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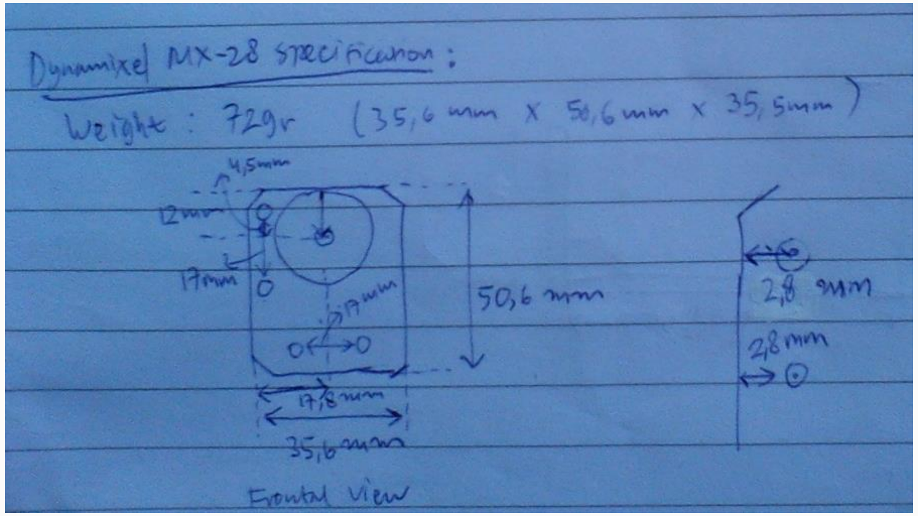
VoBiRo – Vocational Bipedal Robot Platform, Kinematic and Locomotion Control

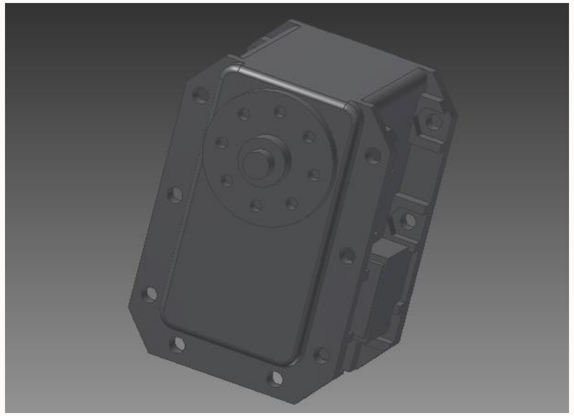
Presented by
Fahmizal, S.T., M.Sc.

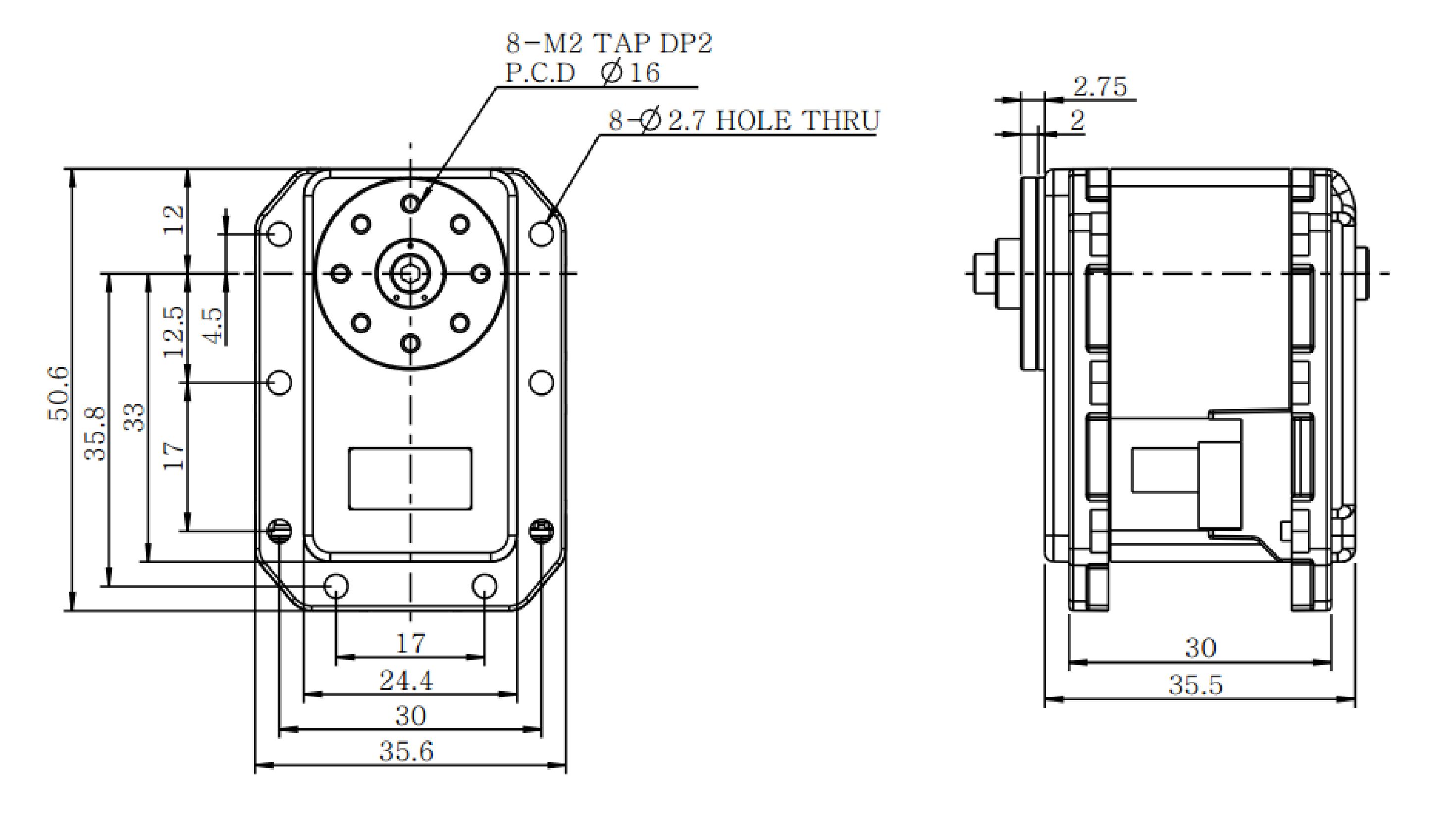
Outline

- This slide shows all information's about Mechanical Design-CAD for Kid-Size Bipedal Robot made by Fahmizal
- The following information such as:
  - Dynamixel MX-28 Dimensions
  - Ankle Design
  - Leg Design
  - HIP Design
  - Body Design
  - Hand Design
  - Head Design
  - Battery and Electronic Circuit
- Gait Analysis
- Total 22 Dynamixel MX-28 are used to build this robot structure.

Dynamixel MX-28







- http://support.robotis.com/en/product/dynamixel/rx_series/mx-28.htm

Ankle Design (2 DOF)

