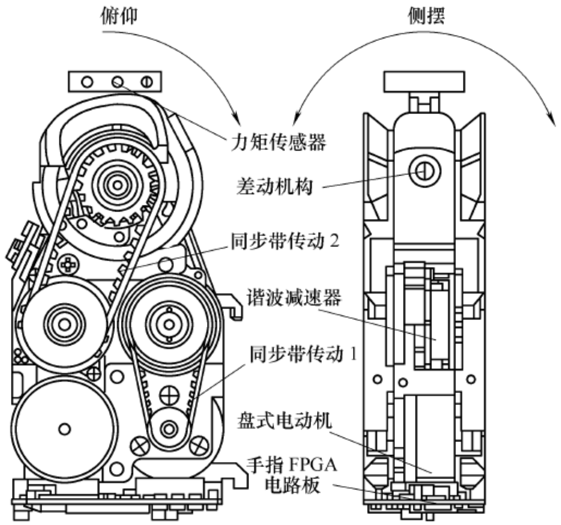


图 4　手指基关节

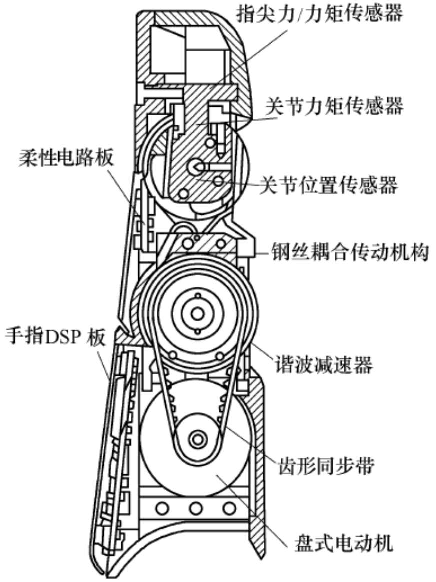
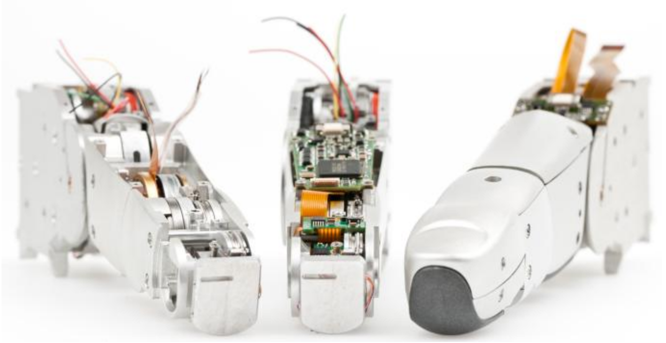
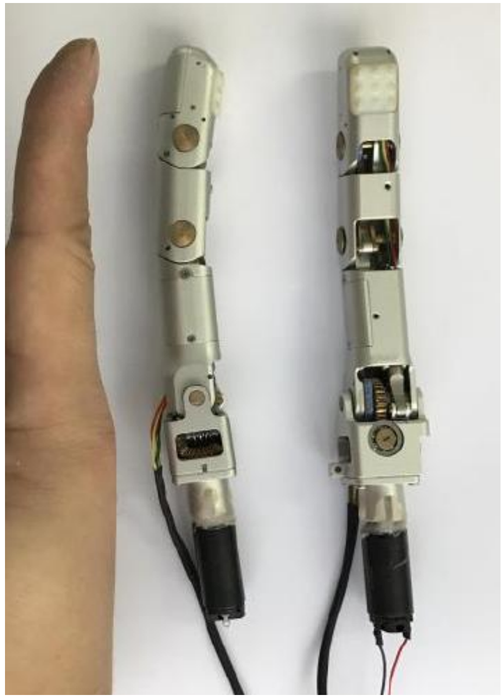


图 5　手指关节



HIT-adaptive finger

蜗轮蜗杆驱动具备自锁，弹性耦合连杆让手指具备适应性，
体积小，模块化设计



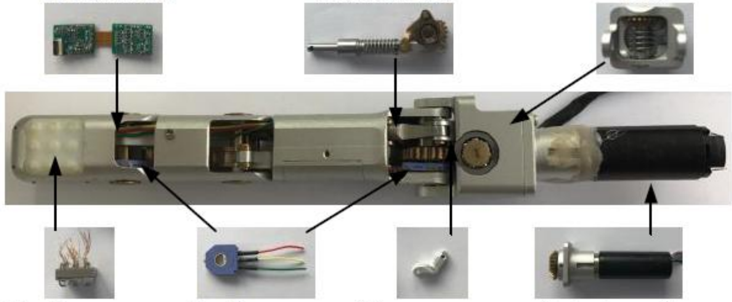


Fig. 7. The compositions of anthropomorphic finger

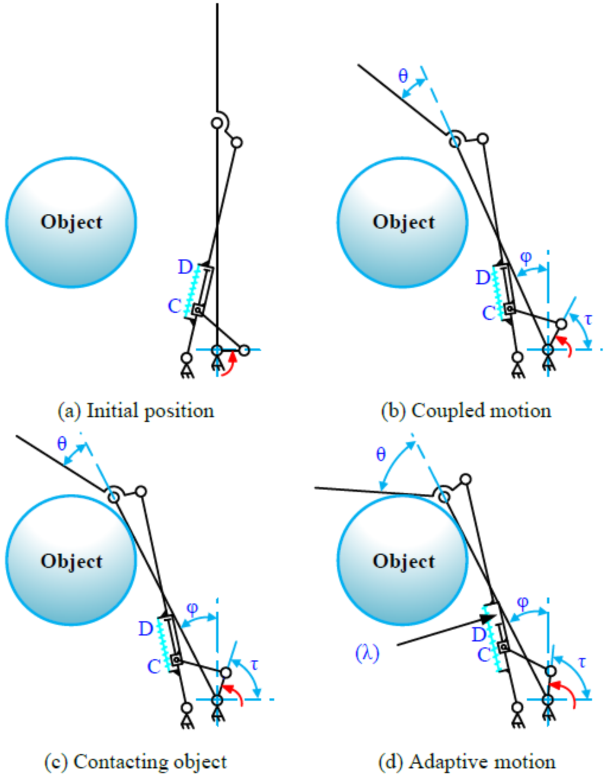


Fig. 5. Coupled-adaptive motion. (a) The finger is in the initial position. (b) The finger carrying out humanoid motion in free space. (c) The proximal phanlanx is contacting the object. (d) Another phalanx coutiue to adaptive motion after the proximal phalanx contacted object till the travel is exhausted.

