DRC HUBO

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Contents

- *All new design – DRC HUBO*
- *Mechanical Changes*
- *Kinematic Information*
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- *Compliance algorithm*
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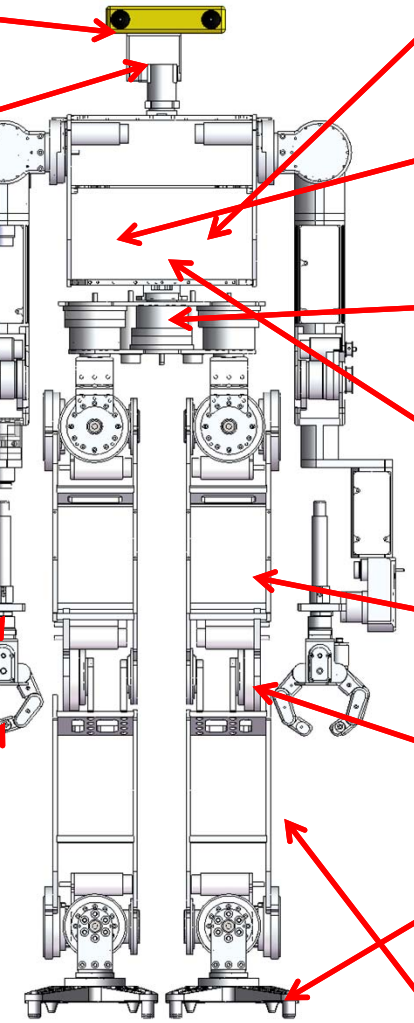
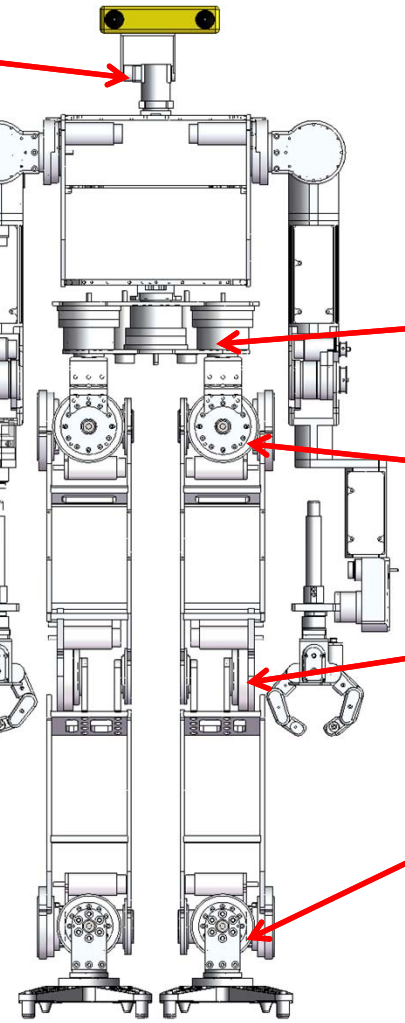
- *Extend the length of arms and legs*
- *Increase torques especially for Knees, Elbows, and wrists*
- *Add one more dof for the wrist*
- *More functional hand*
  - ***Power grasping***
  - ***Independent trigger finger***
- *Complience or hybrid control in firmware level*
- *More robust battery system*
- *More computing power*
- *Simple and practical neck/head*

All new design - DRC HUBO



- Stereo vision system
- Various sensor acceptable head mechanism
- Smaller motor controller with torque control algorithm
- Powerful 7DOF arm design
- End-effector changeable mechanism
- 3-axis FT sensor with increased sensing range
- Power gripper
- Hard real-time linux system (xenomai)
- Increased computing power
- 3-axis IMU
- More durable battery
- Extended leg
- Powerful knee joint
- 4 points support and hookable foot
- Protection shell (duralumin)

Mechanical Change - DOF



Head:
2 DOF

Shoulder:
3 DOF

Elbow:
1 DOF

Wrist:
3 DOF

Hand:
1 DOF

Upper Body:
19 DOF

Lower Body:
13 DOF

Torso:
1 DOF

Hip:
3 DOF

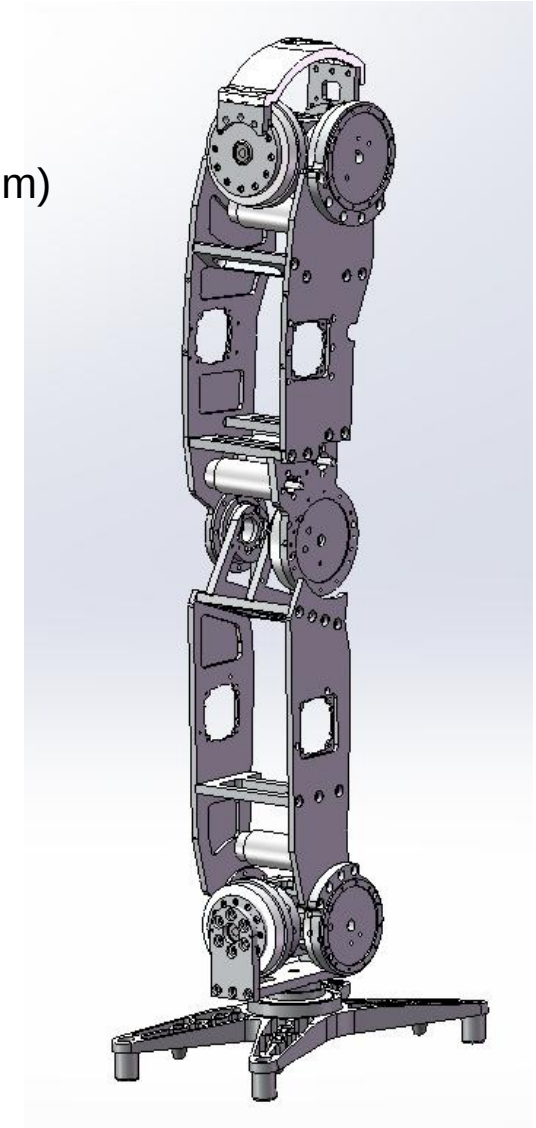
Knee:
1 DOF

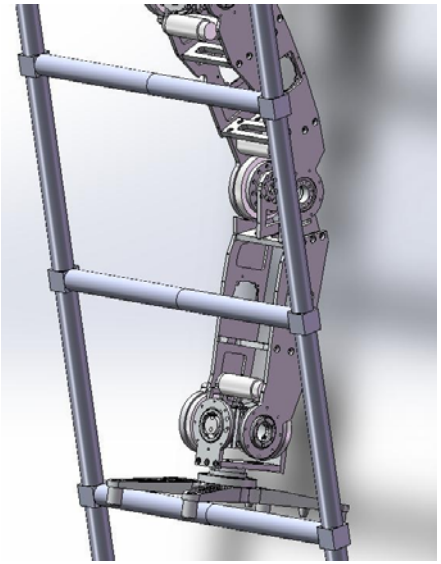
Ankle:
2 DOF

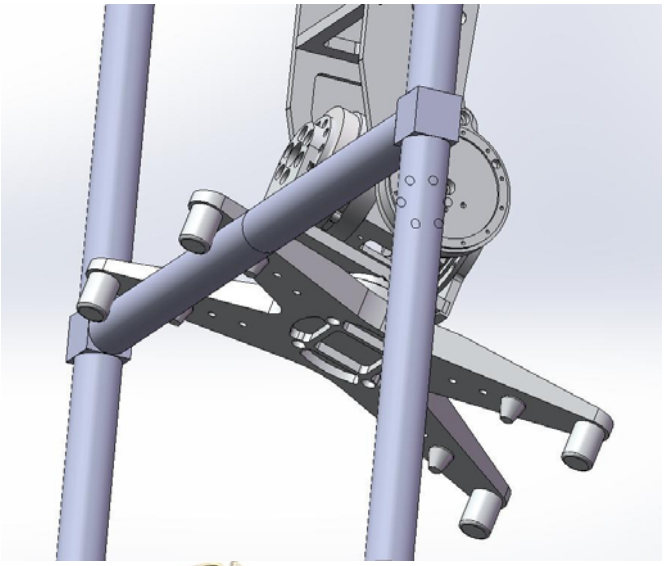
Total:
32 DOF

Mechanical Change - Leg

- **New Leg**
  - Weight : 9.25kg
  - Length : 660mm (including foot : 784mm)
    (Upper Leg : 330mm, Lower Leg : 330mm, Foot : 124mm)
  - 6 DOF
- **New Foot**
  - Weight : 520g (HUBO2 : 420g)
  - Size : 280mm x 150mm
  - 4-Point support to minimize effect of small lumps
  - Designed to climb ladders