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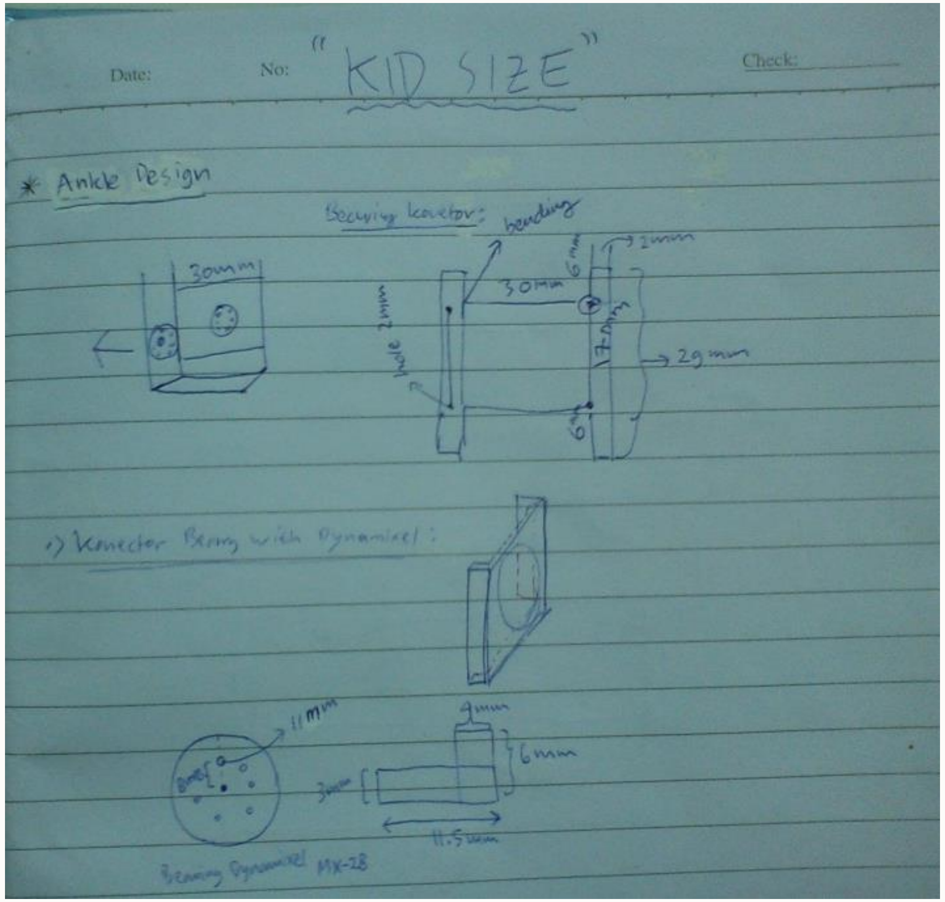
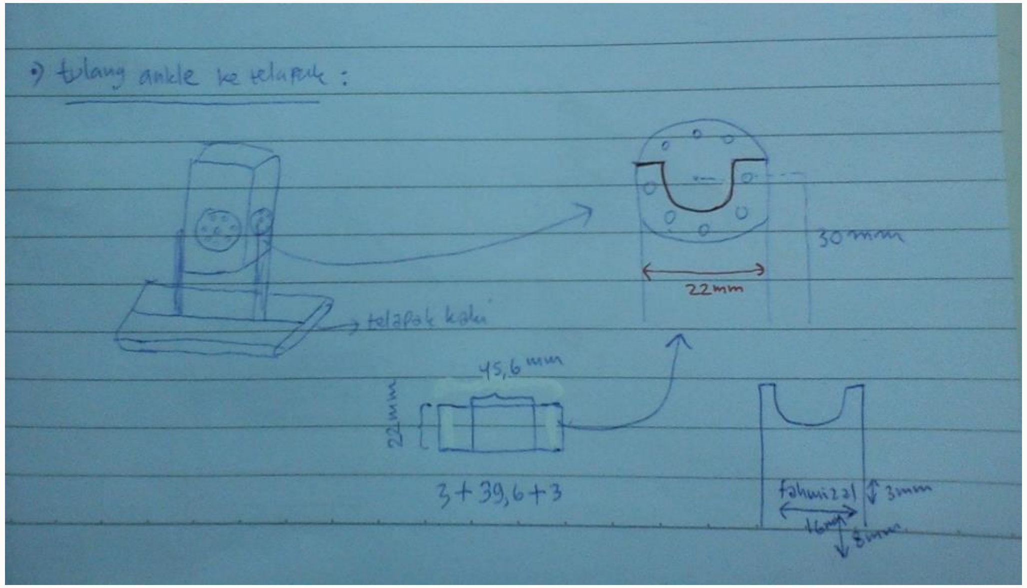
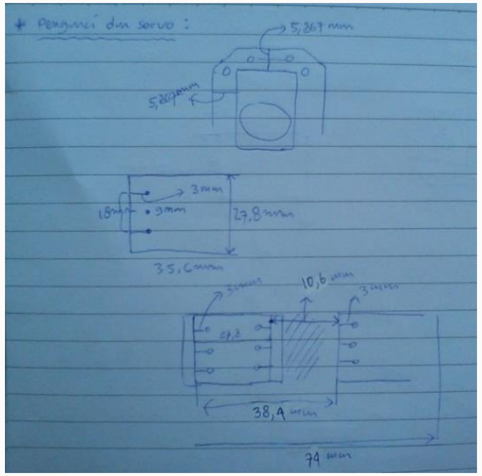
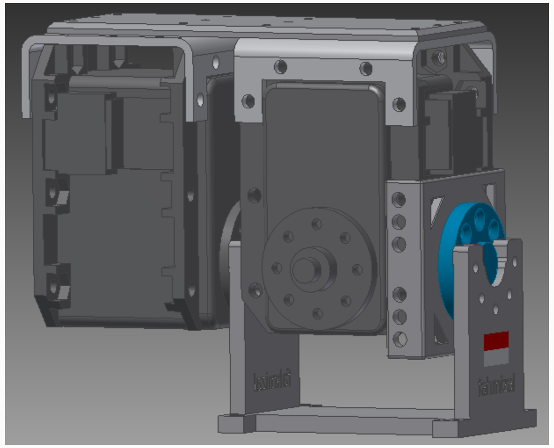
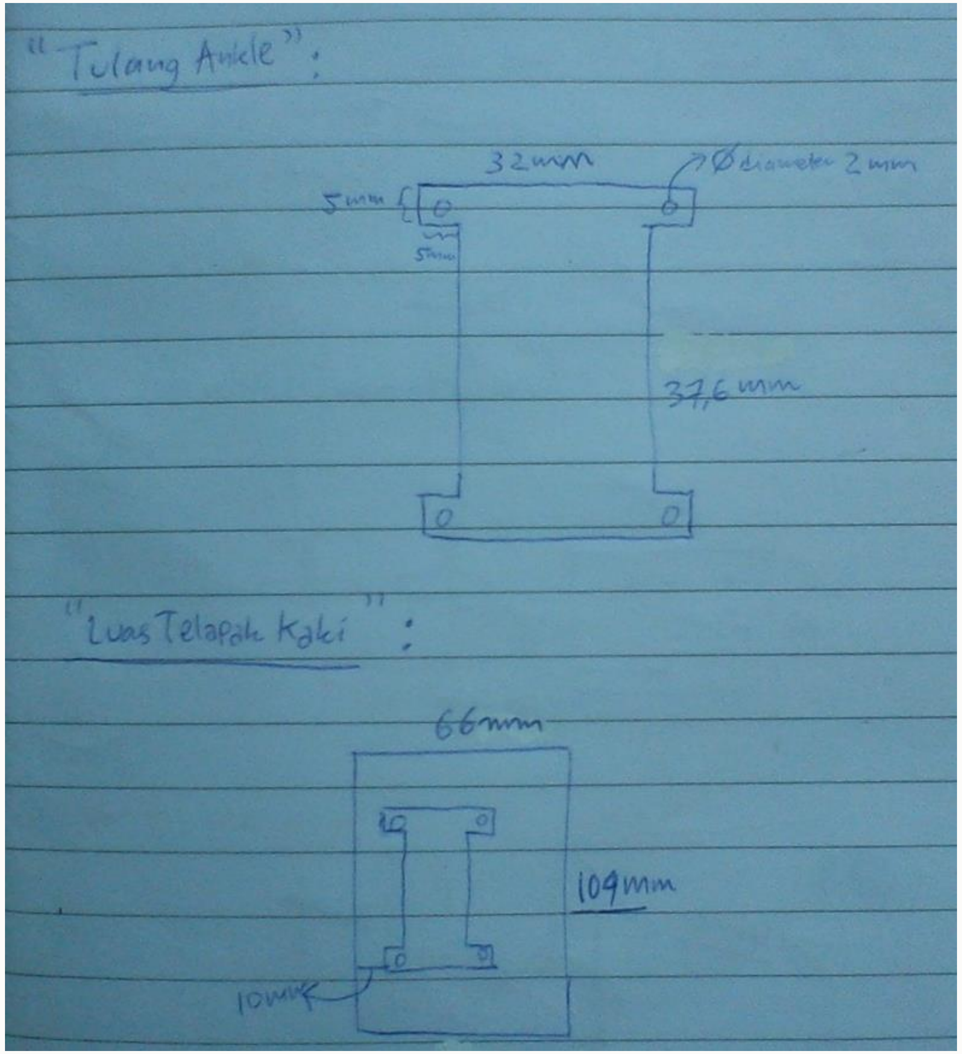


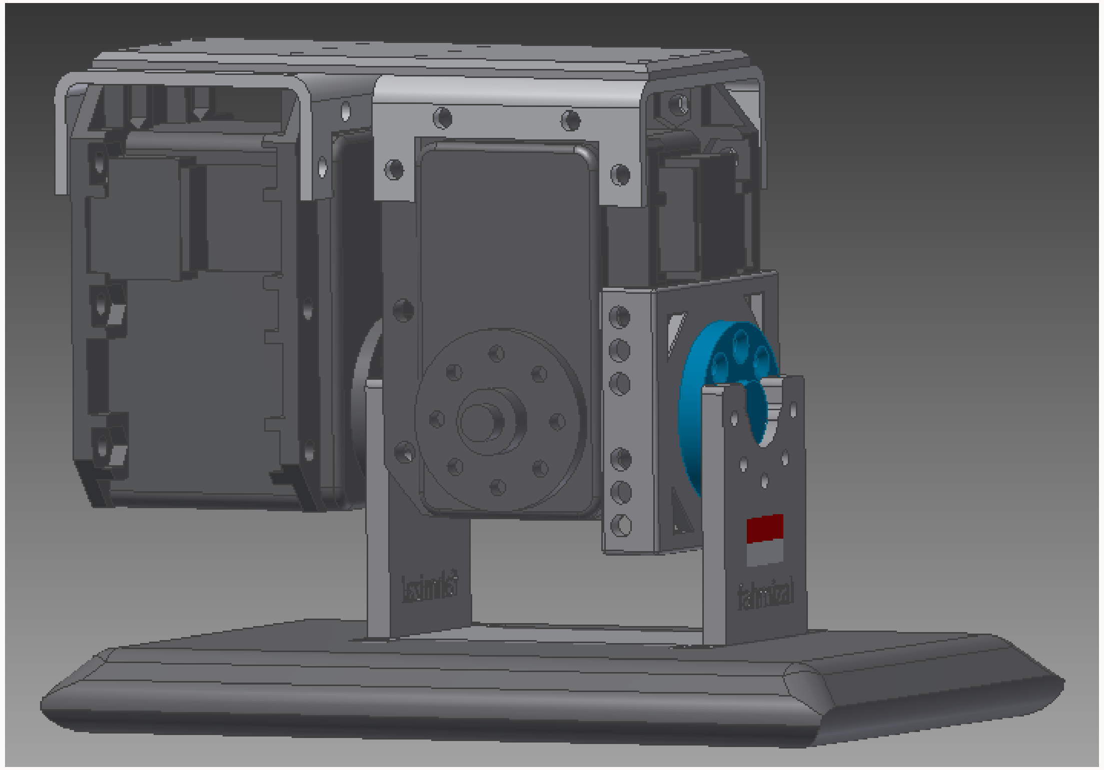






Foot Design


"Tulang Ankle":
32mm
Ø diameter 2mm
5mm
5mm
37,6mm
"Luas Telapak Kaki":
66mm
109mm
10mm



Leg Ankle + Knee (3 DOF)