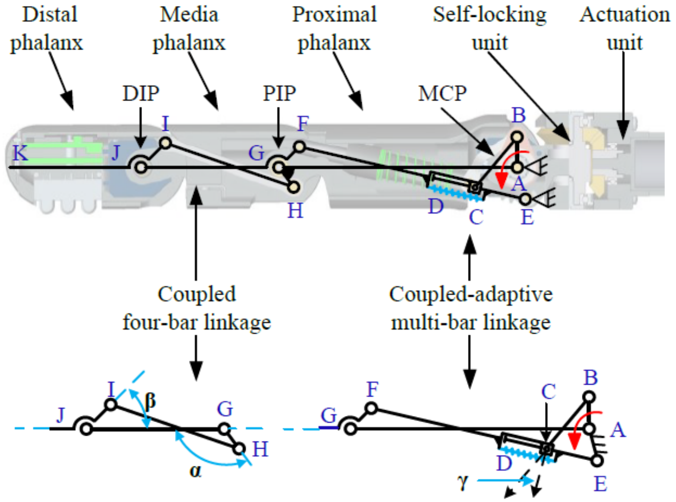
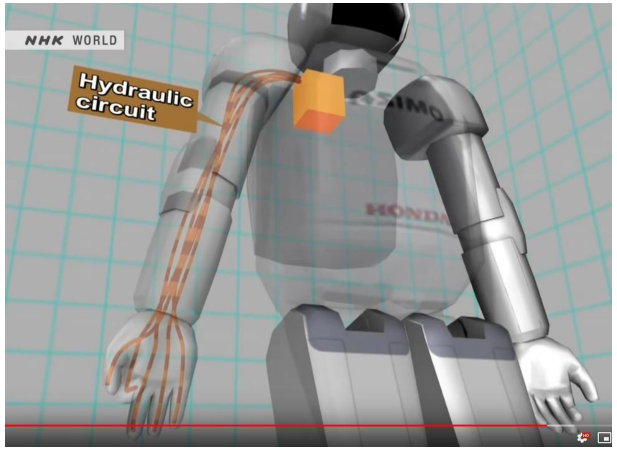
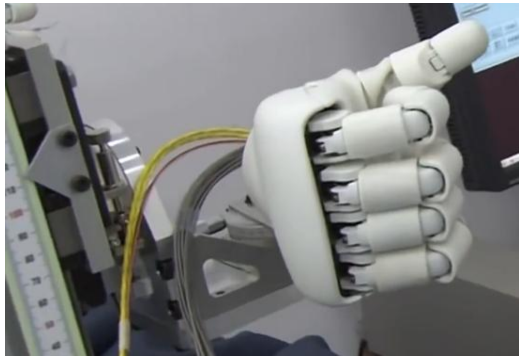


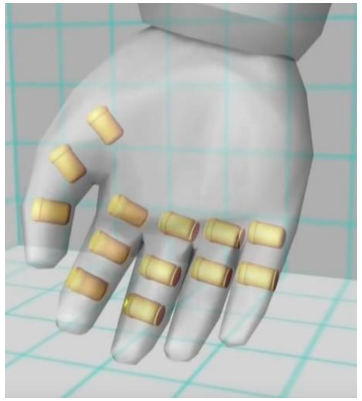
Fig. 4. The coupled-adaptive mechanism of the finger. The red arrow reprensent the direction of rotation of the bar.

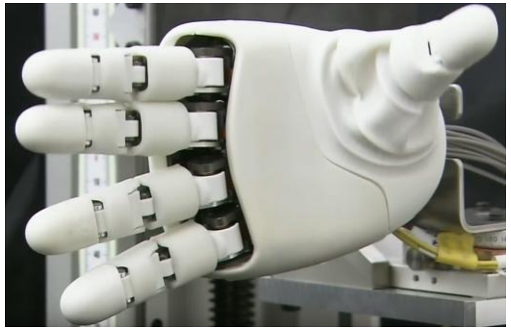
Asimo hand



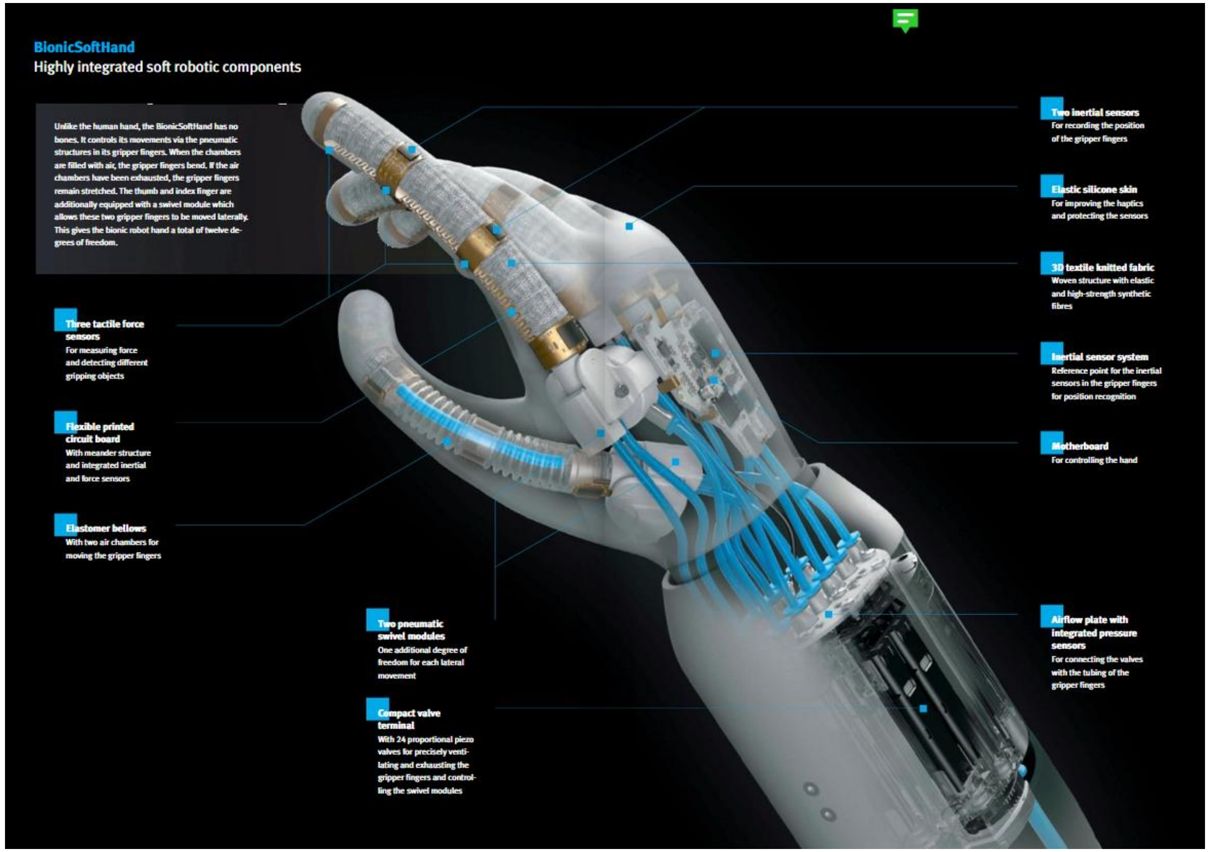
Asimo hand通过胸部的电机驱动液压阀带动手指运动。兼具灵巧性和体积小的优点。



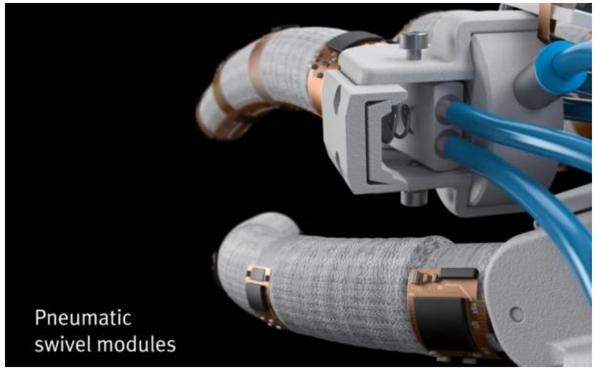




Festo – BionicSoftHand



气动手具备安全与人交互的优点。



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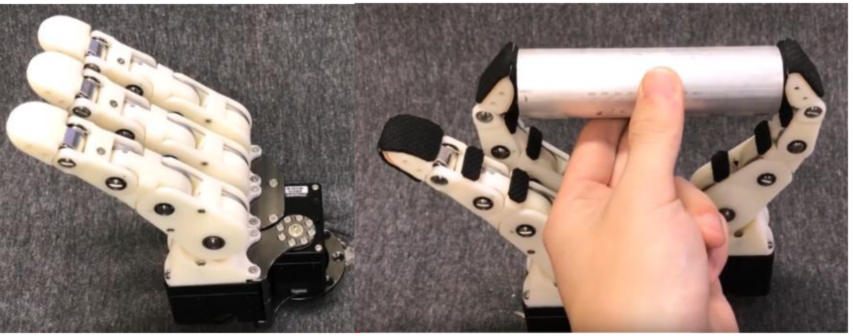
IRIM Lab Koreatech: AMBIDEX