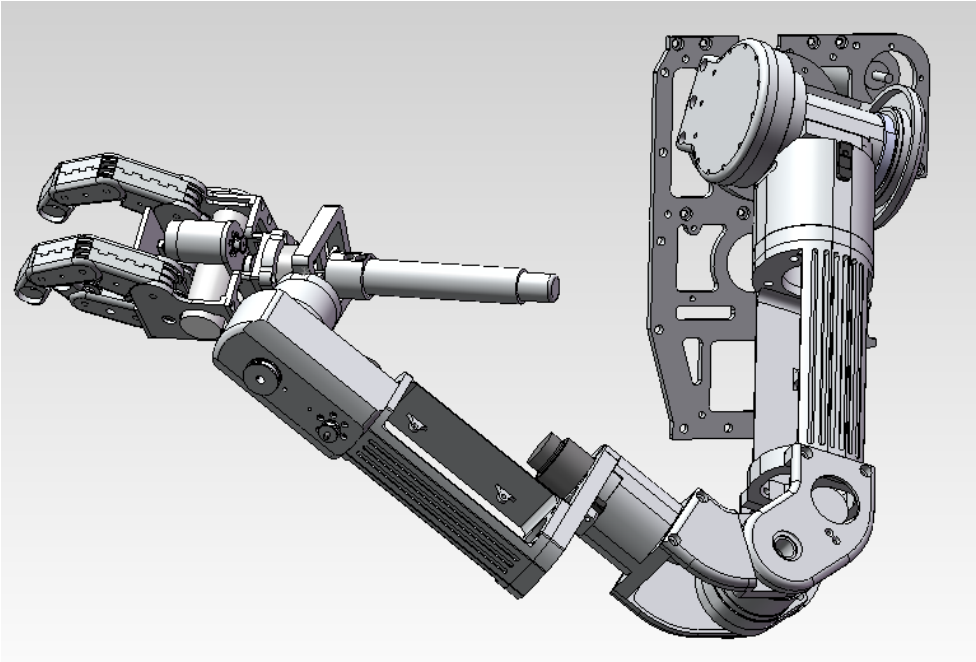


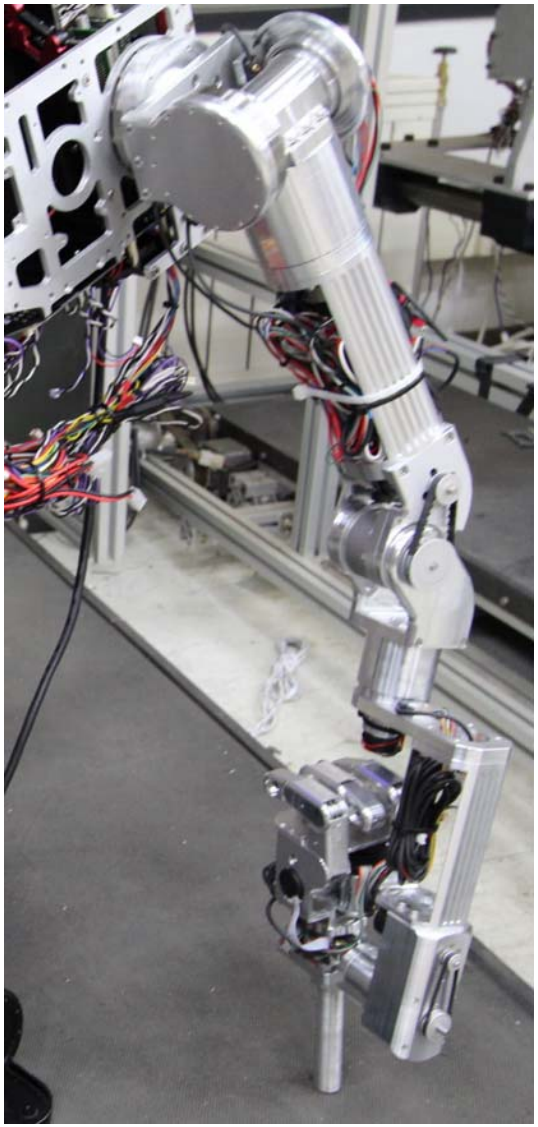




Mechanical Change - Arm

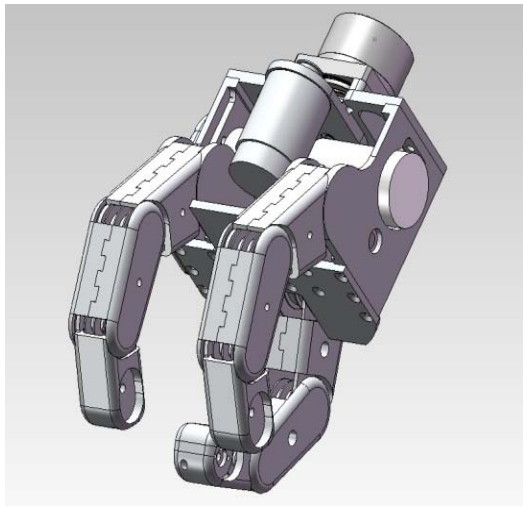
- **New Arm**
  - Hand and rod are exchangeable
  - Weight : 4.4kg (HUBO2 : 3.5kg)
  - Length : 600mm (HUBO2 : 380mm)
    (Upper Arm : 300mm , Lower Arm : 300mm)
  - 7 DOF
  - Payload(fully stretched) : 3.6kg

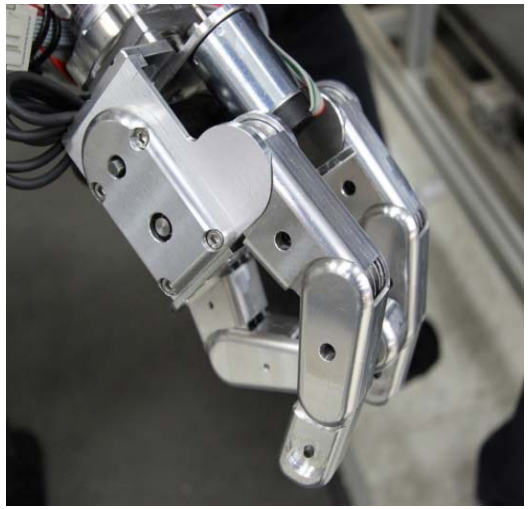


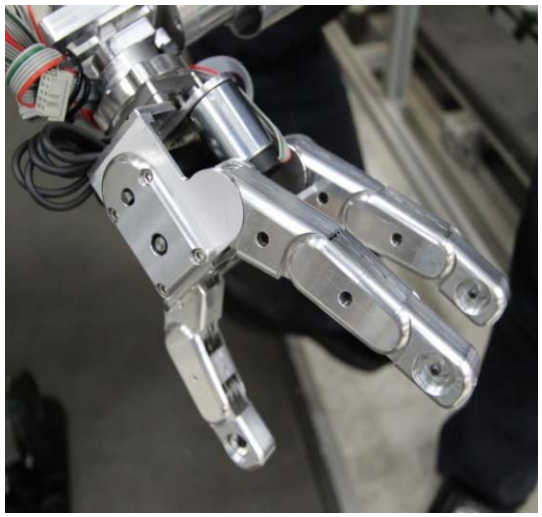


Mechanical Change - Hand

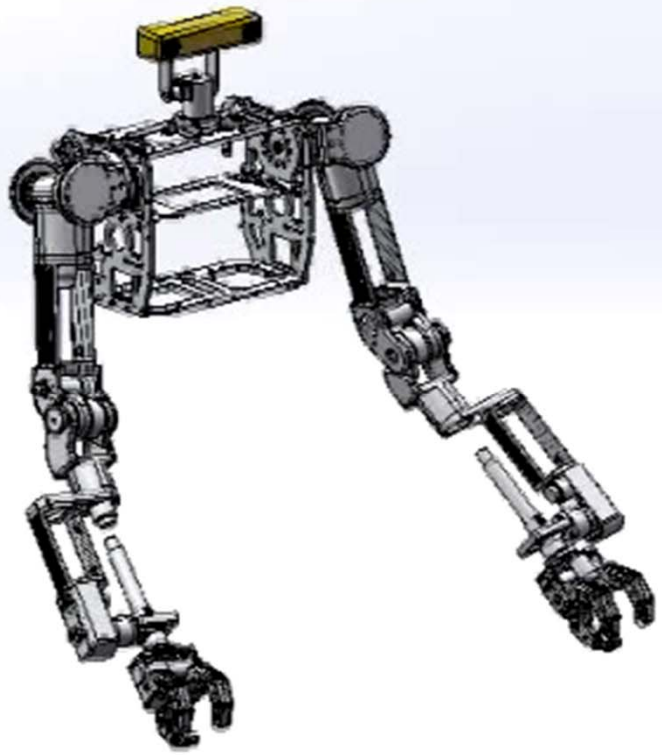
- **New Hand**
  - Weight : 620g(HUBO2 : 300g)
  - Finger Length : 11.6 cm (1st link : 42mm , 2nd link : 30mm , 3rd link : 34mm)
  - Wire-driven under-actuated finger
  - 3 DOF/Finger, 3 fingers
  - Synchronized actuation with single motor
  - **Finger Payload**
    Holding force (Stall Torque) : 1st link : 14.5kg , 2nd link : 8.7kg , 3rd link : 5.6kg
    Holding force (Normal Torque) : 1st link : 4.6kg , 2nd link : 2.6kg , 3rd link : 1.6kg
  - **Full open and clench time** : Less than 1 second