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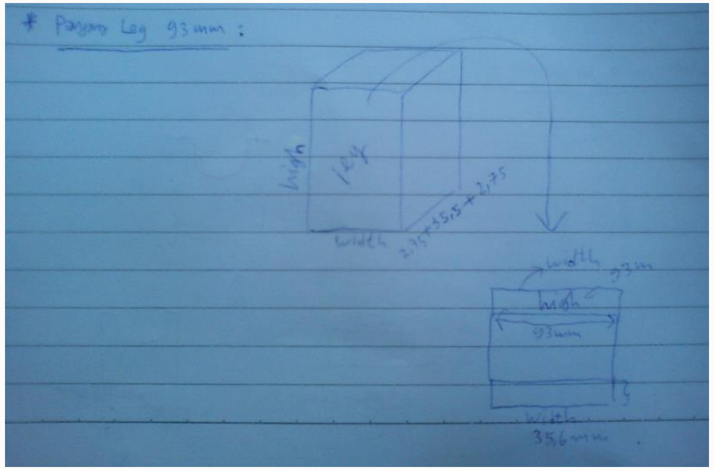
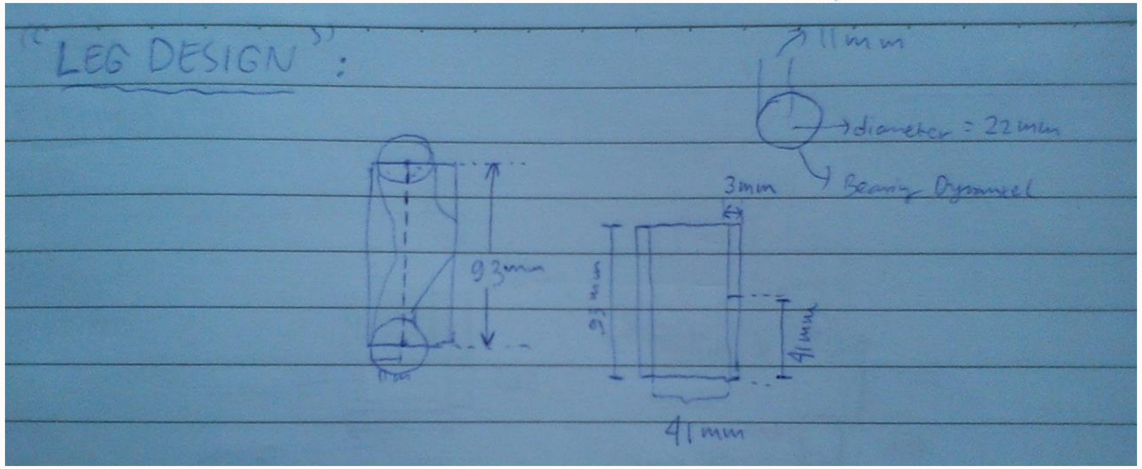
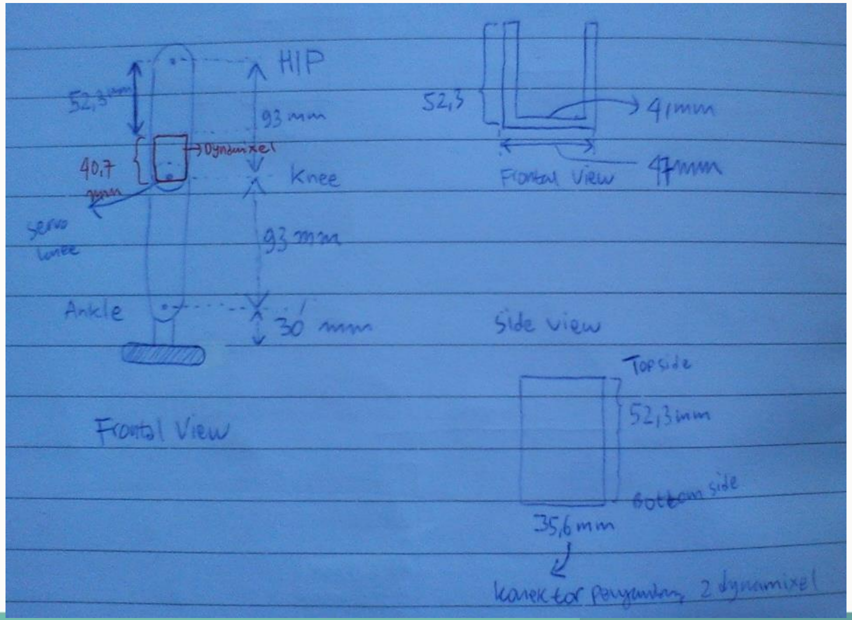
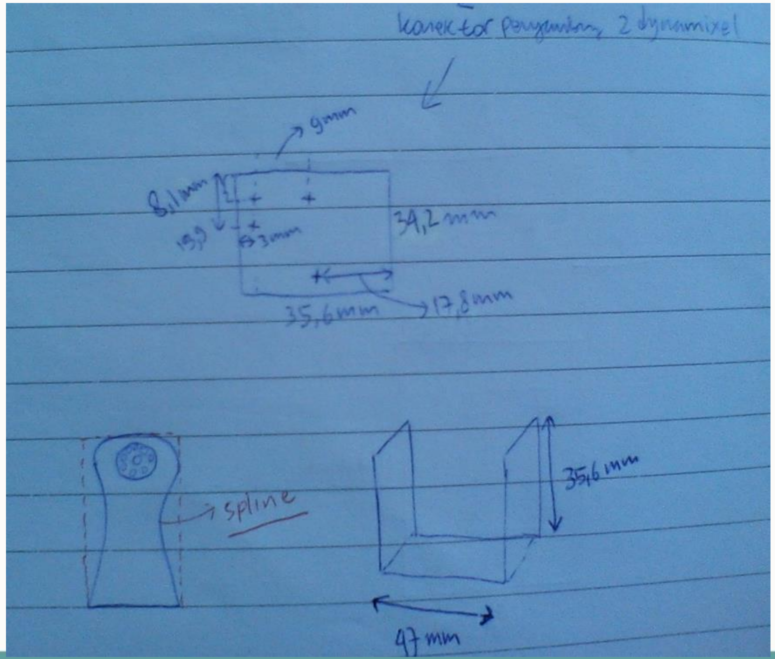
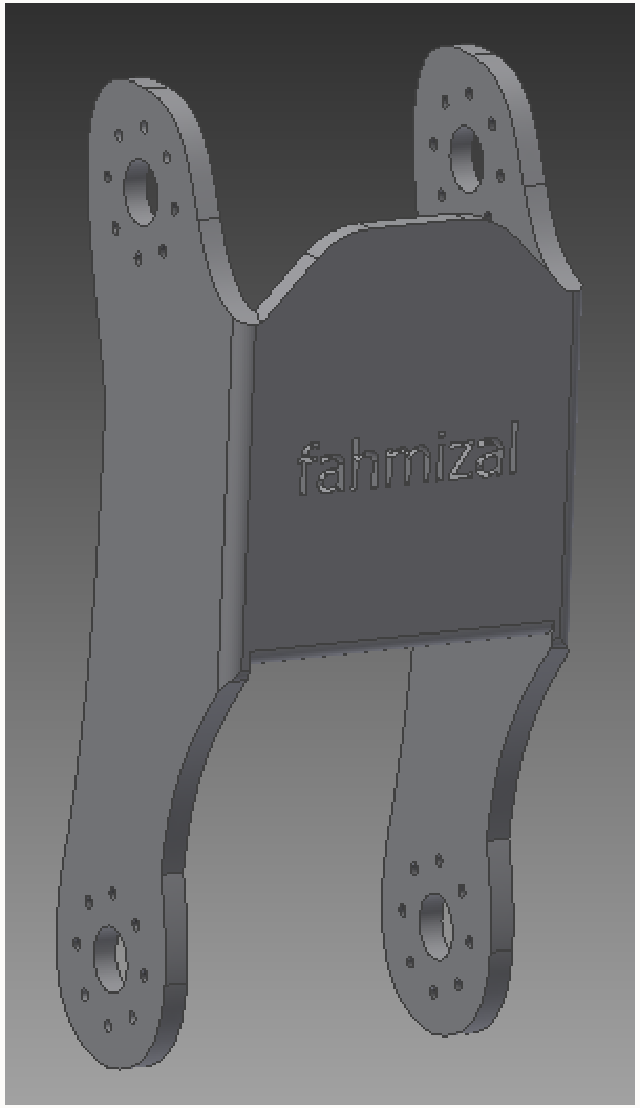


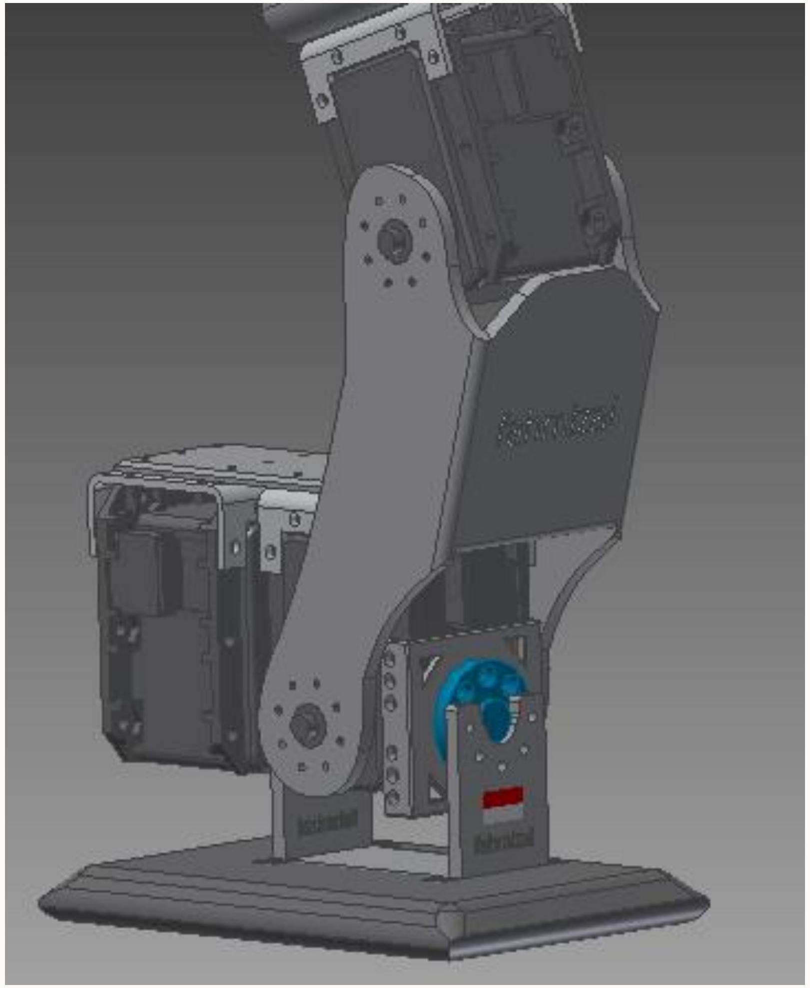




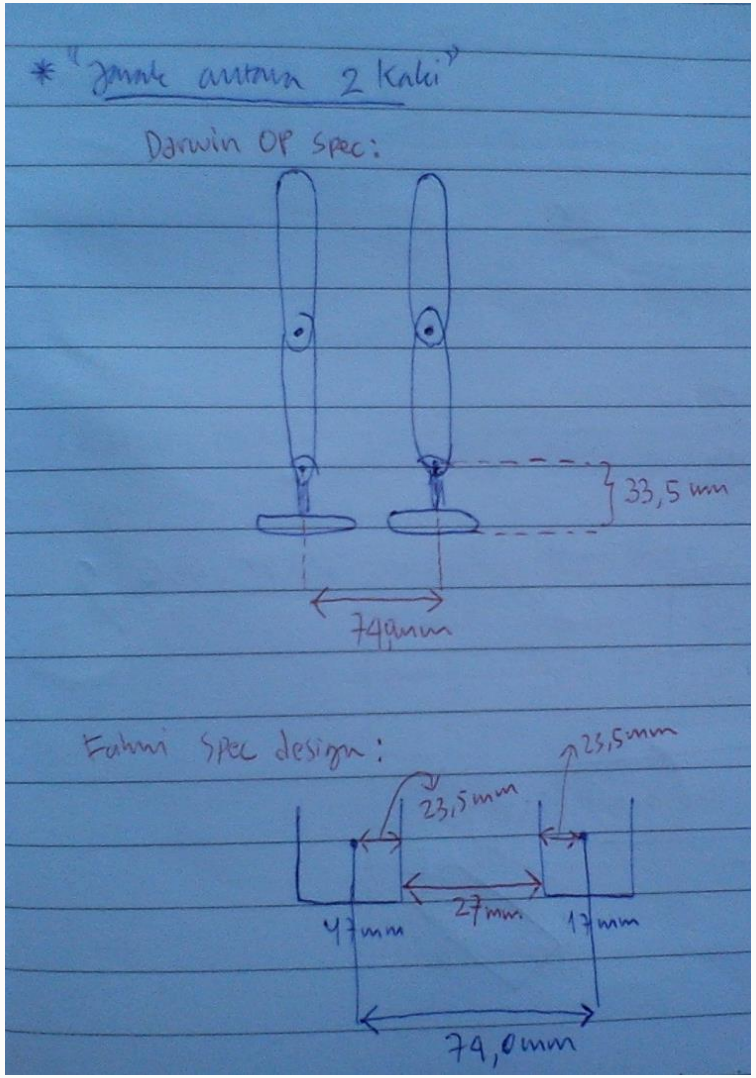


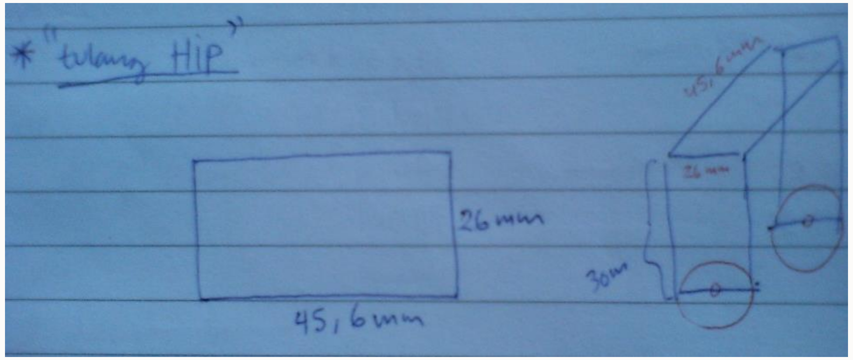
Leg Ankle + Knee (3 DOF)