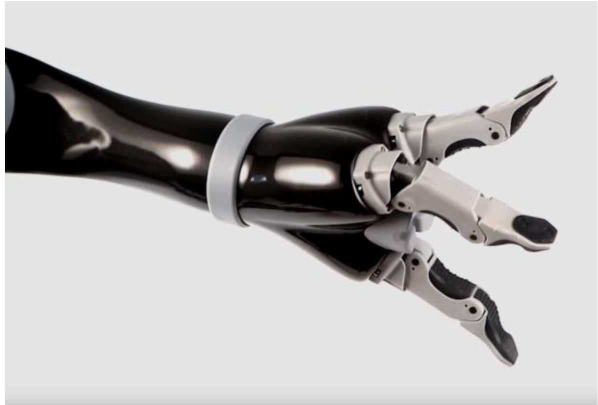
不受仿人外形限制的夹爪通常更加易于实现大负载能力和可靠性。

LIMS2-AMBIDEX Hand
- 4-DOF 3-finger hand
- Underactuated finger mechanism
- Loosely coupled Joints for constant free motion

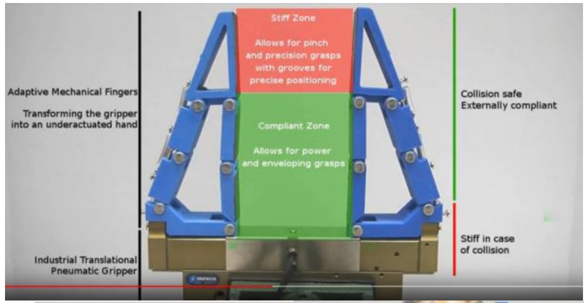


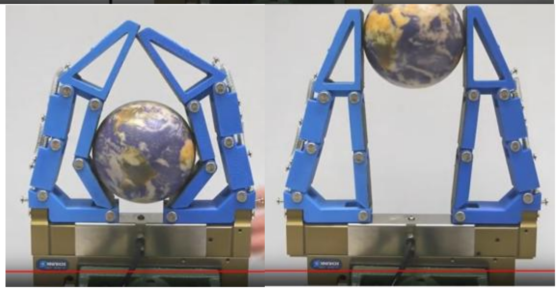
Robotiq

Kinova Gripper KG-3



PaCoMe Adaptive Mechanical Fingers





灵巧手设计需求

除了具备合适的手指握紧速度和指尖输出力之外，应用于家庭机器人上的灵巧手需要满足

1）极高的鲁棒性，较长的寿命和较高的抗冲击的能力；

2）丰富的传感器，关节转角和力传感器，提供给机器人控制抓取动作，判断抓取效果。

3）手指手掌对抓取物体具备广泛的适应性。

4）具有较高的静态载荷承受能力，满足提携物品的任务

5）对环境的适应性，例如潮湿，高温

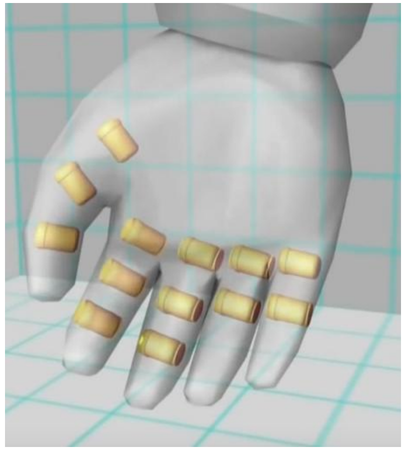
需要在设计过程中确定的问题

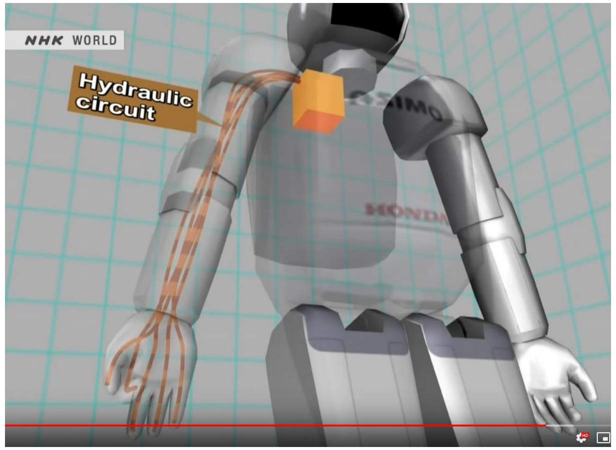
- 自由度：四指分别一个自由度，拇指两个自由度；手指自由度的耦合；手腕自由度；
- 手指握紧速度：0.3s-1s，使用寿命，空载10万次握紧张开；
- 手指指尖输出力：5-20N；
- 驱动器类型：直线（丝杠螺母），旋转绕线盘，蜗轮蜗杆传动；
- 电机减速器选型：有刷，无刷；行星减速器，谐波减速器。
- 驱动器位置：手掌内部，手指指节中，小臂处。
- 传动：线驱，连杆；
- 手指关节角位移的检测：编码器，测驱动的输出量，测手指关节的转动量；
- 手指触觉的实现：指尖压力传感器，电子皮肤，驱动器电流检测；
- 腕部快拆：机械定位锁紧，pogo pin连接；
- 手掌电子设计：驱动器的控制板PCB，金手指，手掌的控制板，是否需要IMU；
- 手掌与机械臂的通讯，电源；
- 手掌调试软件：出厂设定，功能展示等。

自由度

- 手指自由度：通常至少有一个自由度，必要时需要耦合两个手指关节的运动来实现可控的手指动作；
- 大拇指自由度：为了实现较多的抓取动作，大拇指通常至少有两个自由度，一个握紧一个摆动；
- 手腕自由度：两个或者三个自由度，通常会占用手臂的空间；
- 驱动的布局：shadow hands这样数量较多的驱动单元只能在布置在小臂中，并且通过丝线来传递运动。假肢机械手为了适应不同使用者的残疾状态而尽量将驱动器布置在手指内部。Asimo通过将驱动器布置在胸腔而让灵巧手兼具多自由度和小体积。