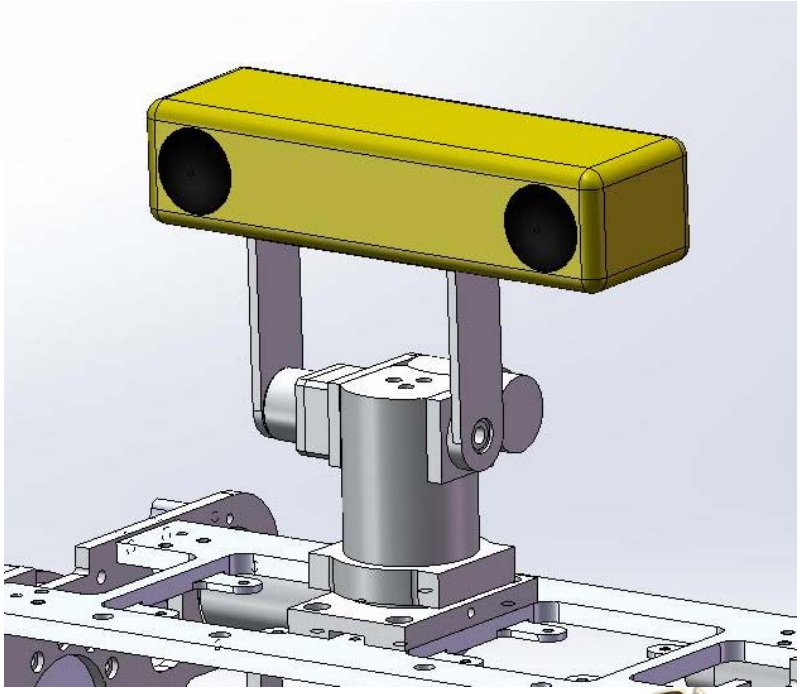
Mechanical Change – Arm and Hand

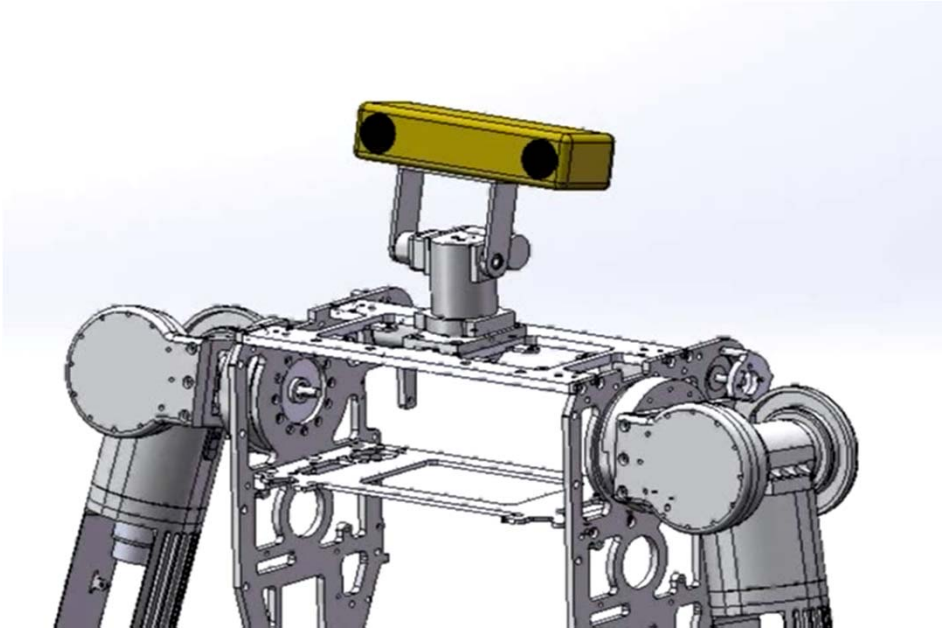


Mechanical Change - Head

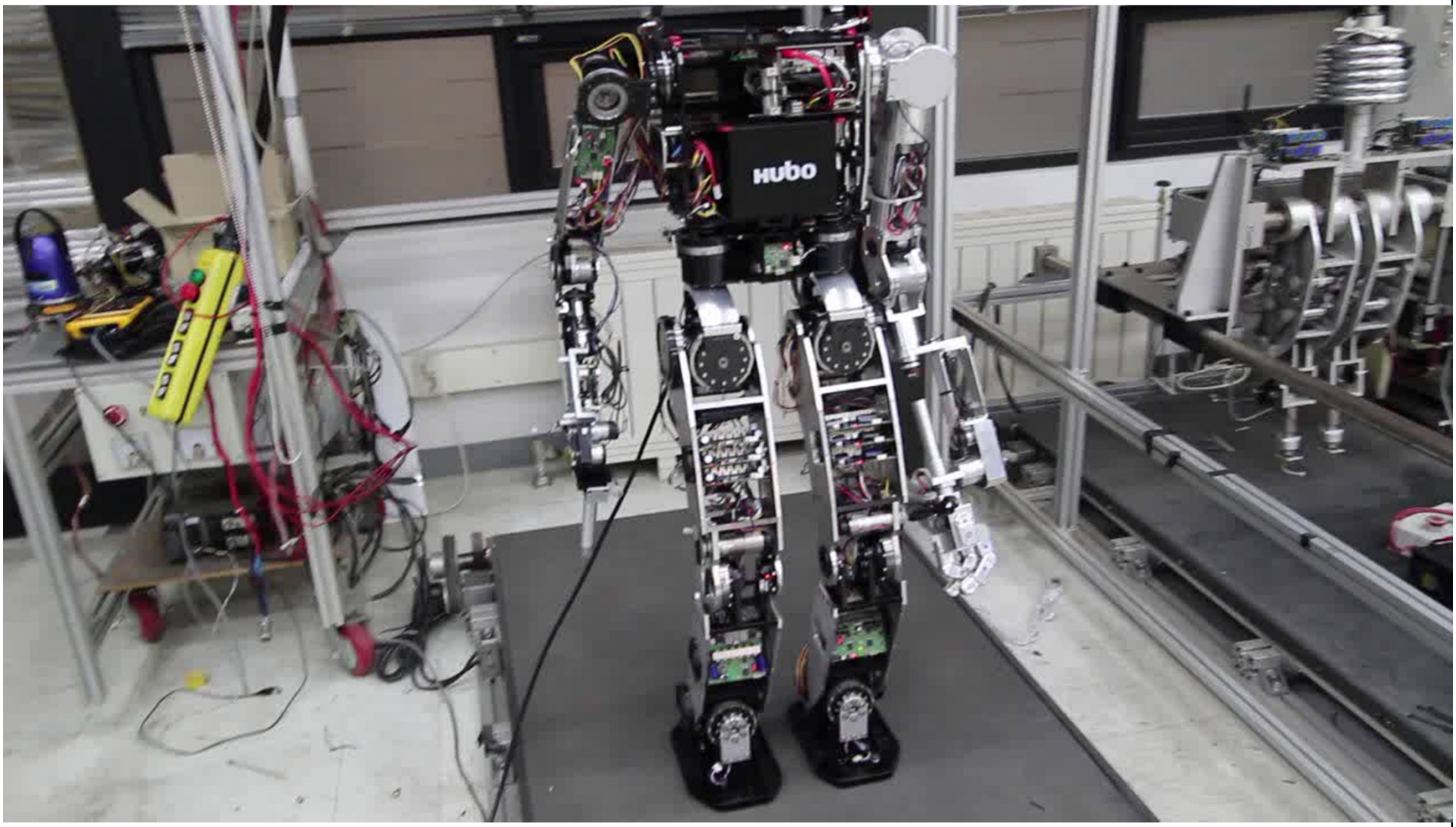
- **New Head**
  - Weight : 300g (Without sensors)
  - 2 DOF
  - Mount can be modified for various sensors
  - Payload : 1.5kg
  - Work range