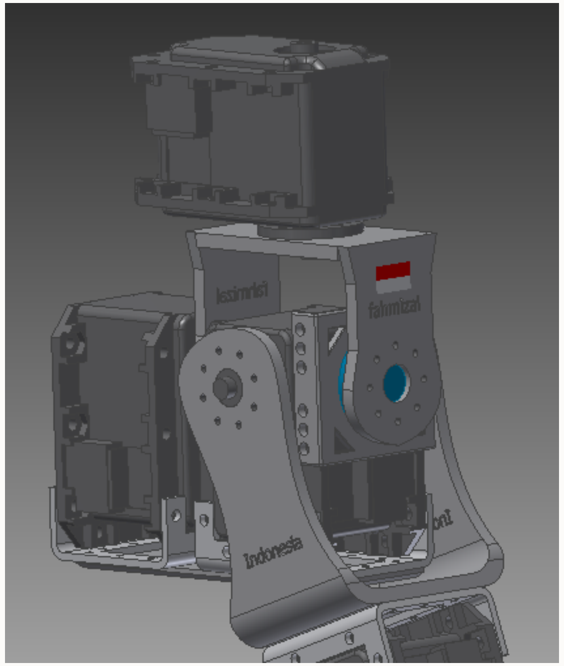




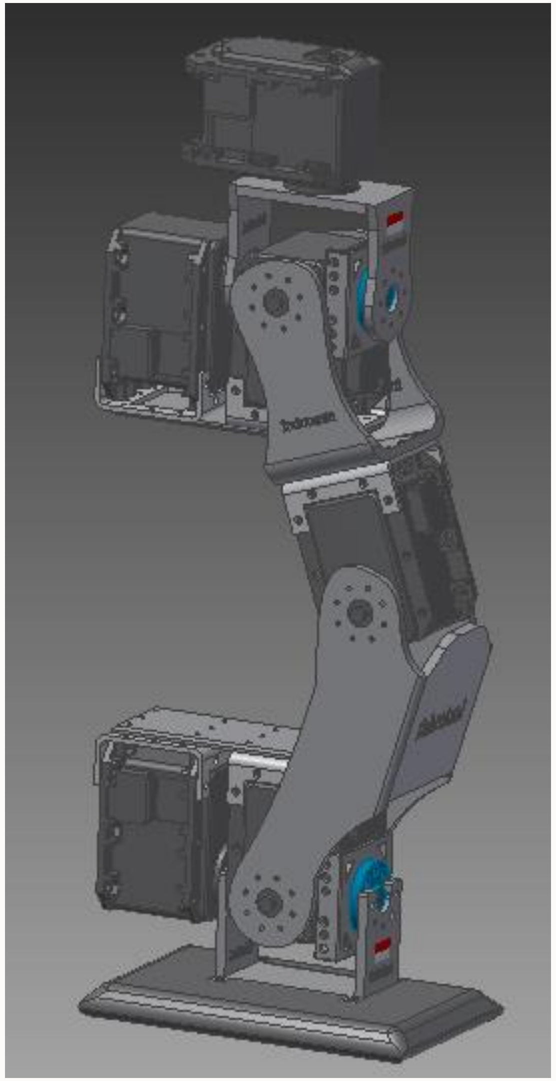
Hip Design (3 DOF)



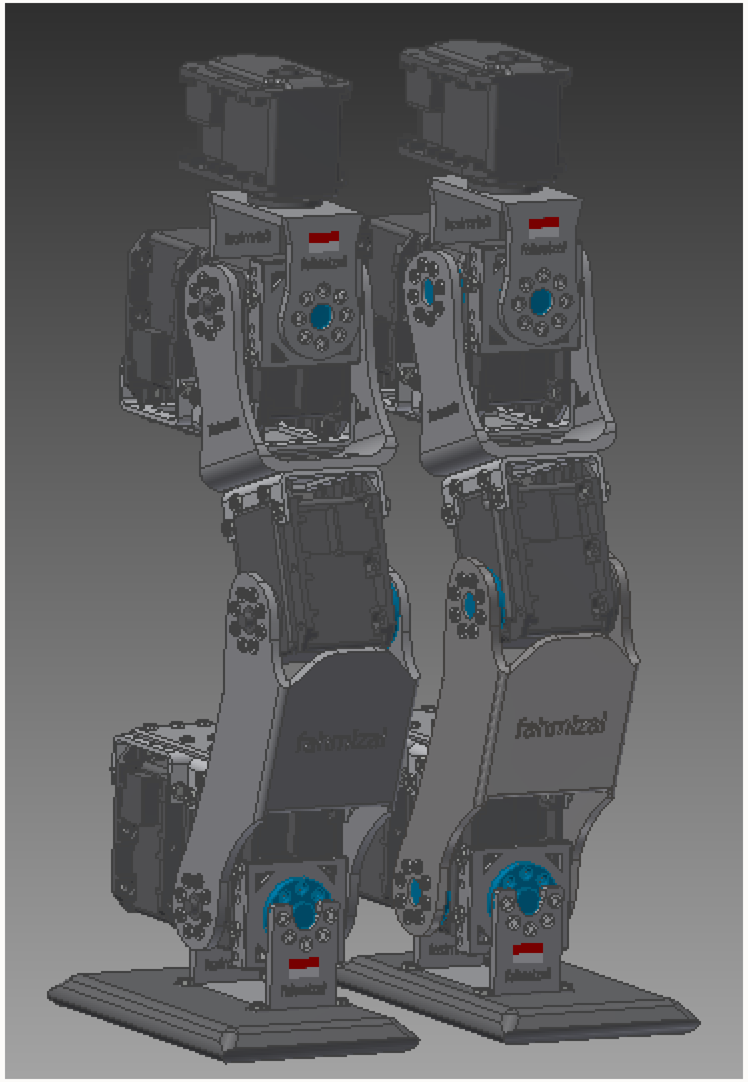




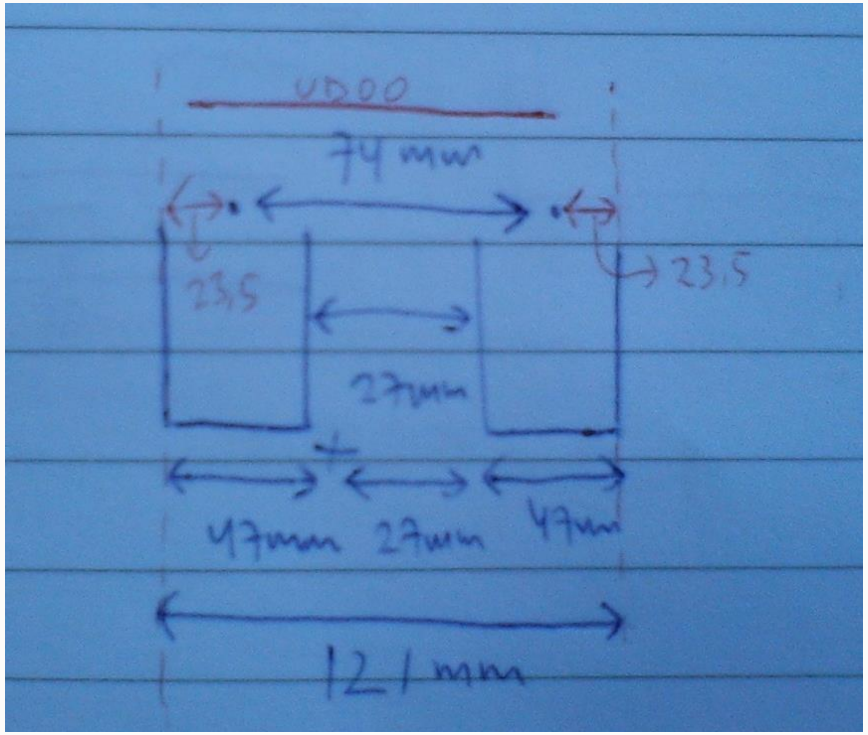
Full One Leg (6 DOF)

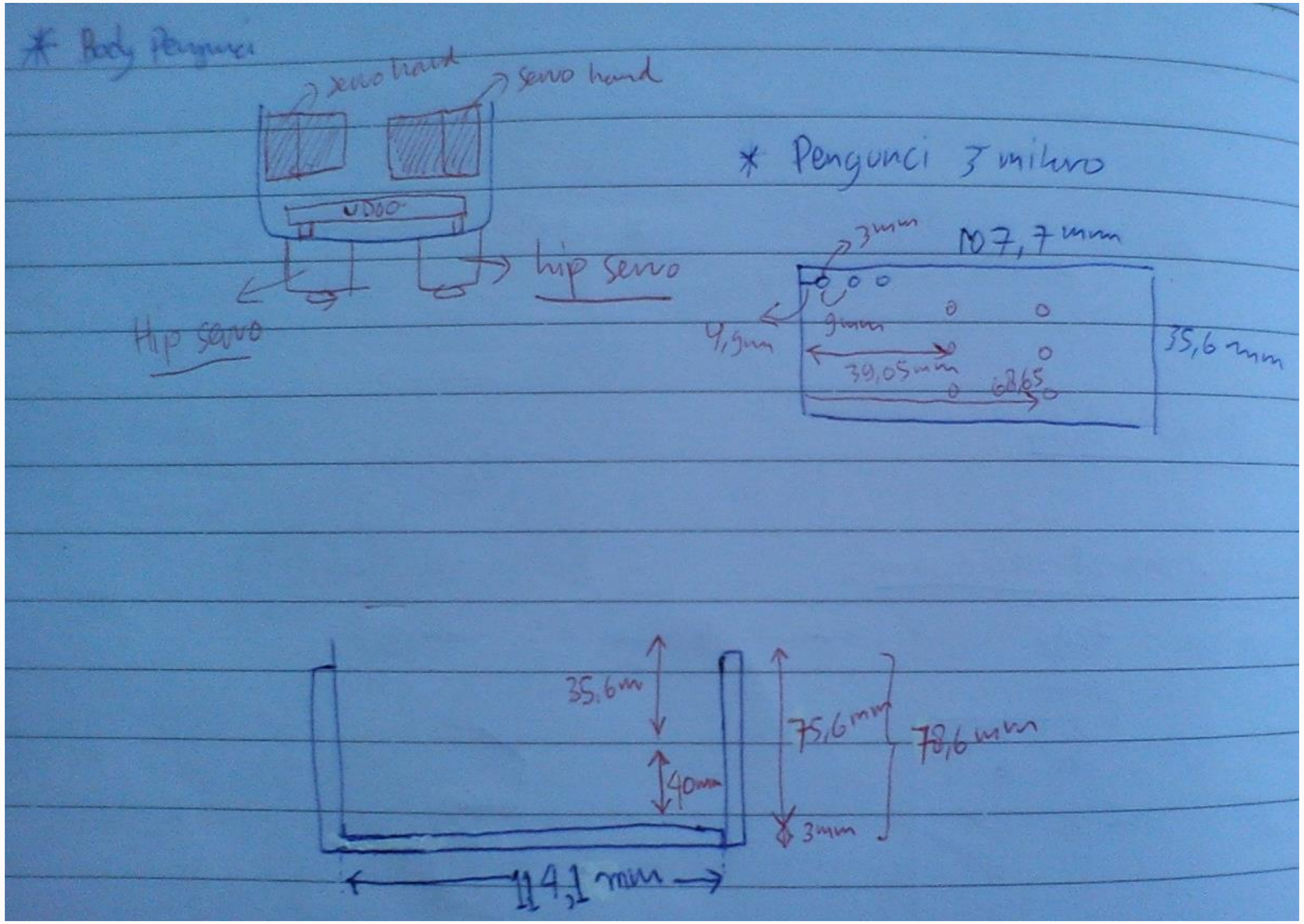


Two Leg; Left is mirror (12 DOF)