ASIMO手具备13个自由度





Shadow手具备20个自由度

驱动方式

DLR，Prensilia IH2 Azzurra和Robonaut hand通过丝杠螺母拉动手指的转动，电机和丝杠螺母的联结不相同。

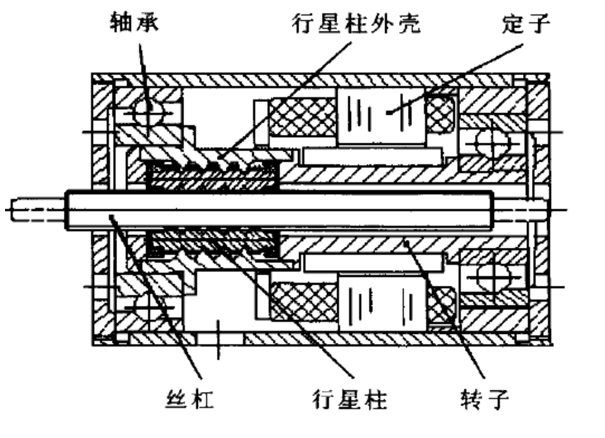
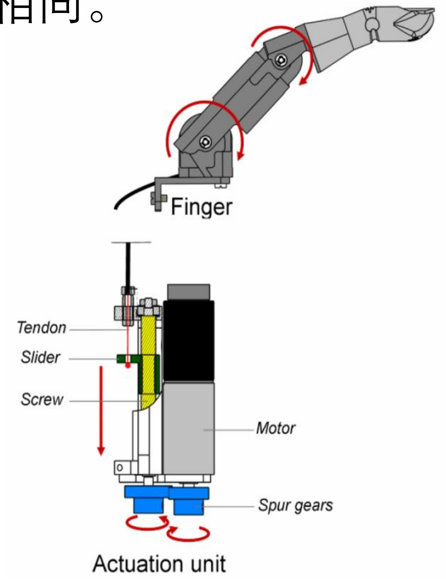
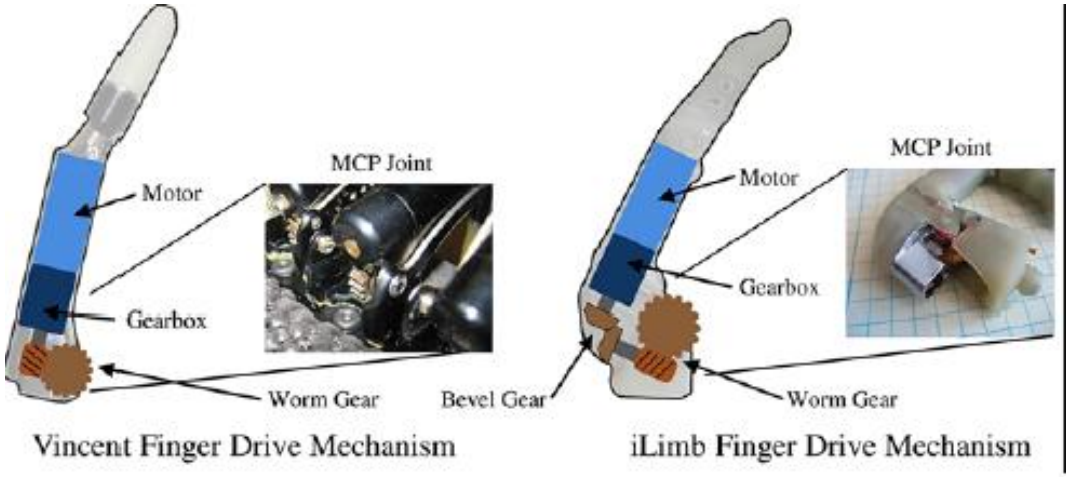
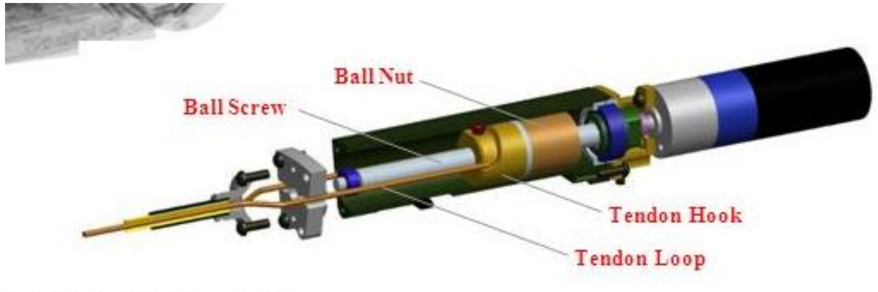


图 2　DLR 线性驱动器主视图



Vincent hand和iLimb的电机位于手指指节内通过蜗轮蜗杆驱动手指转动



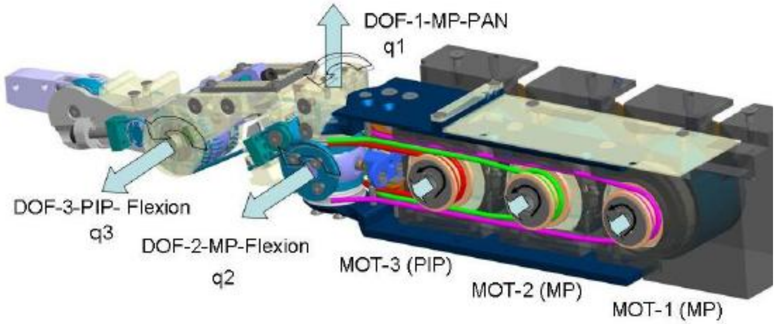


滑动丝杠和蜗轮蜗杆的传动方式都可以实现机械自锁，适合利用在需要较高静态载荷的方案中，比如商品化的假肢。但是传动效率较低，容易磨损。

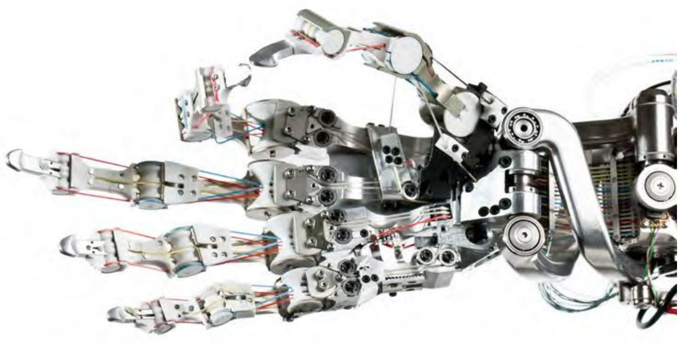
驱动方式

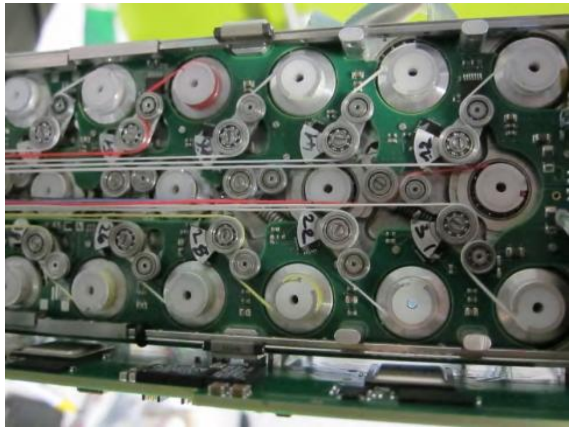
绕线盘的方式具有较高的传动效率，容易布置多个驱动单元实现多自由度的手指。无法直接实现自锁，对电机输出力矩要求较大。

DLR Dexhand 通过手指模块内的电机+谐波+绕线盘的方式驱动手指



DLR_Hand Arm System 通过位于小臂的电机带动绕线盘拉动手指





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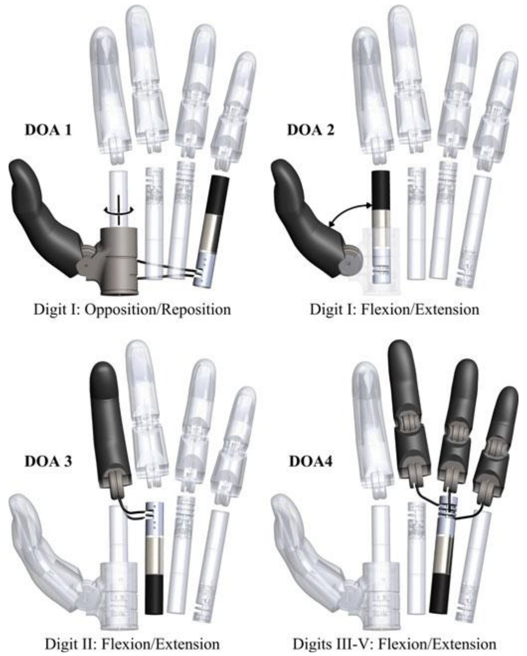
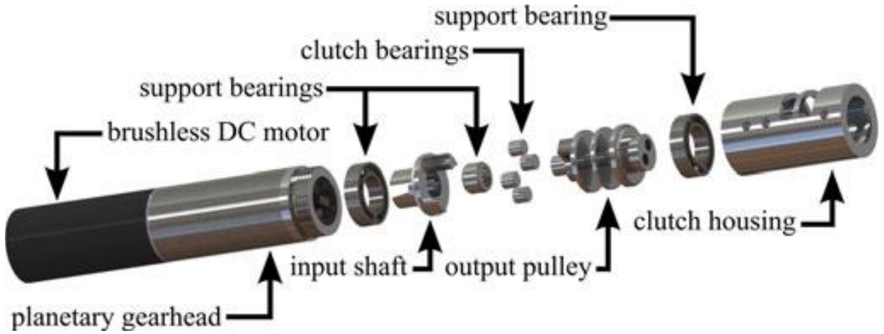
Vanderbilt hand通过一个创新的绕线盘设计让一个电机可以同时拉动三根手指