    Head Yaw : ± 180 deg , Head Pitch : ± 120 deg

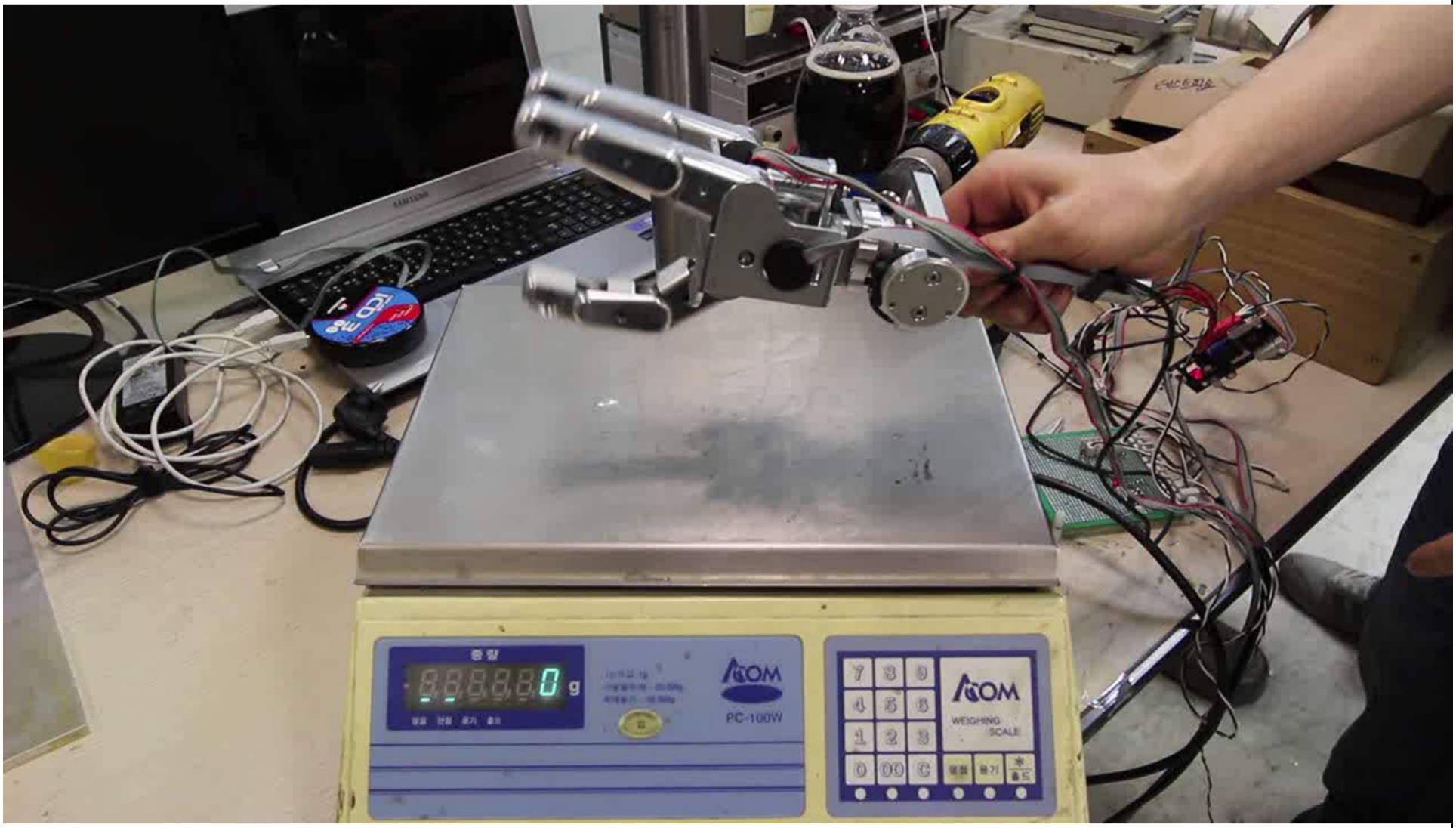




Arm and Hand



Power Gripper

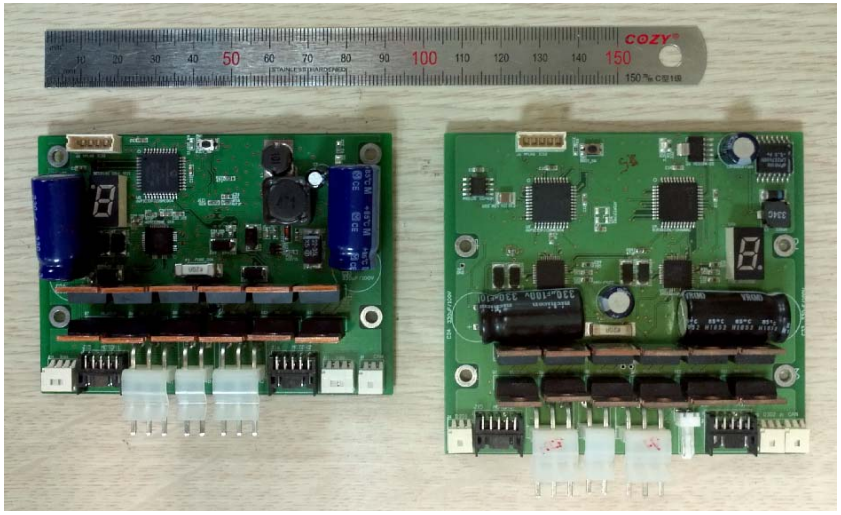


Mechanical Change - Joint Torque

Joint	Reduction Gear Cont.(Nm)	Reduction Gear Stall(Nm)	Motor Cont. (Nm)	Motor Stall(Nm)
Hip yaw	27	71	16.25	428.75
Hip Roll	34	95	32.87	867.24
Hip Pitch	34	95	26.00	686.00
Knee	34	95	40.00 (208.33%)	1055.38 (192.30%)
Ankle Roll	27	71	20.54	542.02
Ankle Pitch	27	71	16.25	428.75
Shoulder Roll	27 (350.65%)	71 (202.86%)	13.00 (216.67%)	343.00 (200.00%)
Shoulder Pitch	27 (350.65%)	71 (202.86%)	16.25 (186.20%)	428.75 (171.88%)
Shoulder Yaw	8.9	25	7.10 (204.61%)	147.00 (200.00%)
Elbow	11 (123.60%)	54 (216.00%)	7.10 (170.51%)	147.00 (166.67%)
Wrist Yaw1	4.8 (145.46%)	9	3.00 (483.87%)	7.60 (73.43%)
Wrist Pitch	8.9 (269.70%)	25 (277.78%)	3.00 (483.87%)	7.60 (73.43%)
Wrist Yaw2 (New)	4.8	9	1.20	3.00
Head Yaw	0.94	2.7	0.60	2.75
Head Pitch	0.94	2.7	0.60	2.75
Waist	27	71	15.00	428.75

Electrical Change - Motor Driver

- 2-Ch Motor Driver
  - Basic Spec.
    - Applicable to DC or/and BLDC motors
    - Up to 48V motor voltage (over 200W for each channel)
    - 40MIPS microprocessor (Microchip dsPIC)
    - 2-Ch encoder and hall-sensor input
    - Two digital IOs for limit switches
    - Temperature and current sensing
    - State indicator using 7-segment
    - Auto scaling algorithm based on the main control-loop time
    - Functions for setting parameters (gain, vel. and acc. limit, home position, limit position, etc.)
    - Various error control algorithm (big error, encoder failure, over current)
    - CAN communication



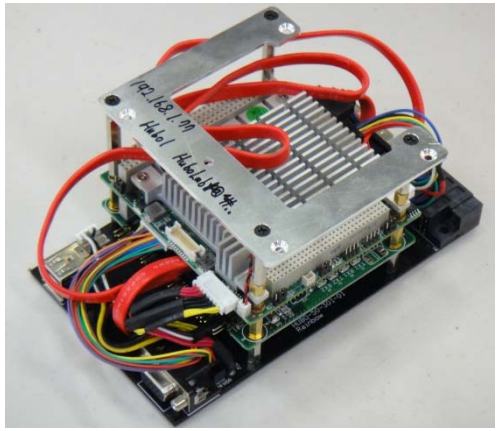
New version Old version

  - Enhancements
    - Smaller layout, 90mm x 65mm x 20mm (18% reduced)
    - Single input voltage (12V ~ 48V)
    - Enhanced encoder-failure protection
    - Two open-loop modes : Complementary switching and Non-complementary switching

Electrical Change - Computing Power

- **PC for Motion**

  SBC (PCM 3362, Advantech Co.)
  - CPU clock : ATOM 1.6GHz
  - RAM : 2GByte
  - OS : Ubuntu 10.04 with xenomai
  - Interface : 2 CAN, 1 LAN and 2 USB



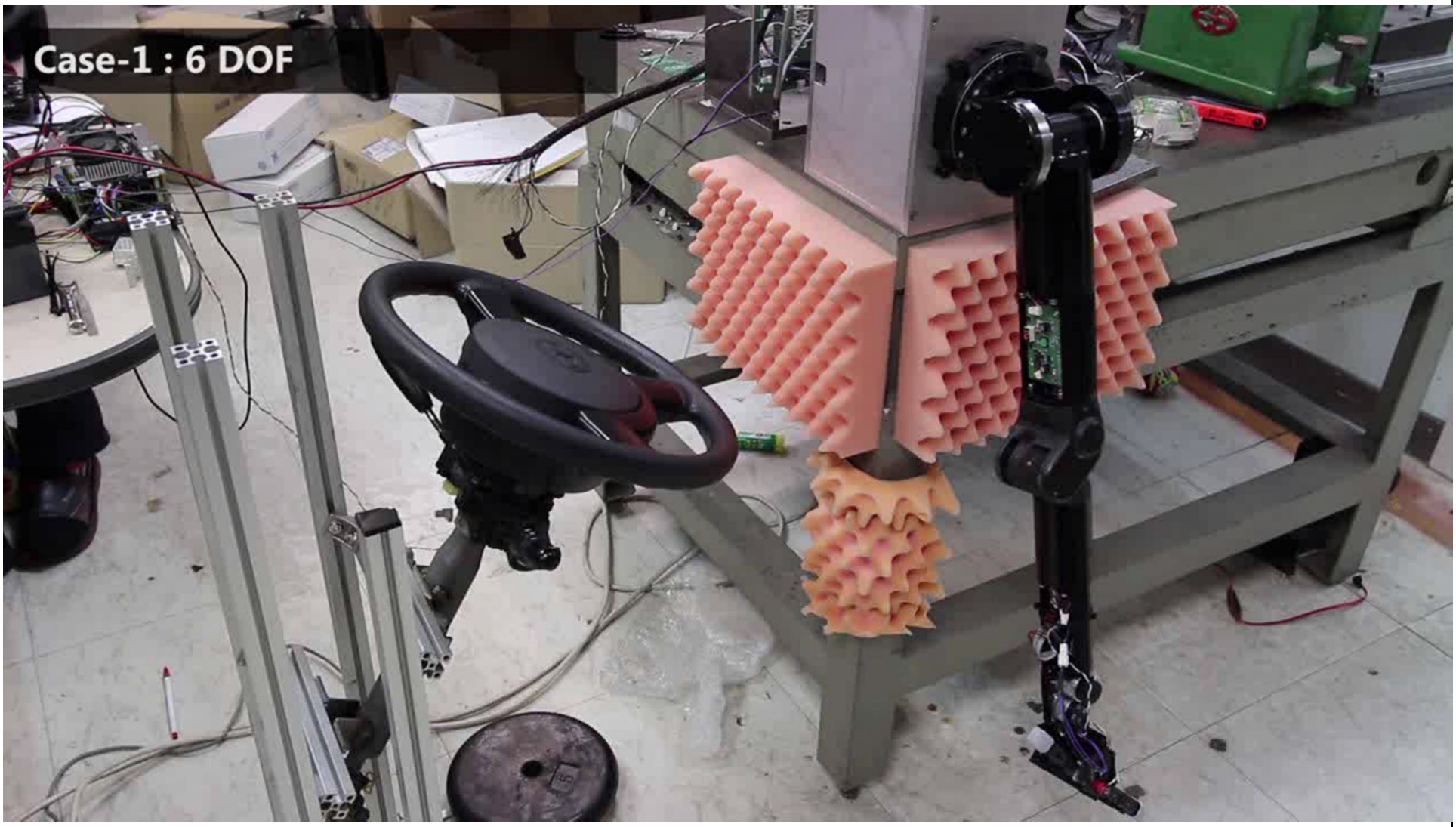
(Photograph of PCM 3362)