Body Design


UDOO
74 mm
23,5
23,5
27mm
47mm
27mm
47mm
121 mm


* Pengunci 3 mikro
servo hand
UDOO
hip servo
Hip servo
3mm
107,7 mm
35,6 mm
39,05 mm
35,6mm
40mm
75,6mm
78,6mm
3mm
114,1 mm

Body Design

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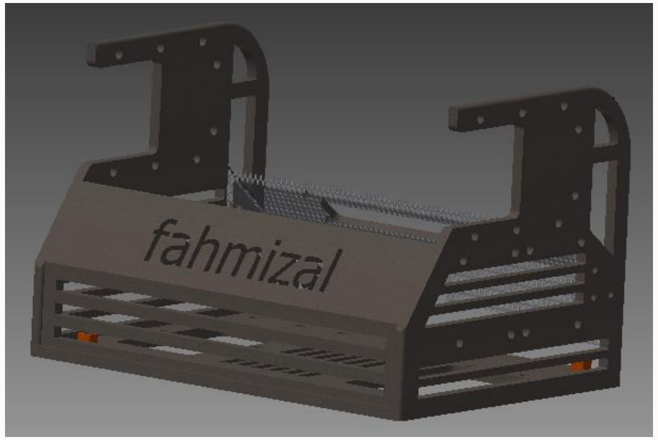
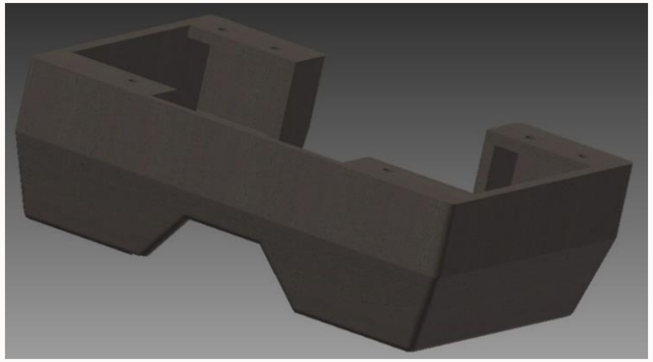
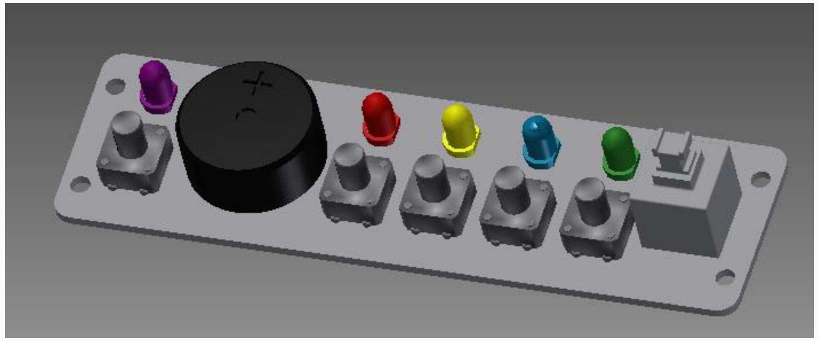


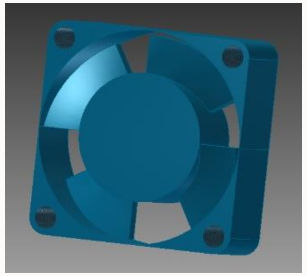
+

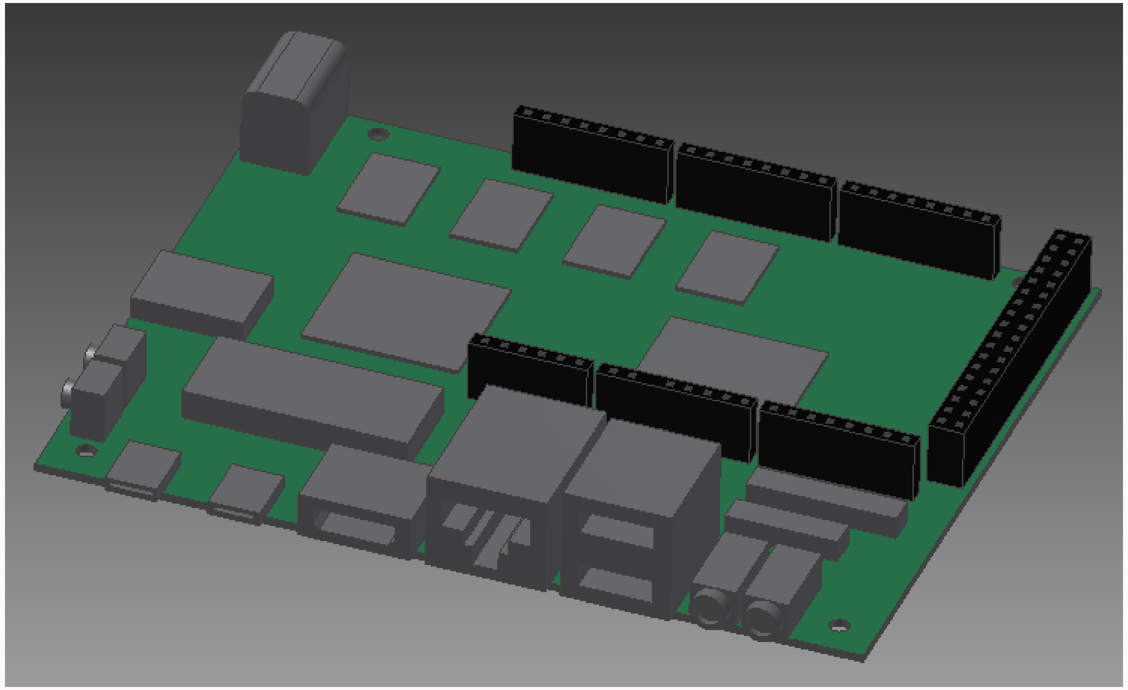


Inside of Body

- Udoo and Arduino
- Fan Cooler
- Control Panel







Body with two Leg (15 DOF)

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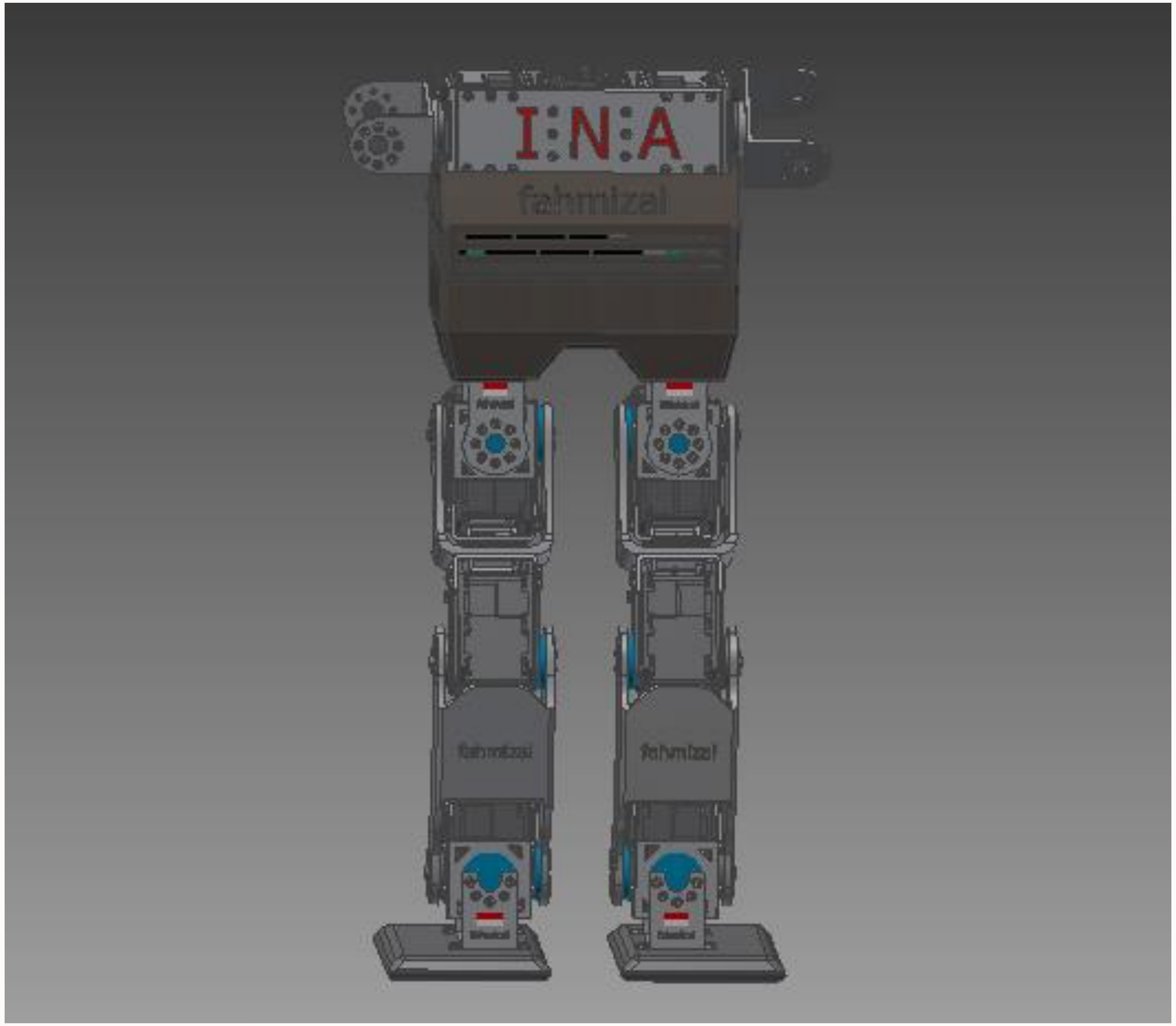
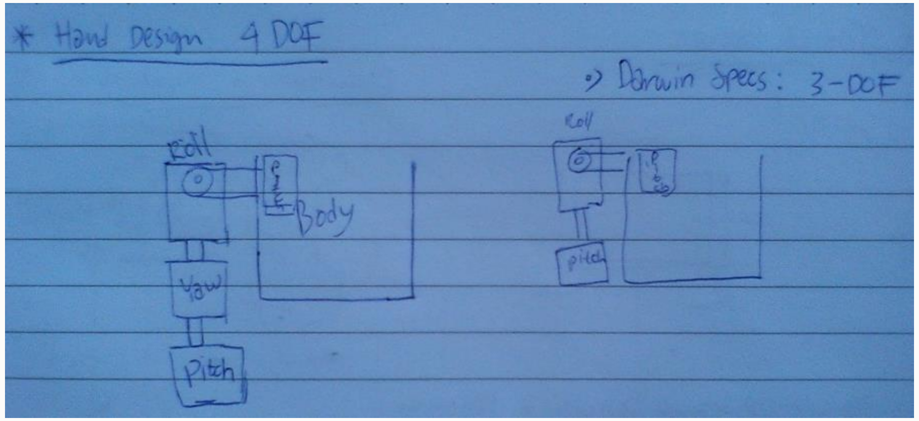
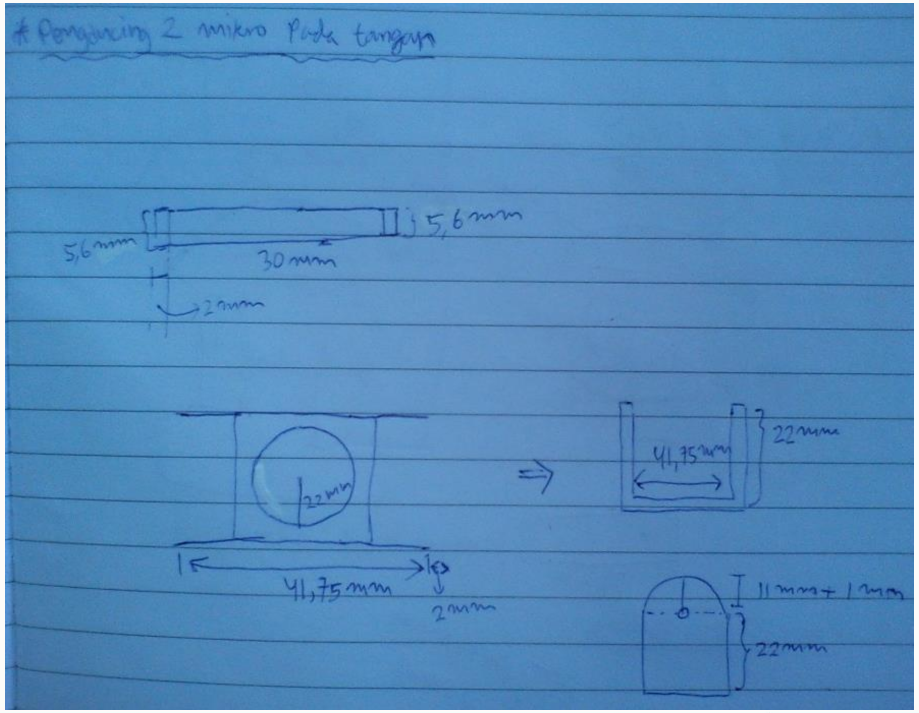
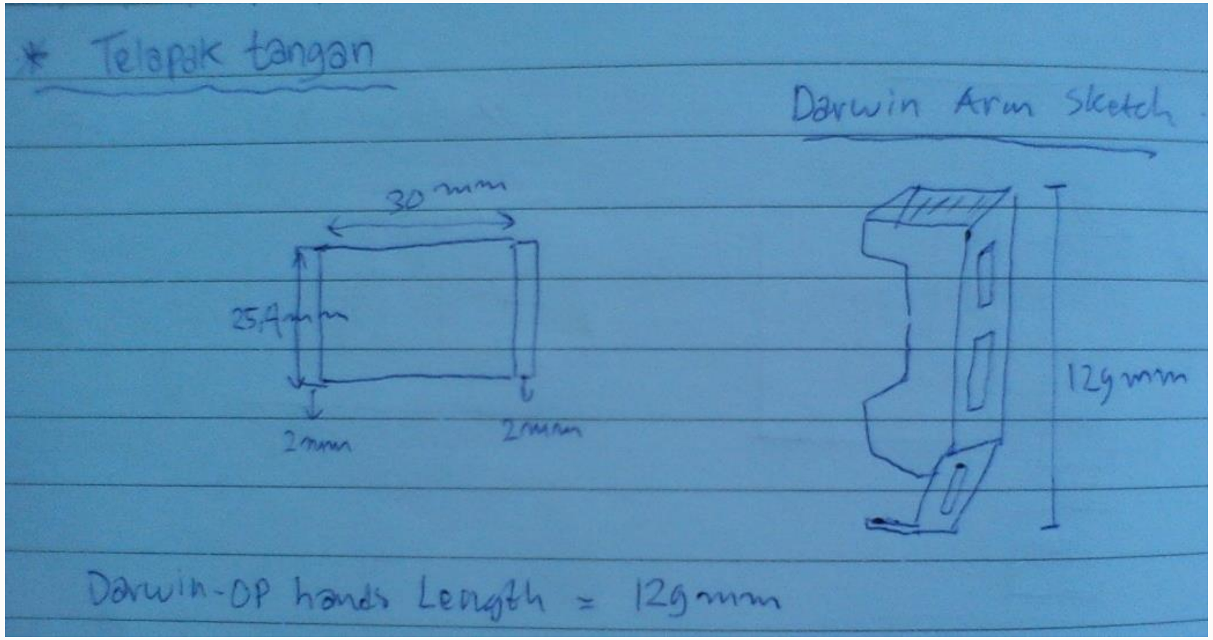