驱动方式

齿轮组的传动方式设计较复杂，安装精度要求高，成本较高。

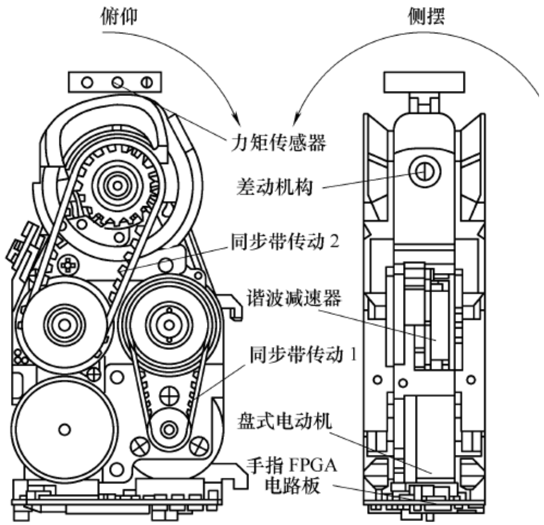


图 4　手指基关节

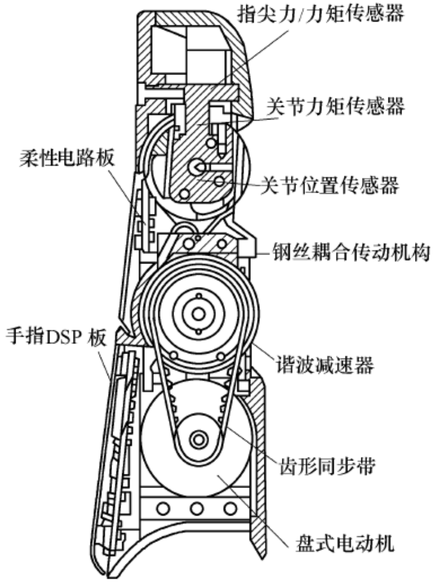
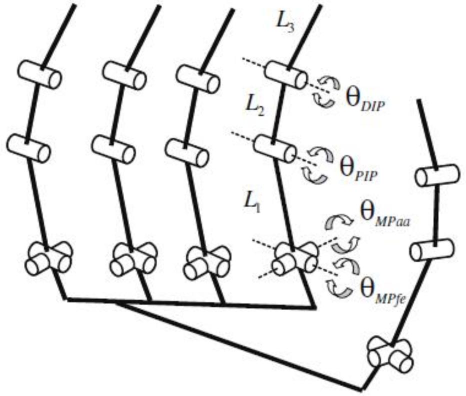


图 5　手指关节

DLR/HIT II使用锥齿轮差速机构，同步带和谐波减速器实现手指的三个自由度



(b) Kinematics

Fig. 1. A multifingered robot hand, the NAIST hand: the hand has four fingers and 12 DOFs.

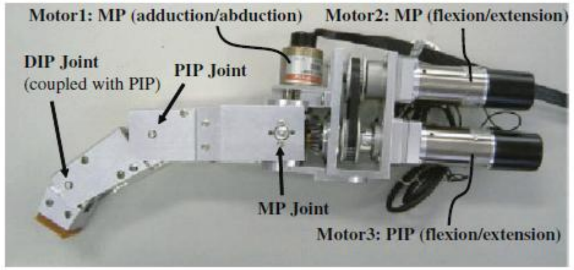
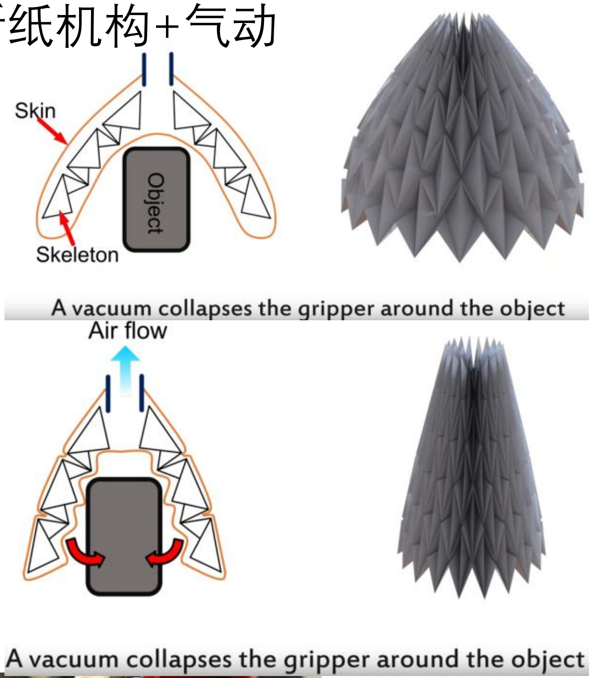


Fig. 2. Finger module (without the fingertip).