- **PC for Peripheral Task**

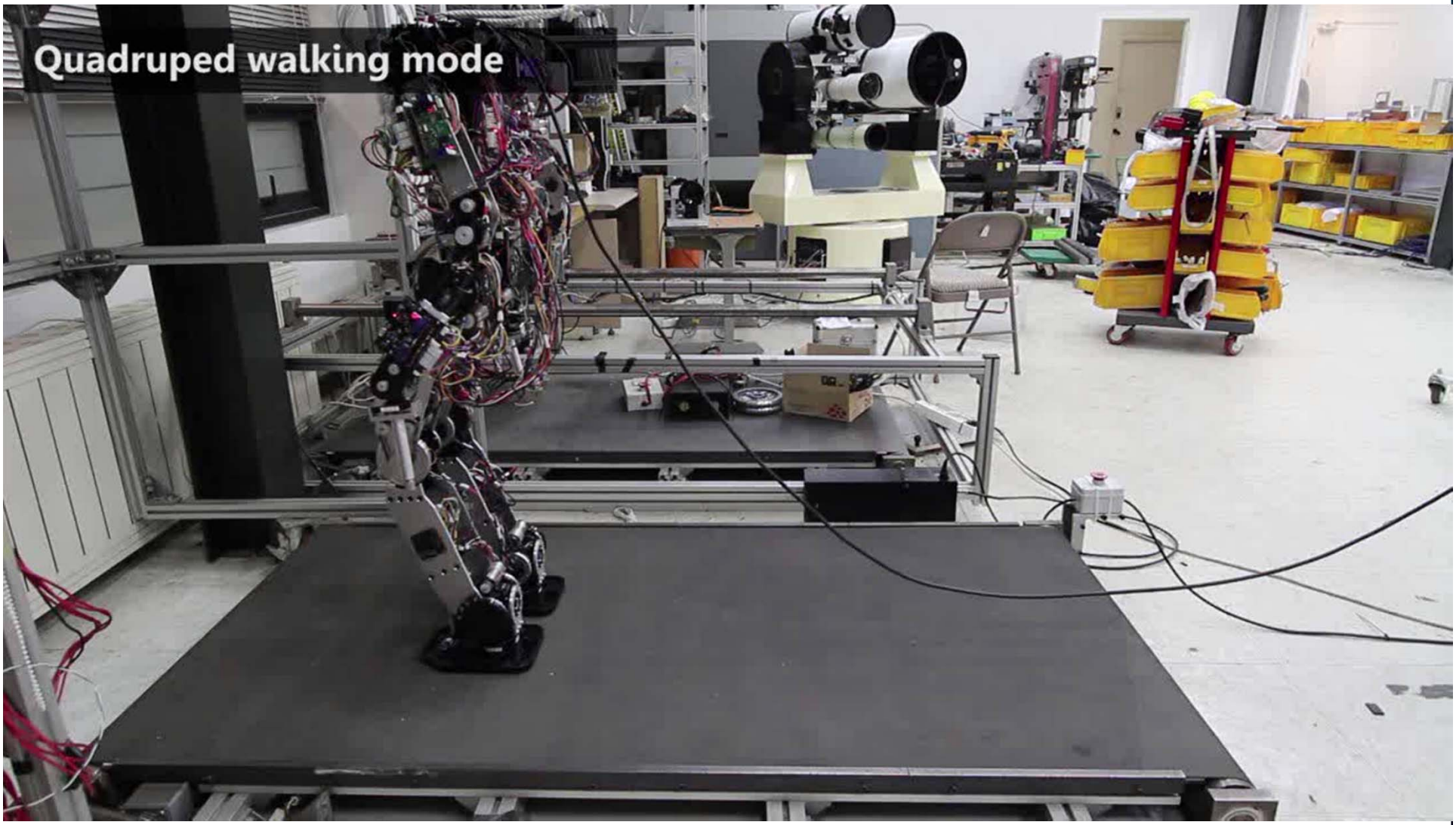
  SBC (ADLQM67PC-2715QE)
  - CPU clock : Core i-7 2.2GHz
  - RAM : 4GByte
  - OS : WIndows7 or Ubuntu
  - Interface : 2 IEEE1394, 2 LAN and 4 USB

(Photograph of ADLQM67PC)

Handle

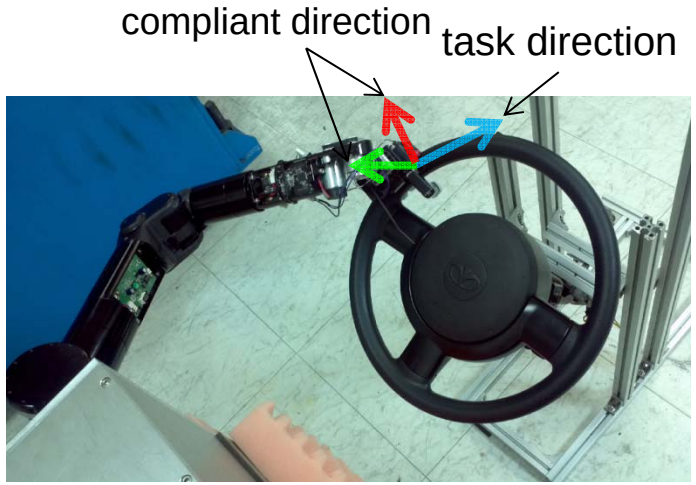


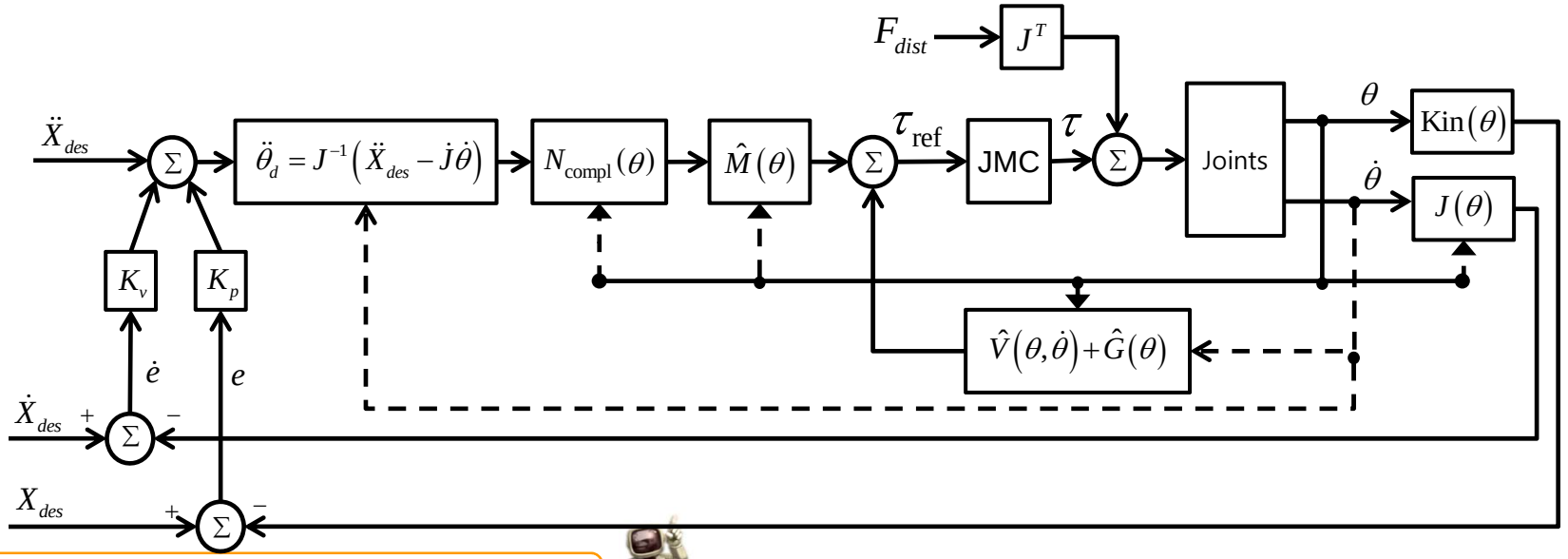
Quadped Walking



Compliant Control Algorithm

- The task space is spanned by compliant direction and task direction.
- A null space projection operator $N_{compl}(\theta)$ projects the desired joint acceleration onto the null space of compliant direction.
- The joint motion controller (JMC) can generate joint torques by current feedback control or open-loop control.