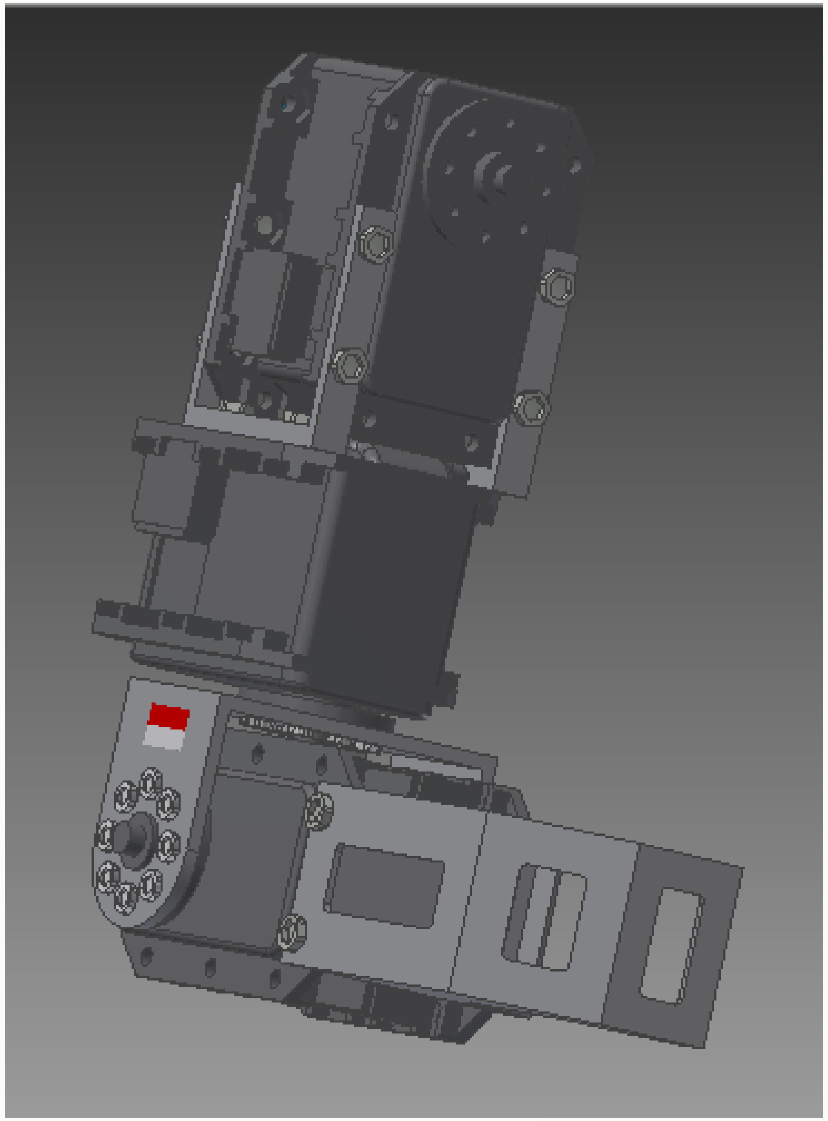
Hand Design (4 DOF)

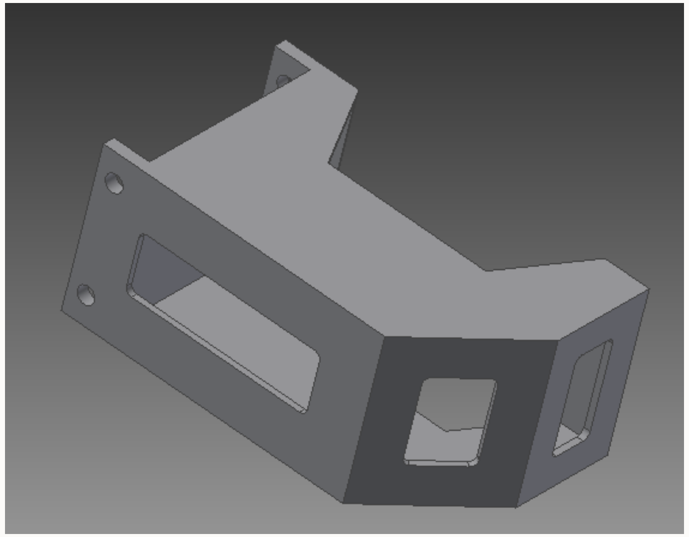




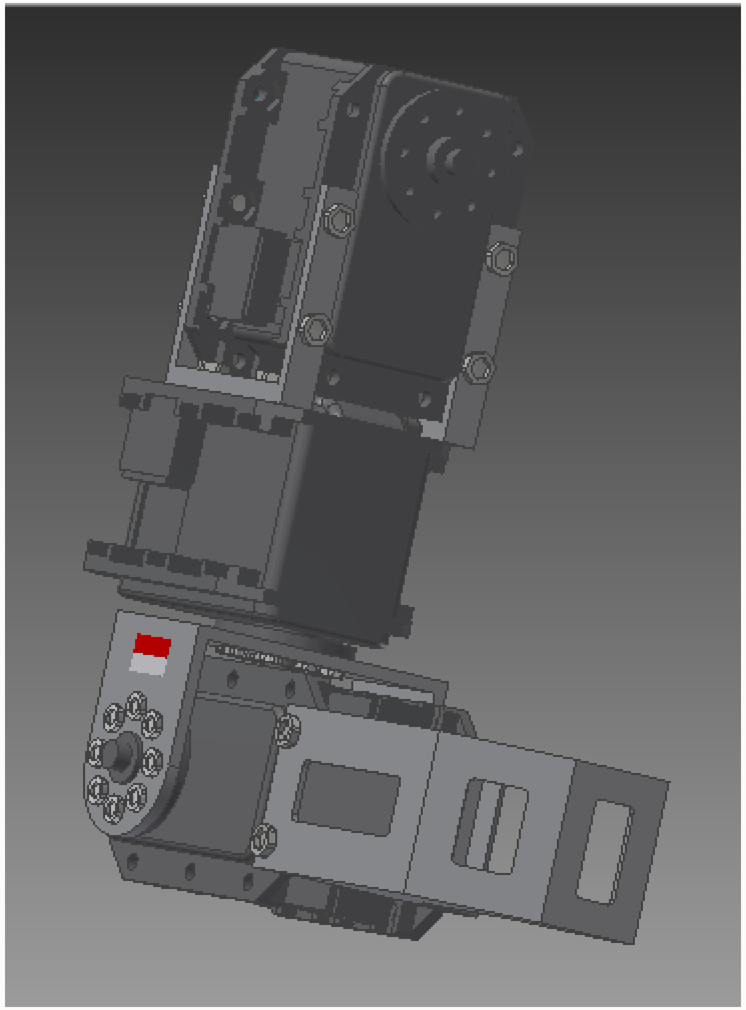


Hand Design (4 DOF)