Naist hand利用齿轮组，同步带以及连杆实现三个自由度

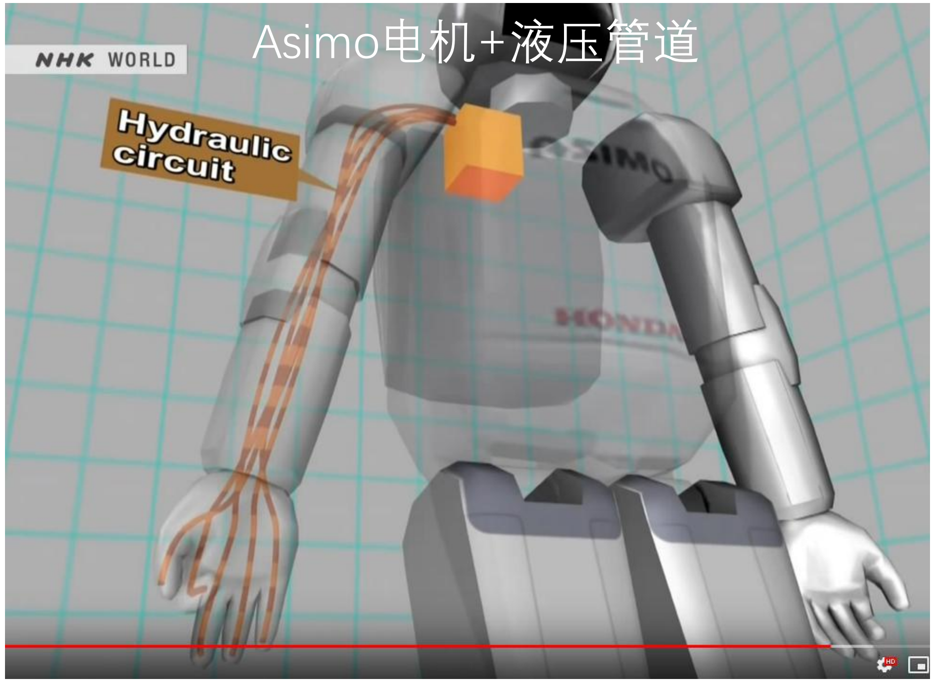
驱动方式

MITCSAIL Origami Robotic Gripper
折纸机构+气动



Festo BionicSoftHand 气动

Asimo电机+液压管道



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驱动方式

差速机构驱动可实现欠驱动抓取，并对被抓取物体的形状具有广泛适应性。无法实现精确的运动控制。

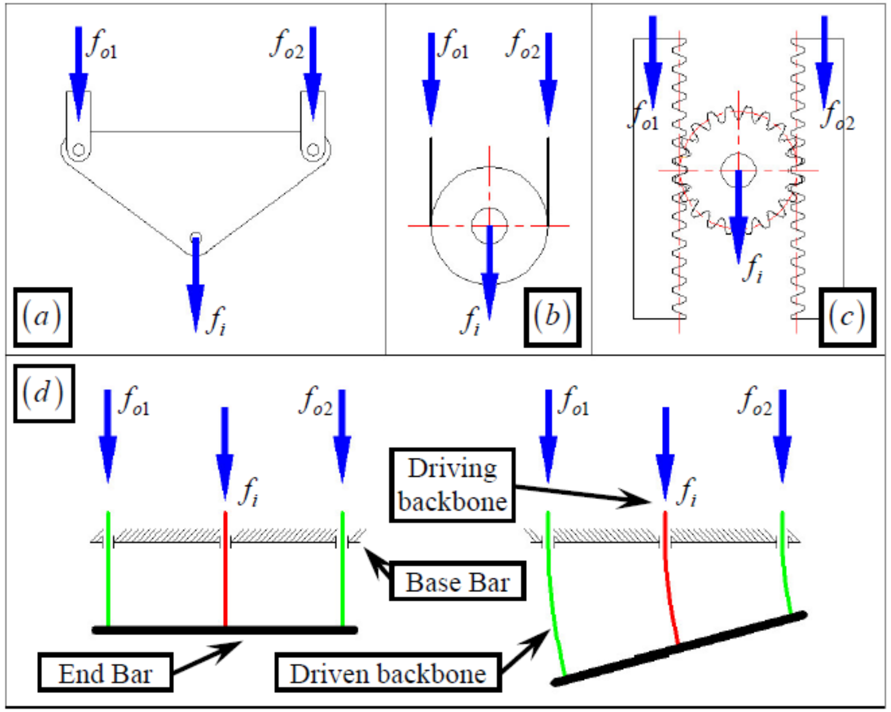

Fig. 2. Differential mechanisms: (a) a lever-based mechanism, (b) a pulley-based one, (c) a pinion-based one, and (d) a continuum one

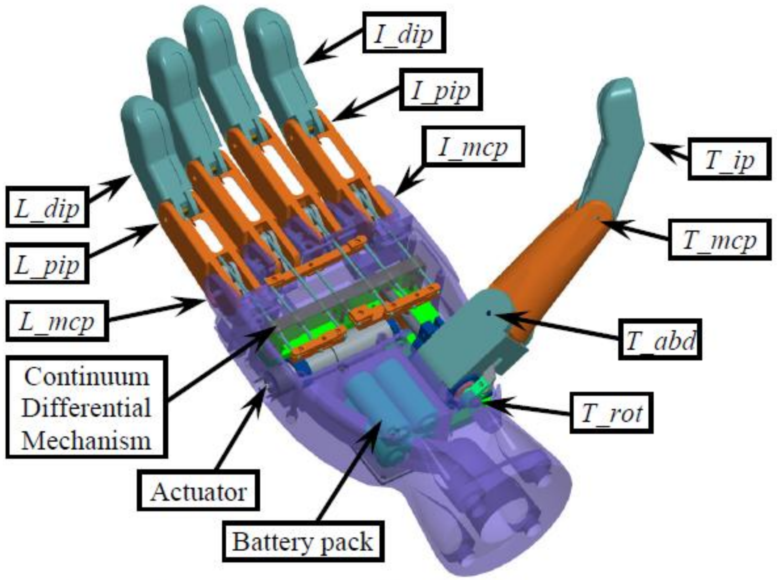

Fig. 3. The single-actuator prosthetic hand

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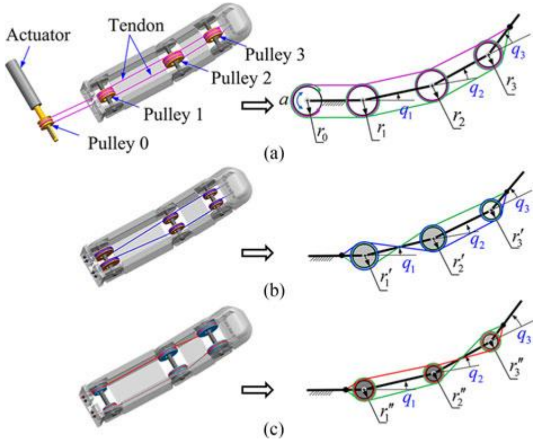
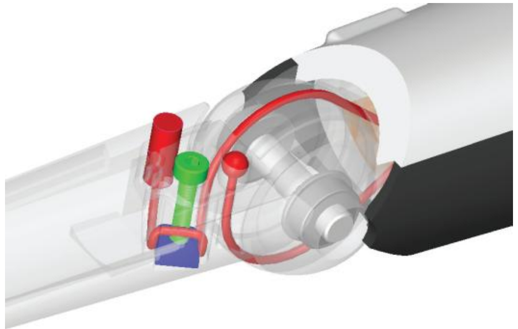
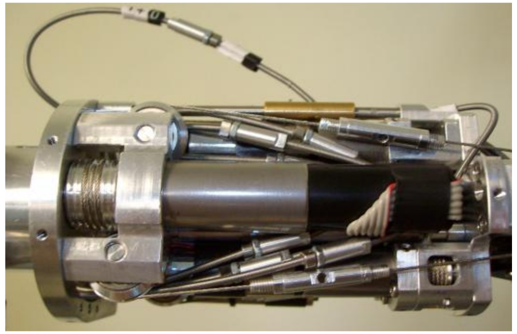
传动方式

线拉：利用钢丝或者大力马线拉动手指关节转动。具有体积小，重量轻，拓展性好的特点。缺点是不耐磨，一致性较差，需要张紧。







连杆：承受负载大，设计较简单。空间体积占用较大，较难实现多自由度。

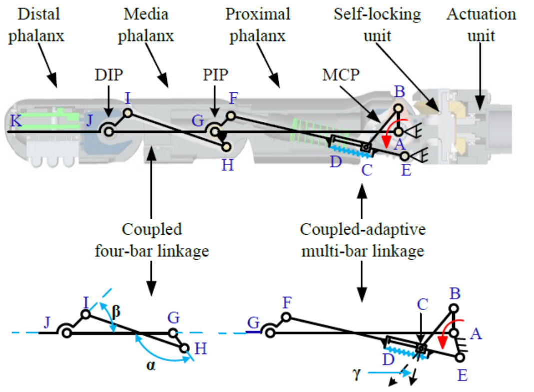
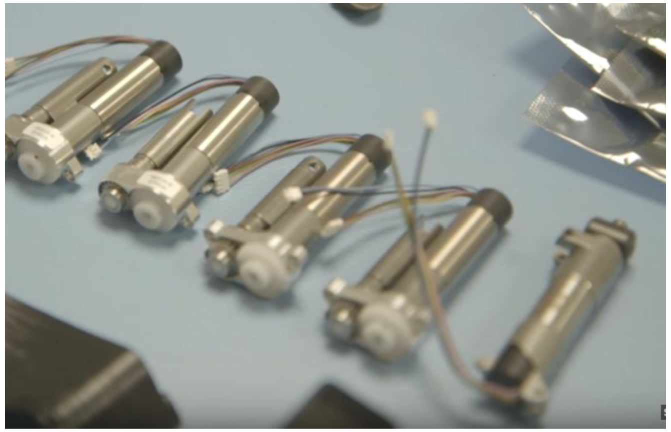


Fig. 4. The coupled-adaptive mechanism of the finger. The red arrow repensent the direction of rotation of the bar.