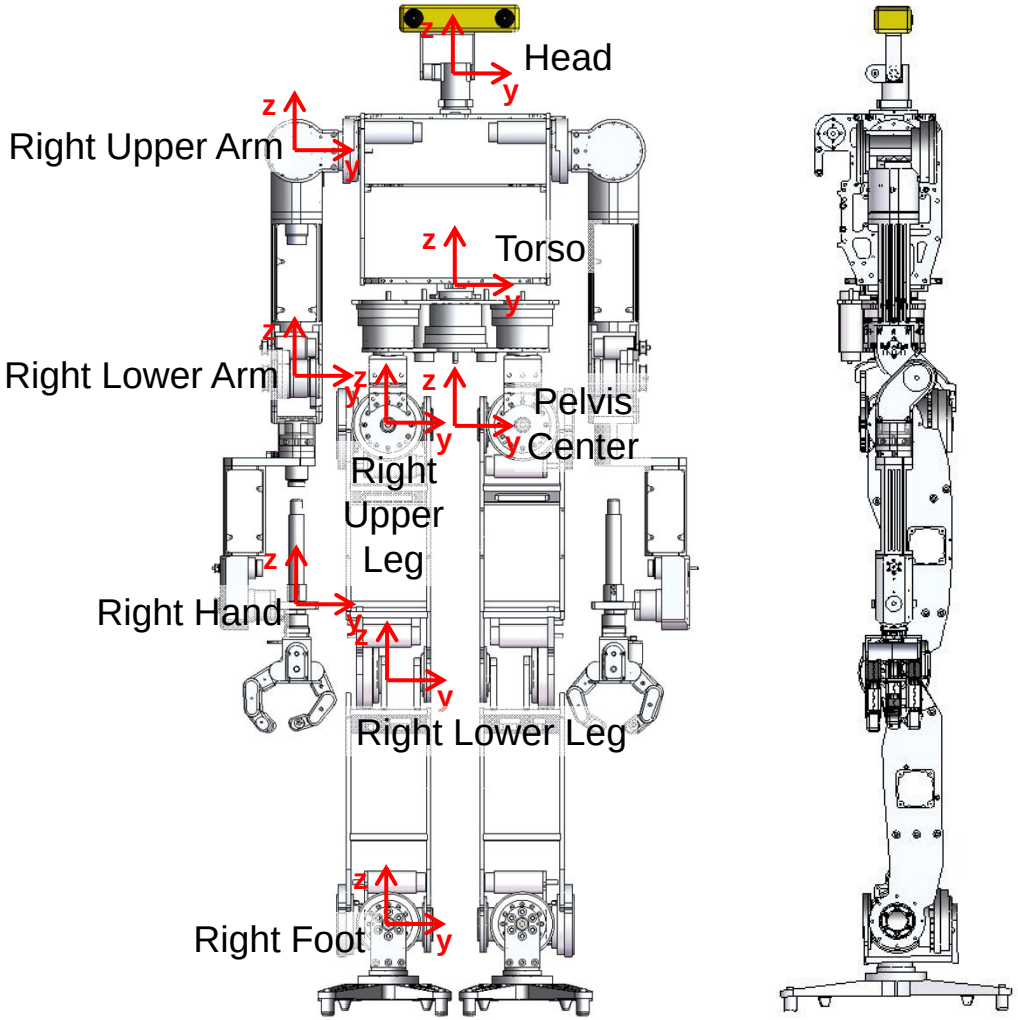


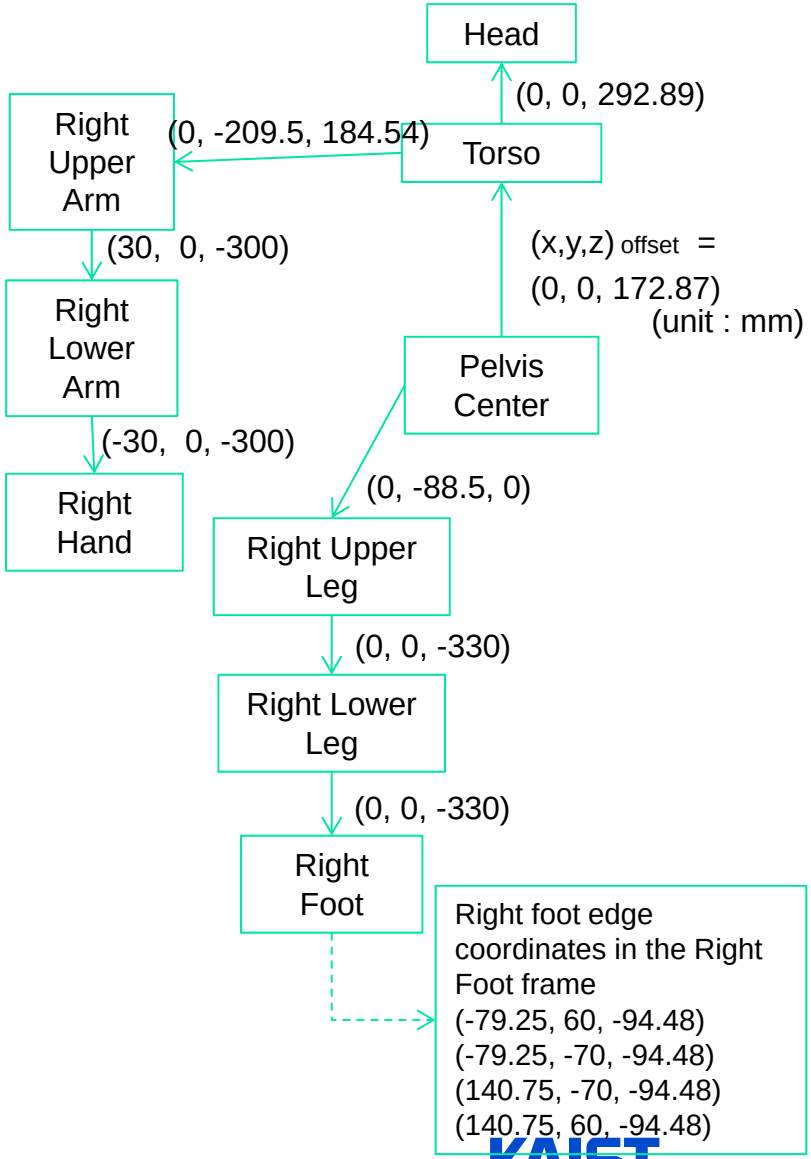


Further Considerations

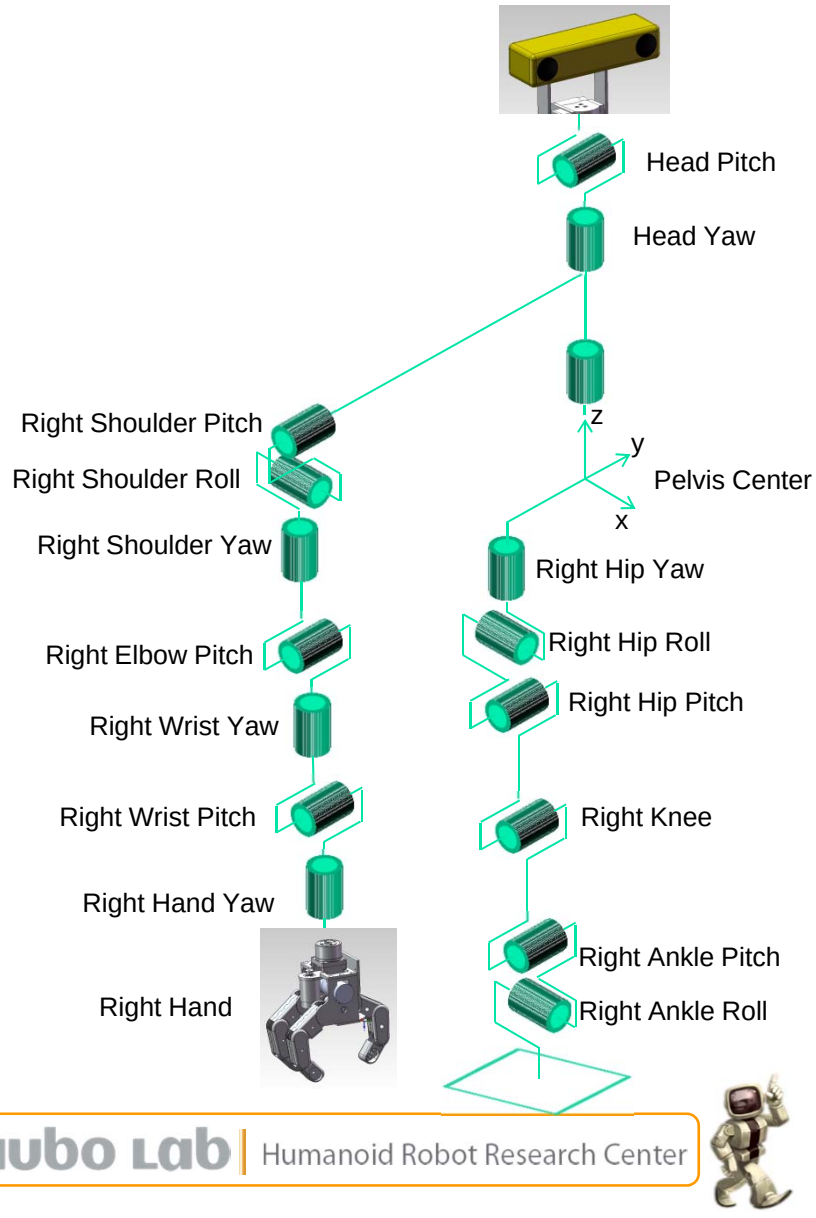
- ***Protection from:***
  - Dust
  - Physical external impact
  - Self collision
- ***Safe fall over and recovery***
- ***Sensors?***
  - Laser ranger
  - Bumblebee: one or two?
  - kinect
  - Extra camera to see bottom
  - Others? – proximity, ultra sonic…etc.
- ***Whole body motion.***