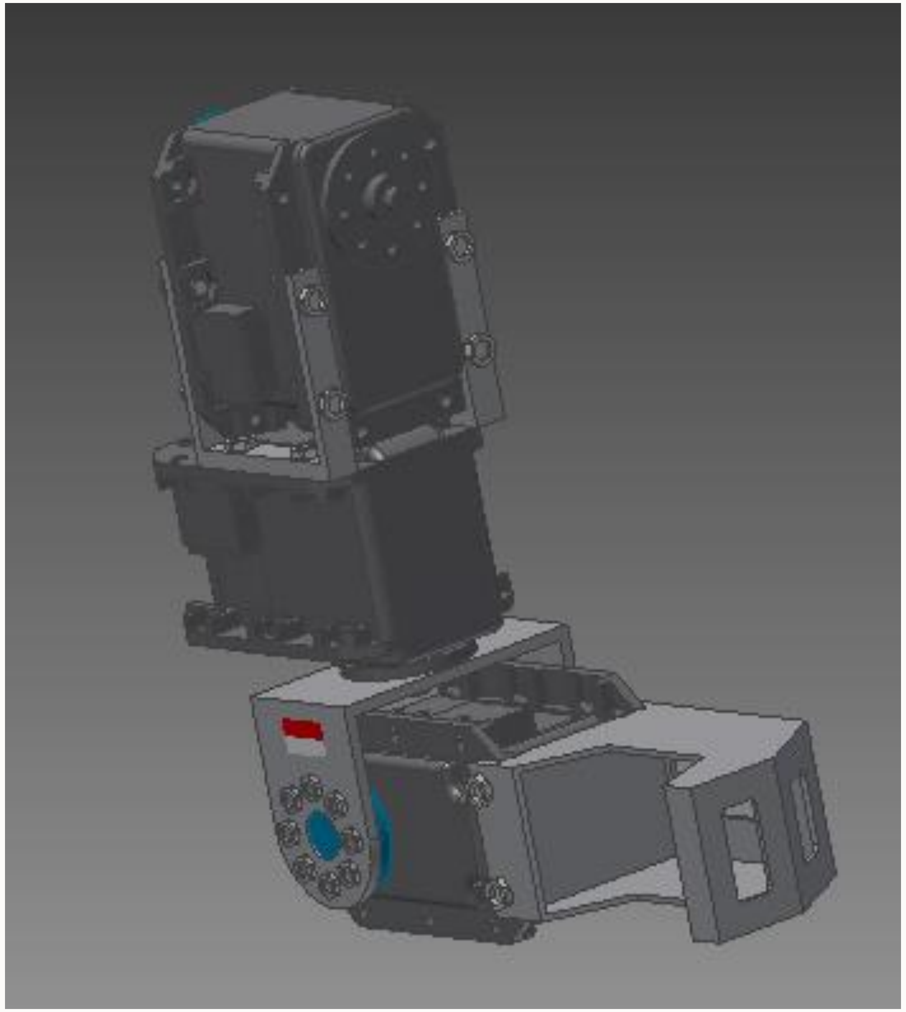




Two Hand; Left is mirror (8 DOF)

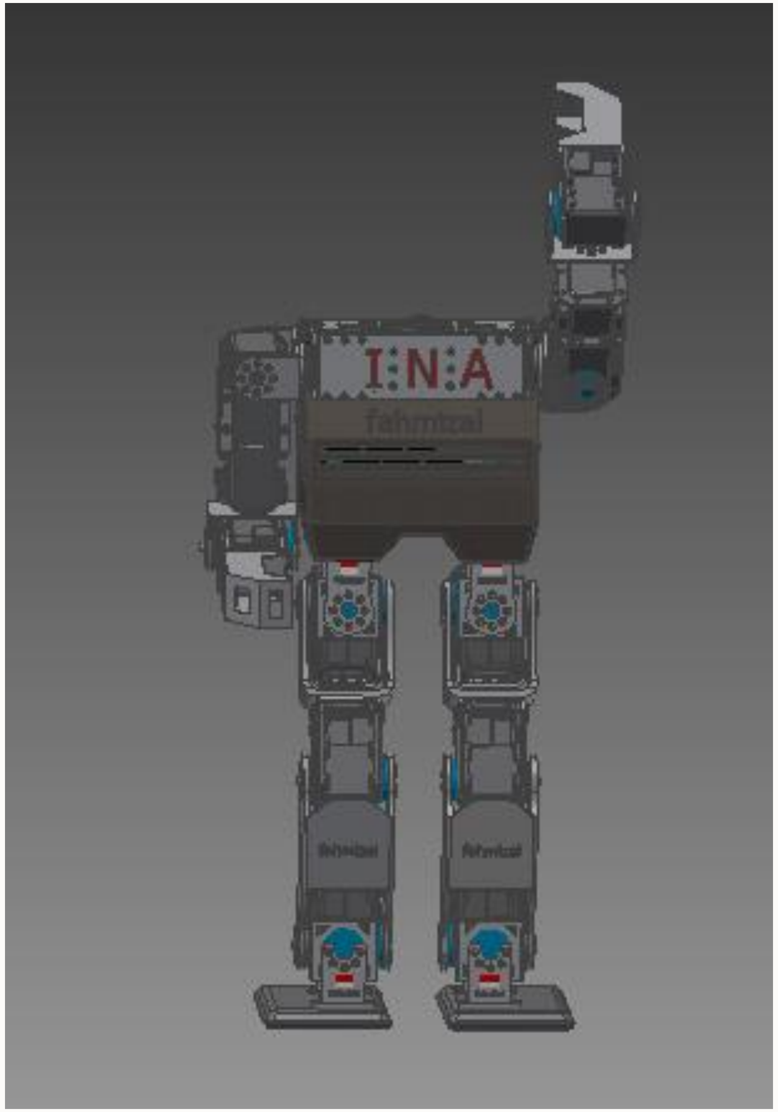


Right

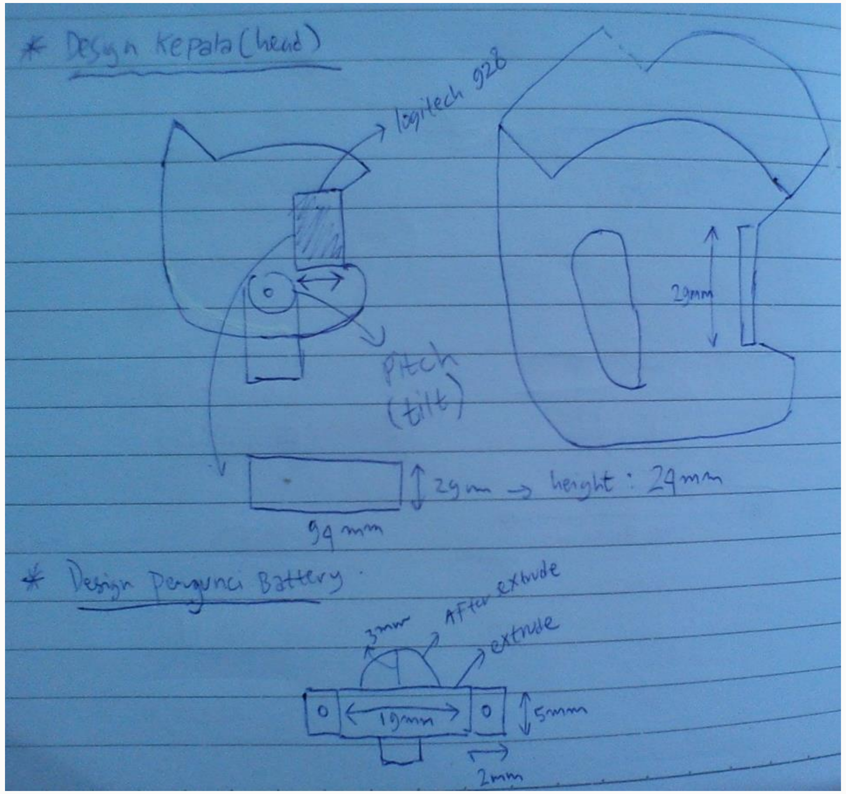


Left

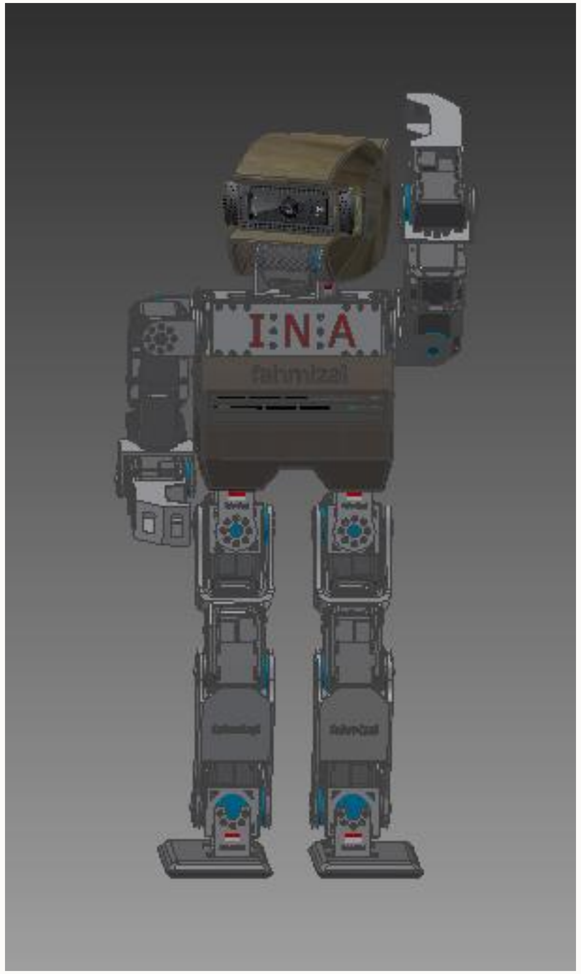
Body+Hand+Leg Full (20 DOF)