电机减速器选型



电机的选型需要综合驱动方式，传动方式，灵巧手自由度以及电机布置的位置来选择

- 输出力矩：根据指尖输出力，手掌抓握力来计算得出；
- 输出转速：根据驱动方式不同而不同；
- 尺寸：直径和长度不可兼得；
- 行星减速器和谐波减速器：精度和价格差别较大；
- 电机刹车：代替机械刹车，同时实现高传动效率和自锁。

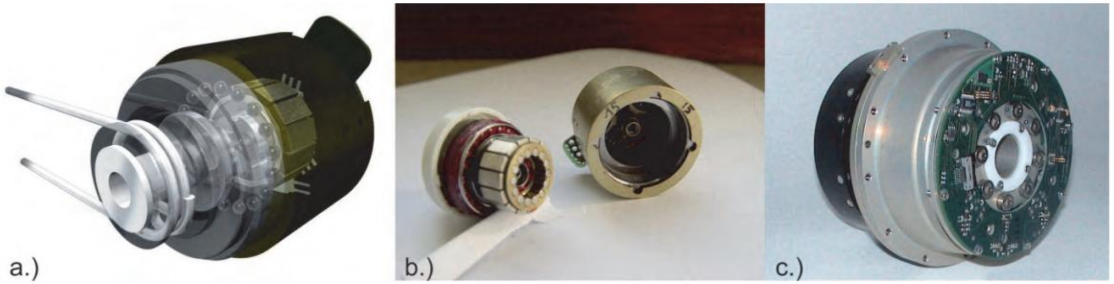


Figure 4: DLR drive train concept a.) DEXHAND unit CAD, b.) DEXHAND unit photo, c.) ROKVISS unit photo

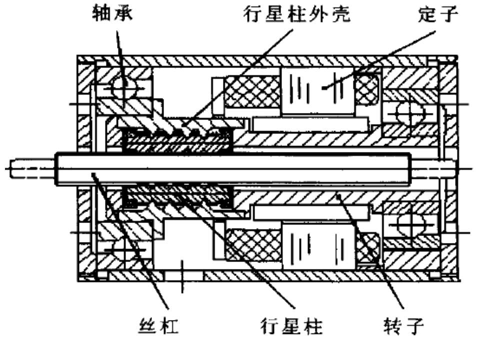
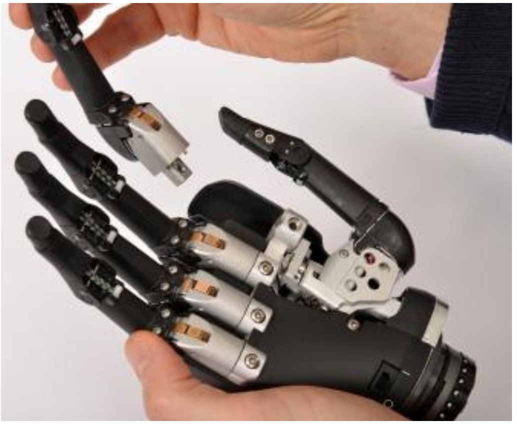
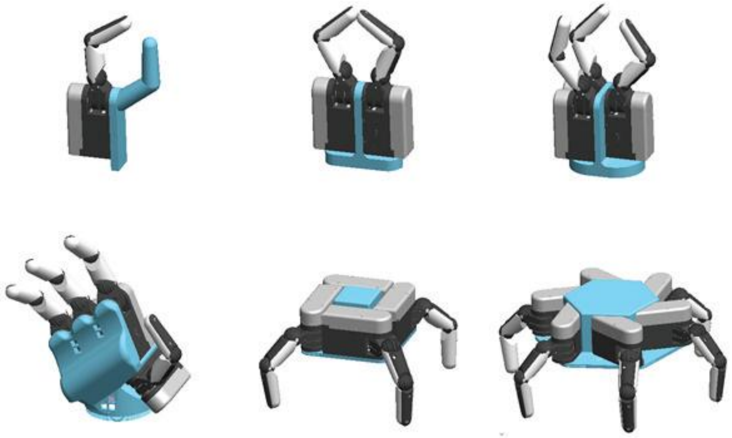