Mechanical Change - Local Coordinate Frames





Mechanical Change - Joint Hierarchy



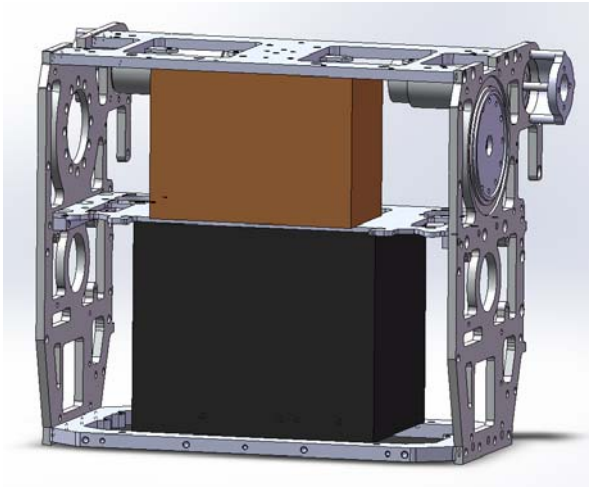
Movable joint angle range

Joint		Angle range
Shoulder	Roll	-15 ° ~ +180 °
	Pitch	-180 ° ~ +180 °
	Yaw	-180 ° ~ +180 °
Elbow	Pitch	-170 ° ~ 0 °
Wrist	Yaw1	-180 ° ~ +180 °
	Pitch	-180 ° ~ +180 °
	Yaw1	-180 ° ~ +180 °
Hip	Roll	-10 ° ~ +45 °
	Pitch	-90 ° ~ +90 °
	Yaw	-100 ° ~ +100 °
Knee	Pitch	-10 ° ~ +150 °
Ankle	Roll	-25 ° ~ +25 °
	Pitch	-90 ° ~ +90 °
Head	Yaw	-180 ° ~ +180 °
	Pitch	-120 ° ~ +120 °

Material property – Body

- **Torso**

mass(kg)	7.203E+00		
COM(m)	x	y	z
	-1.150E-02	1.000E-04	1.347E-01
inertia due to COM (kg*m^2)	x	y	z
x	6.950E-02	-1.000E-04	-4.700E-03
y	-1.000E-04	4.680E-02	0.000E+00
z	-4.700E-03	0.000E+00	5.210E-02
inertia due to origin (kg*m^2)	x	y	z
x	2.001E-01	-1.000E-04	-1.590E-02
y	-1.000E-04	7.840E-02	1.000E-04
z	-1.590E-02	1.000E-04	5.310E-02



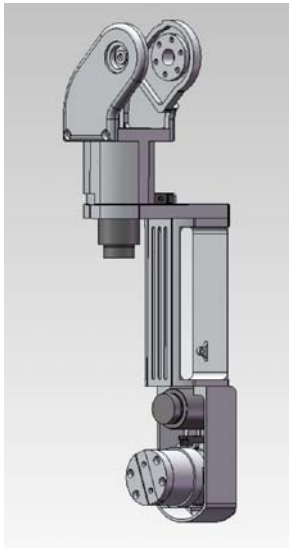
- **Pelvis**

mass(kg)	3.465E+00		
COM(m)	x	y	z
	-1.713E-02	0.000E+00	1.280E-01
inertia due to COM (kg*m^2)	x	y	z
x	7.315E-02	2.287E-07	-7.448E-03
y	2.287E-07	6.294E-02	1.020E-06
z	-7.448E-03	1.020E-06	1.918E-02
inertia due to origin (kg*m^2)	x	y	z
x	1.634E-02	3.529E-07	1.525E-04
y	3.529E-07	5.118E-03	9.119E-08
z	1.525E-04	9.119E-08	1.816E-02

Material property – Left Arm

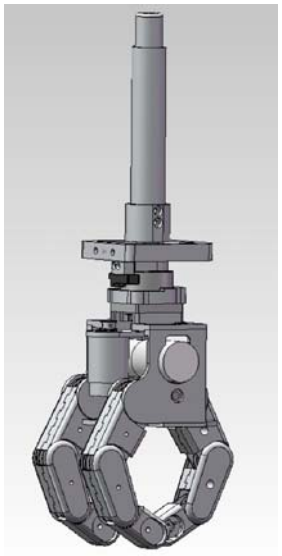
• Left Lower Arm

mass(kg)		1.318E+00		
COM(m)		x	y	z
		-2.881E-02	2.306E-02	-1.802E-01
inertia due to COM (kg*m^2)		x	y	z
	x	5.884E-02	-9.362E-04	7.117E-03
	y	-9.362E-04	5.745E-02	-9.528E-03
	z	7.117E-03	-9.528E-03	4.033E-03
inertia due to origin (kg*m^2)		x	y	z
	x	1.534E-02	-6.069E-05	2.751E-04
	y	-6.069E-05	1.355E-02	-4.051E-03
	z	2.751E-04	-4.051E-03	2.239E-03



• Left Hand

mass(kg)		7.853E-01		
COM(m)		x	y	z
		-1.100E-04	-2.689E-02	-5.058E-02
inertia due to COM (kg*m^2)		x	y	z
	x	5.428E-03	2.005E-06	-4.362E-06
	y	2.005E-06	4.987E-03	1.030E-03
	z	-4.362E-06	1.030E-03	1.037E-03
inertia due to origin (kg*m^2)		x	y	z
	x	7.837E-04	3.580E-09	-9.753E-06
	y	3.580E-09	9.125E-04	-2.160E-06
	z	-9.753E-06	-2.160E-06	4.220E-04



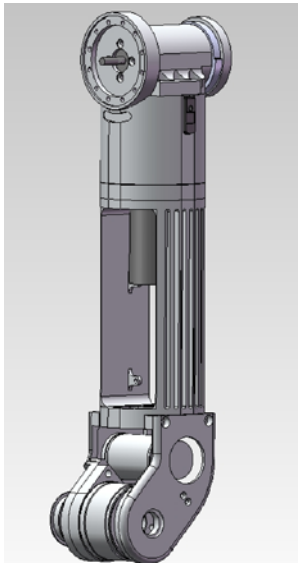
Material property – Left Arm

• Left Shoulder

mass(kg)	6.591E-01		
COM(m)	x	y	z
	9.930E-03	-1.300E-04	-4.827E-02
inertia due to COM (kg*m^2)	x	y	z
x	2.691E-03	-7.430E-07	-5.491E-04
y	-7.430E-07	3.245E-03	-7.046E-07
z	-5.491E-04	-7.046E-07	1.157E-03
inertia due to origin (kg*m^2)	x	y	z
x	1.156E-03	1.321E-07	-2.332E-04
y	1.321E-07	1.644E-03	-4.958E-06
z	-2.332E-04	-4.958E-06	1.092E-03

• Left Upper Arm

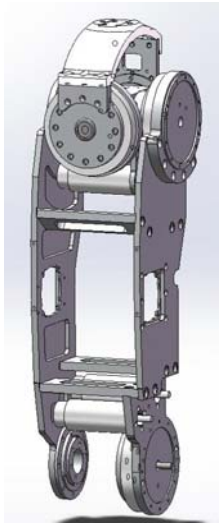
mass(kg)	1.867E+00		
COM(m)	x	y	z
	-2.712E-02	-1.120E-03	-1.153E-01
inertia due to COM (kg*m^2)	x	y	z
x	4.742E-02	2.525E-05	3.966E-03
y	2.525E-05	4.904E-02	5.893E-04
z	3.966E-03	5.893E-04	2.693E-03
inertia due to origin (kg*m^2)	x	y	z
x	2.259E-02	-3.133E-05	-1.873E-04
y	-3.133E-05	2.285E-02	3.488E-04
z	-1.873E-04	3.488E-04	1.317E-03



Material property – Left Leg

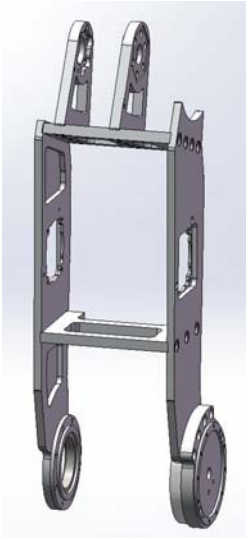
• Left Upper Leg

mass(kg)	5.222E+00		
COM(m)	x	y	z
	4.841E-02	-2.081E-01	5.938E-02
inertia due to COM (kg*m^2)	x	y	z
x	3.492E-01	-5.376E-02	1.439E-02
y	-5.376E-02	4.231E-02	-6.641E-02
z	1.439E-02	-6.641E-02	3.439E-01
inertia due to origin (kg*m^2)	x	y	z
x	1.047E-01	-1.167E-03	-6.249E-04
y	-1.167E-03	1.166E-02	-1.895E-03
z	-6.249E-04	-1.895E-03	1.056E-01



• Left Lower Leg

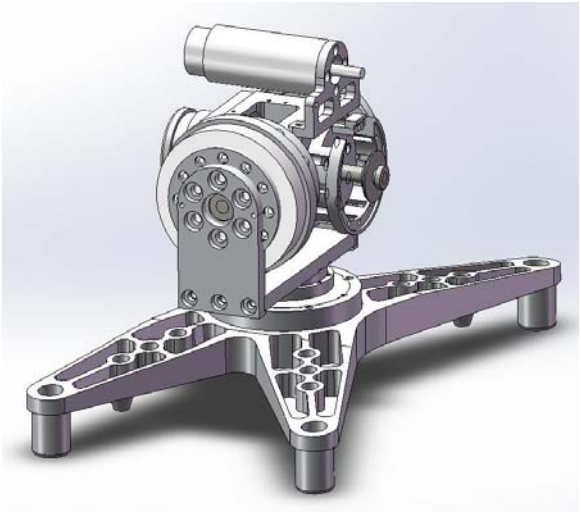
mass(kg)	1.308E+00		
COM(m)	x	y	z
	-7.164E-02	-4.493E-02	4.879E-02
inertia due to COM (kg*m^2)	x	y	z
x	2.416E-02	6.581E-03	-4.809E-03
y	6.581E-03	1.354E-02	-3.944E-03
z	-4.809E-03	-3.944E-03	2.988E-02
inertia due to origin (kg*m^2)	x	y	z
x	1.840E-02	2.370E-03	-2.369E-04
y	2.370E-03	3.712E-03	-1.077E-03
z	-2.369E-04	-1.077E-03	2.053E-02



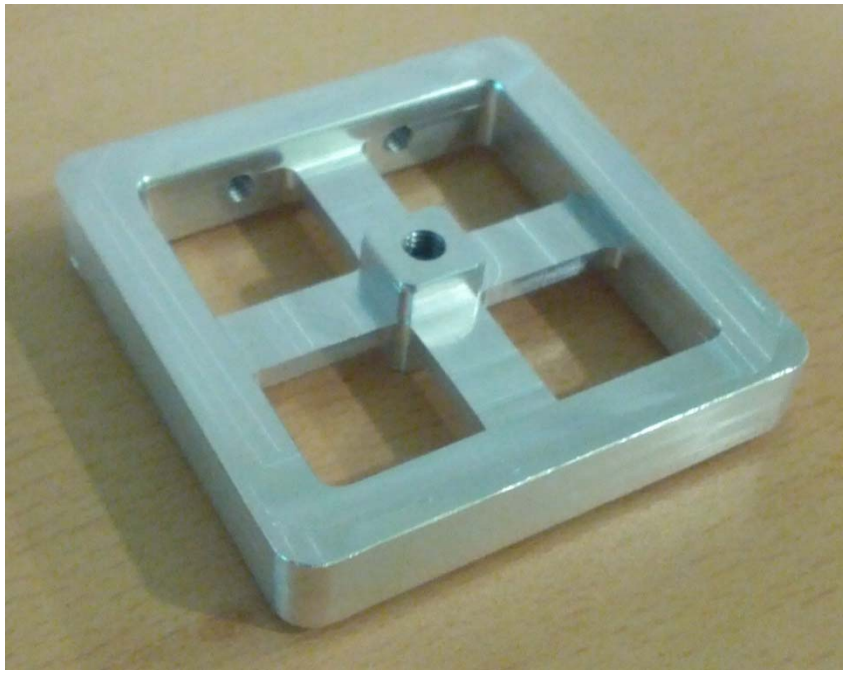
Material property – Left Foot

- **Left Foot**

mass(kg)	2.722E+00		
COM(m)	x	y	z
	2.293E-02	2.441E-02	6.789E-02
inertia due to COM (kg*m^2)	x	y	z
x	2.872E-02	1.845E-03	4.230E-03
y	1.845E-03	2.384E-02	3.744E-03
z	4.230E-03	3.744E-03	1.282E-02
inertia due to origin (kg*m^2)	x	y	z
x	1.455E-02	3.217E-04	-7.014E-06
y	3.217E-04	9.868E-03	-7.658E-04
z	-7.014E-06	-7.658E-04	9.773E-03



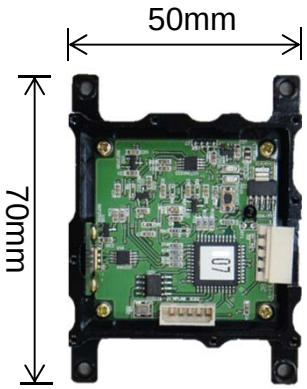
Electrical Change – FT Sensor



F/T Sensor in Wrist

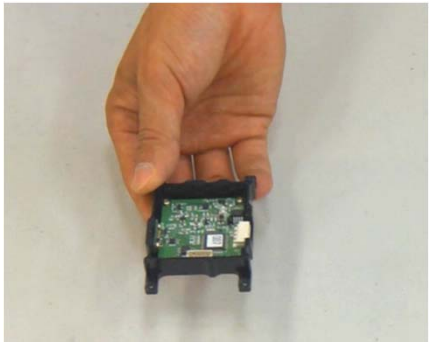
- Microchip dsPIC
- 2 moments & 1 normal force
- Up to 15 Nm, up to 500N
- Auto Balancing
- Strain gage amp circuit
- CAN communication
- Temperature Sensing
- 58mm × 58mm × 10mm

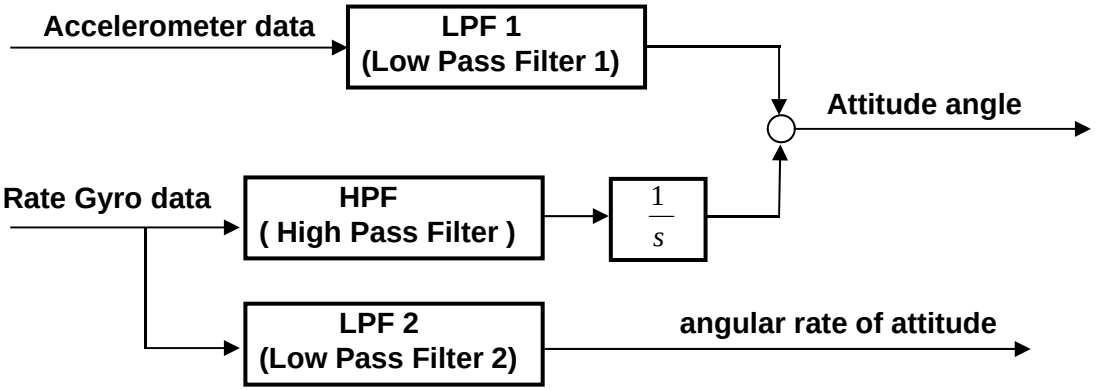
Electrical Change - IMU



- CAN communication
- Microchip dsPIC
- 3 - axis accelerometer (< 2g)
- 3 - axis rate gyro sensor (±100º/s)
- Easy Calibration
- Measurable range : ± 85 deg in each axis
- 50mm × 70mm × 14mm

(Photograph of inertial sensor)





(Attitude calculation using complementary filter)

Electrical Change - Vision(Bumblebee2)

Specification	BB2-03S2
Image Sensor	Sony 1/3” progressive scan CCD(Color) ICX424(648*488 max pixels)
Focal Lengths	6mm with 43deg HFOV
Frame Rates	48FPS
Interfaces	6-pin IEEE-1394a for camera control
Power Consumption	2.5W at 12V
Dimensions	157*36*47.4mm
Mass	342 grams

Electrical Change - Battery

- Li-Ion 51.8V – 8.8Ah (14S-4P)
- 213mm × 150mm × 86mm
- Weight : 4.69Kg (will be reduced)
- Continuous Discharge Current : 10A
- Peak Discharge Current : 20A (Less than 2.3sec)