图 2 DLR 线性驱动器主视图

手指模块化

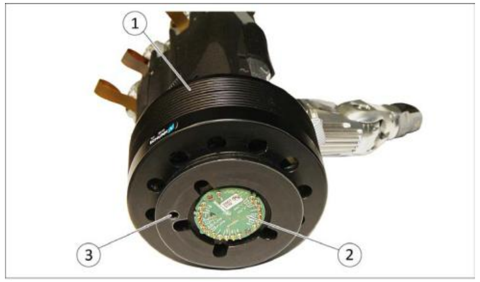
方便设计和生产，降低成本，容易实现多种构型

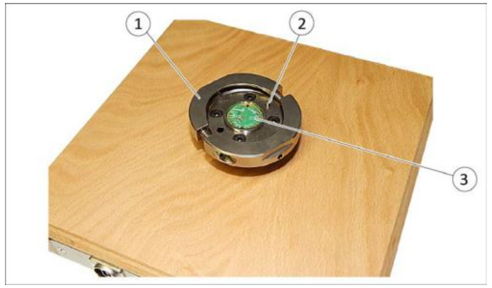




手腕快拆

方便拆装和维护，可实现与手臂接口的标准化

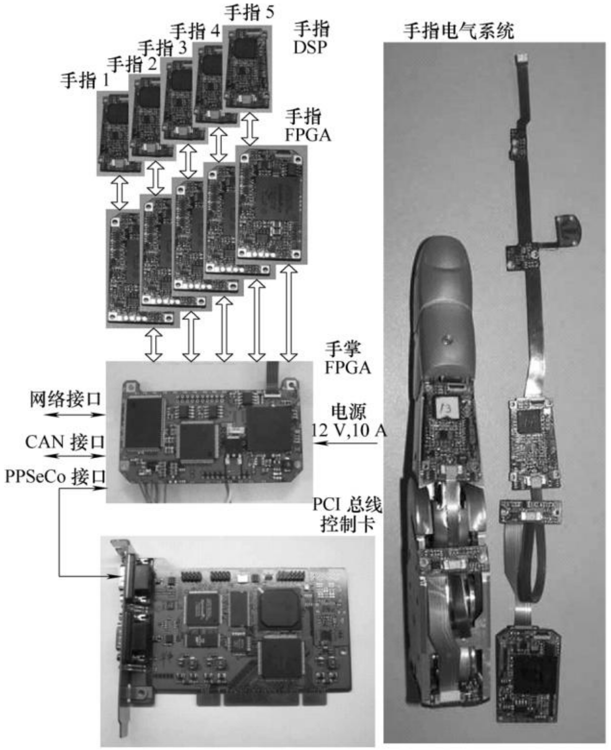




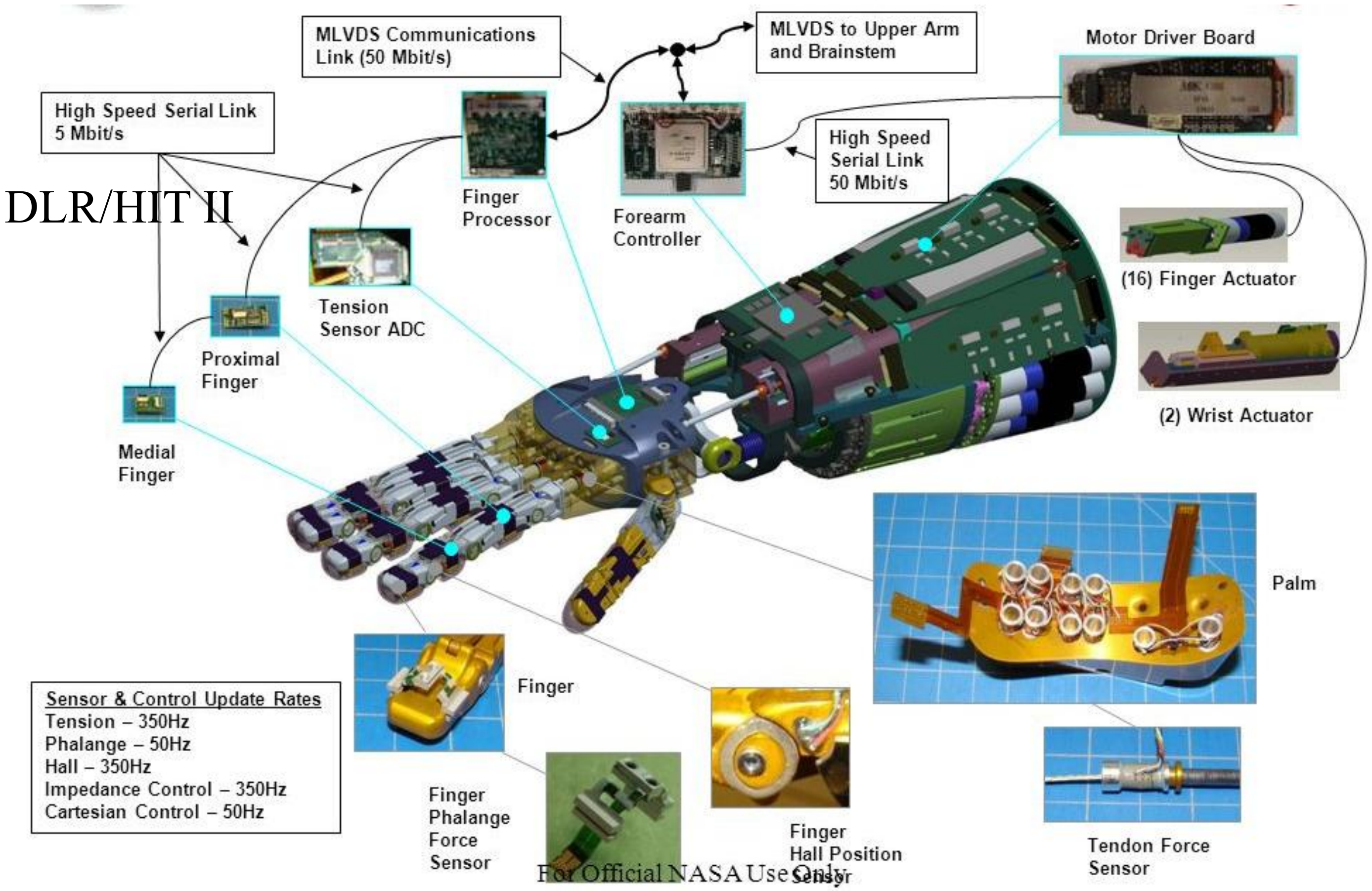
电子设计

- 位移，转角传感器：霍尔传感器，电位器
- 力：指尖，指腹
- 触感：点阵
- 温度
- IMU

- 控制板位置
- 通信协议
- 电源

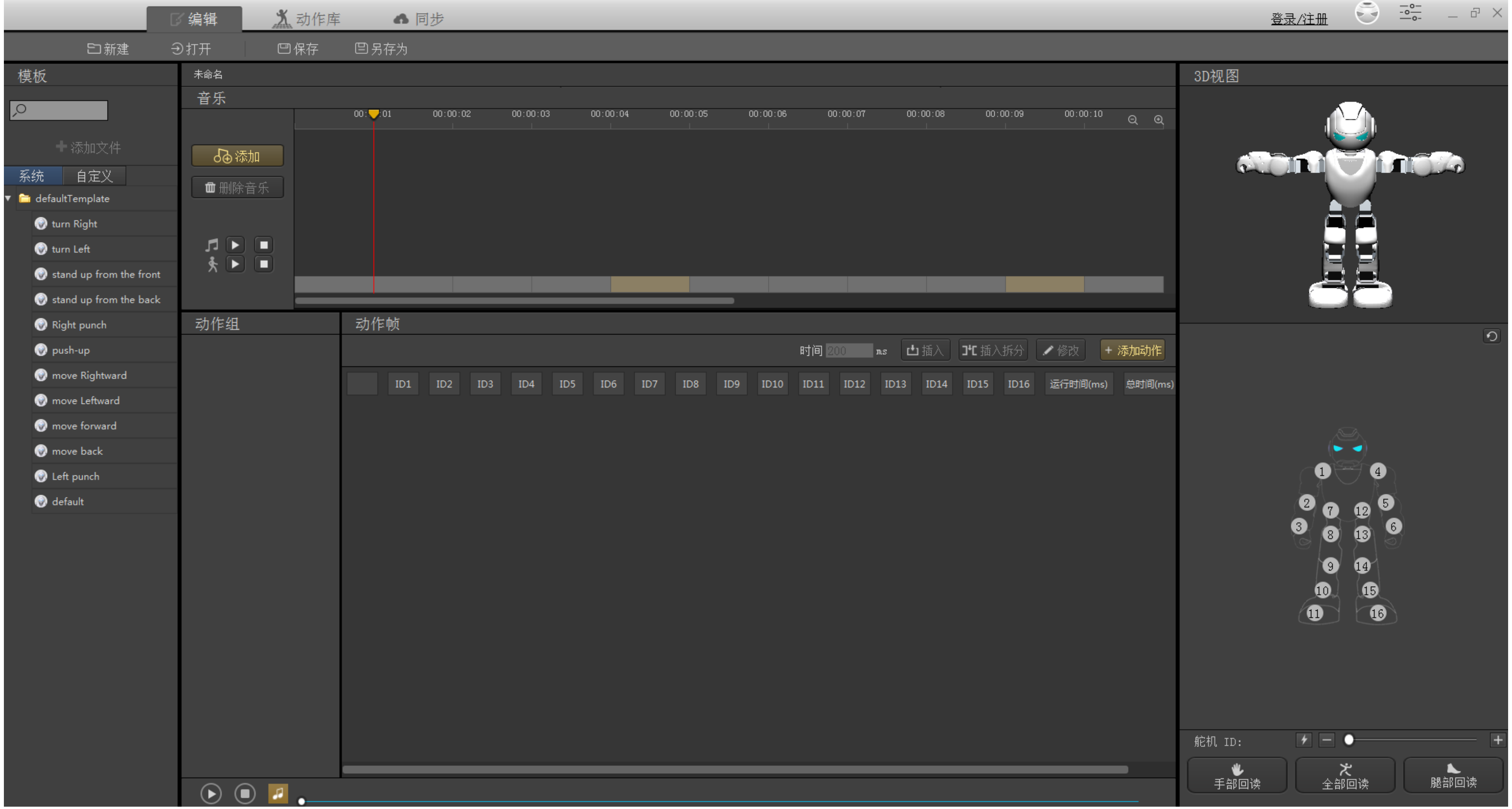


DLR/HIT II



软件设计

- 出厂标定定
- 功能展示
- 单独编程使用



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谢谢！
Thanks!