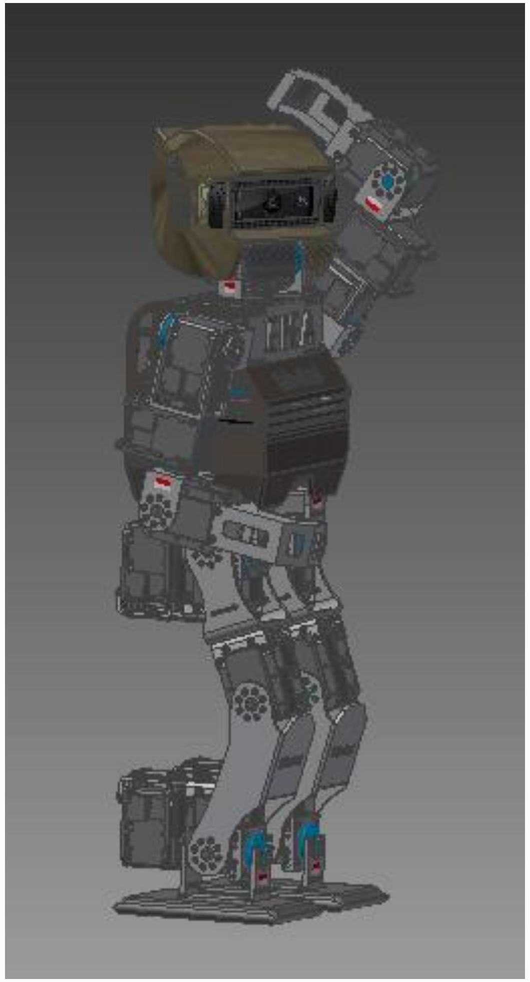


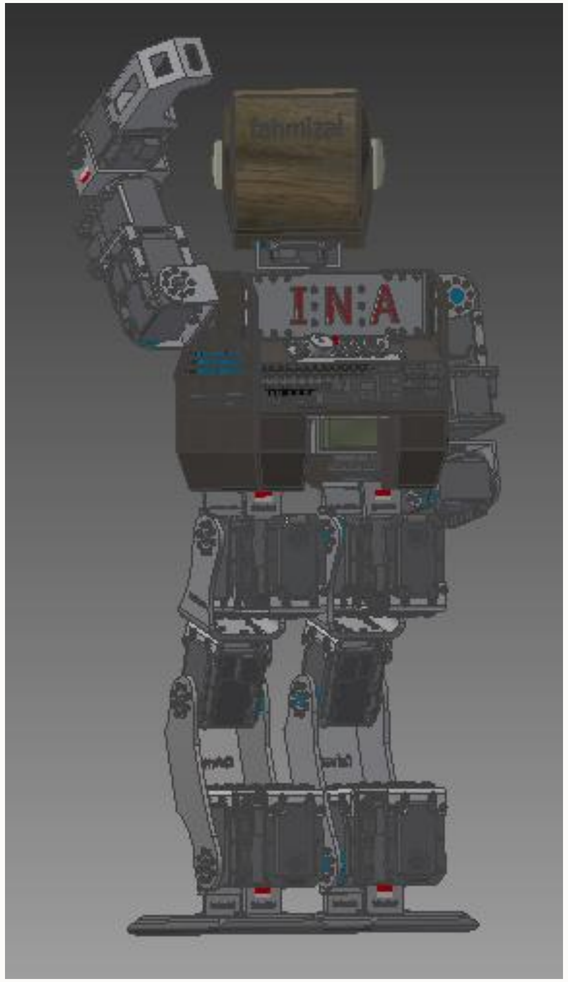
Head Design (2 DOF)



22 DOF Kid-Size Biped Robot







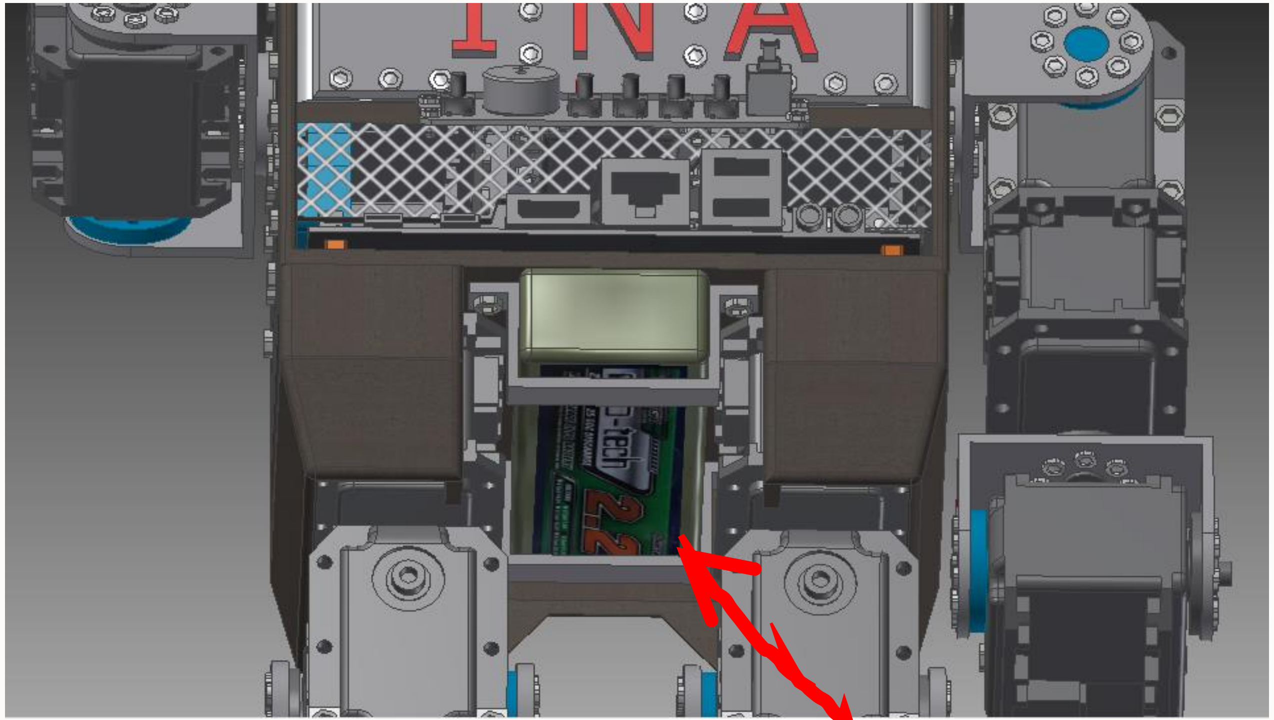
Battery 3S 1.4 A

Capacity(mAh)	1400
Config(s)	3
Discharge(c)	40
Weight(g)	119
Max Charge Rate (C)	10
Length-A(mm)	87
Height-B(mm)	34
Width-C(mm)	19

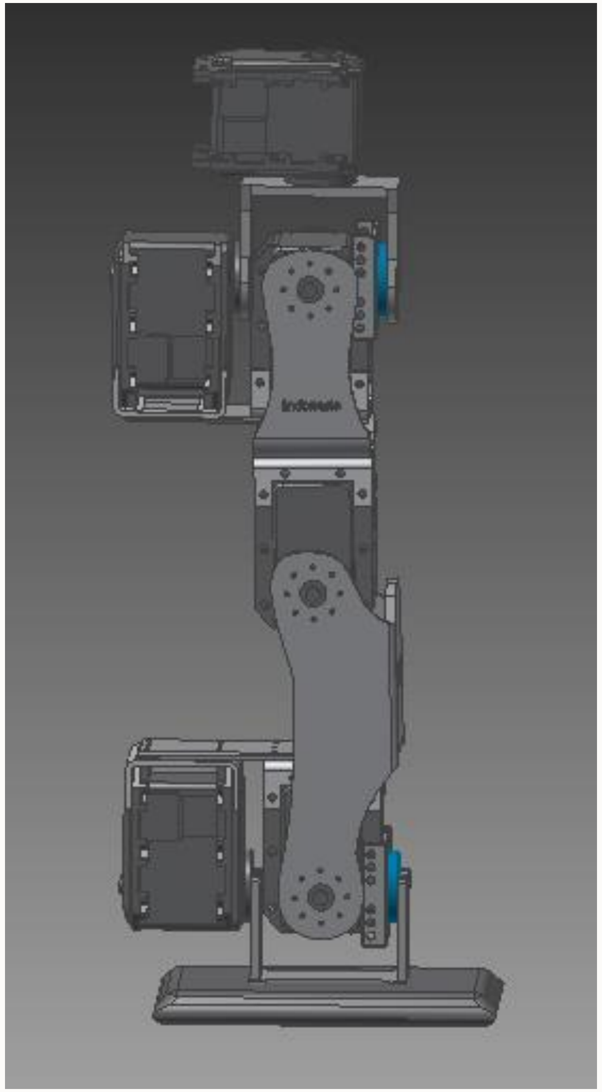
Spec.
Capacity: **1400mAh**
Voltage: **3S1P / 3 Cell / 11.1V**
Discharge: **40C Constant / 80C Burst**
Weight: **118.7g (including plug & case)**
Dimensions: **87 x 19 x 34mm**
Discharge Plug: **TRX plug**

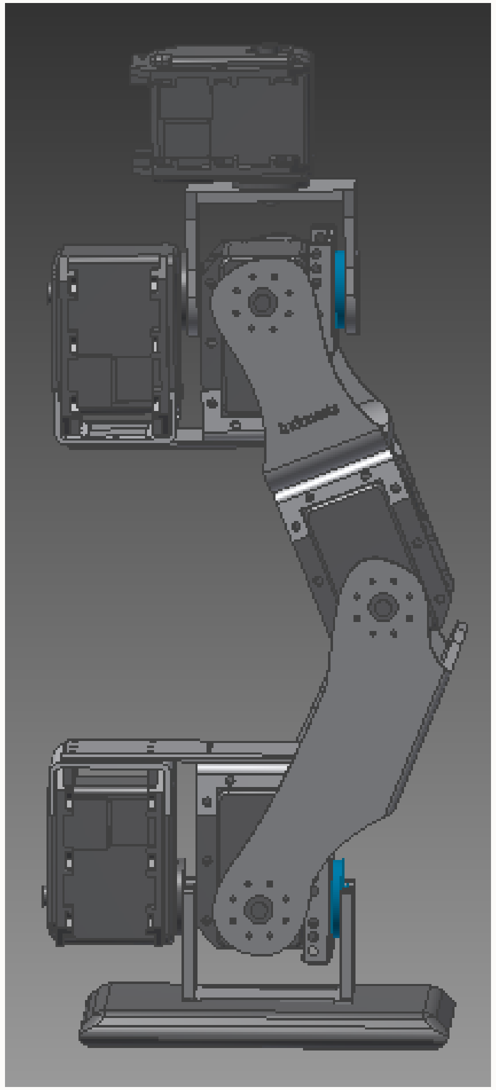
- *http://hobbyking.com/hobbyking/store/__20391__Turnigy_nano_tech_1400mah_3S_40_80C_Lipo_Pack_TRA2823_Traxxas_1_16_models_.html*

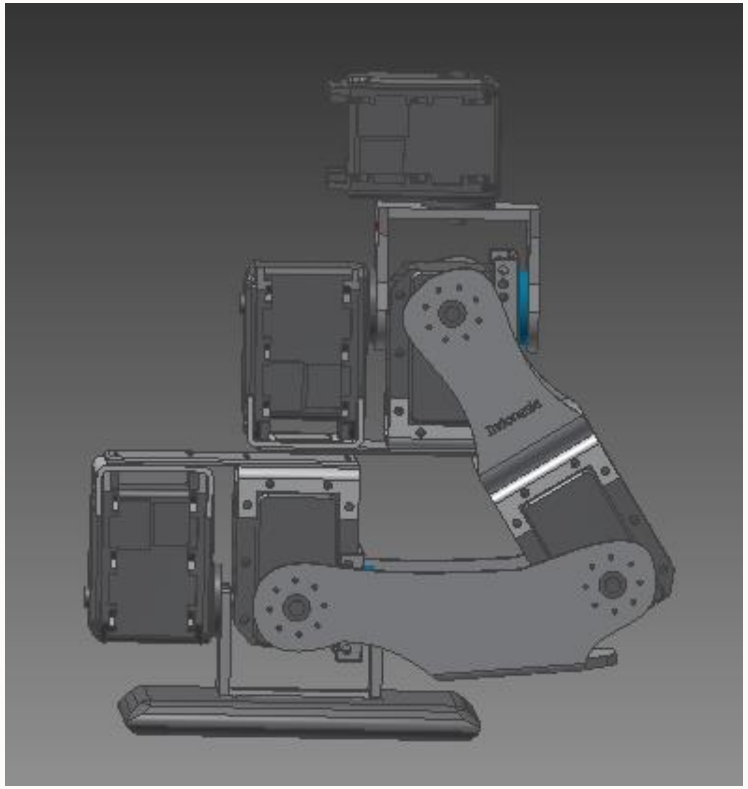
Battery position and location



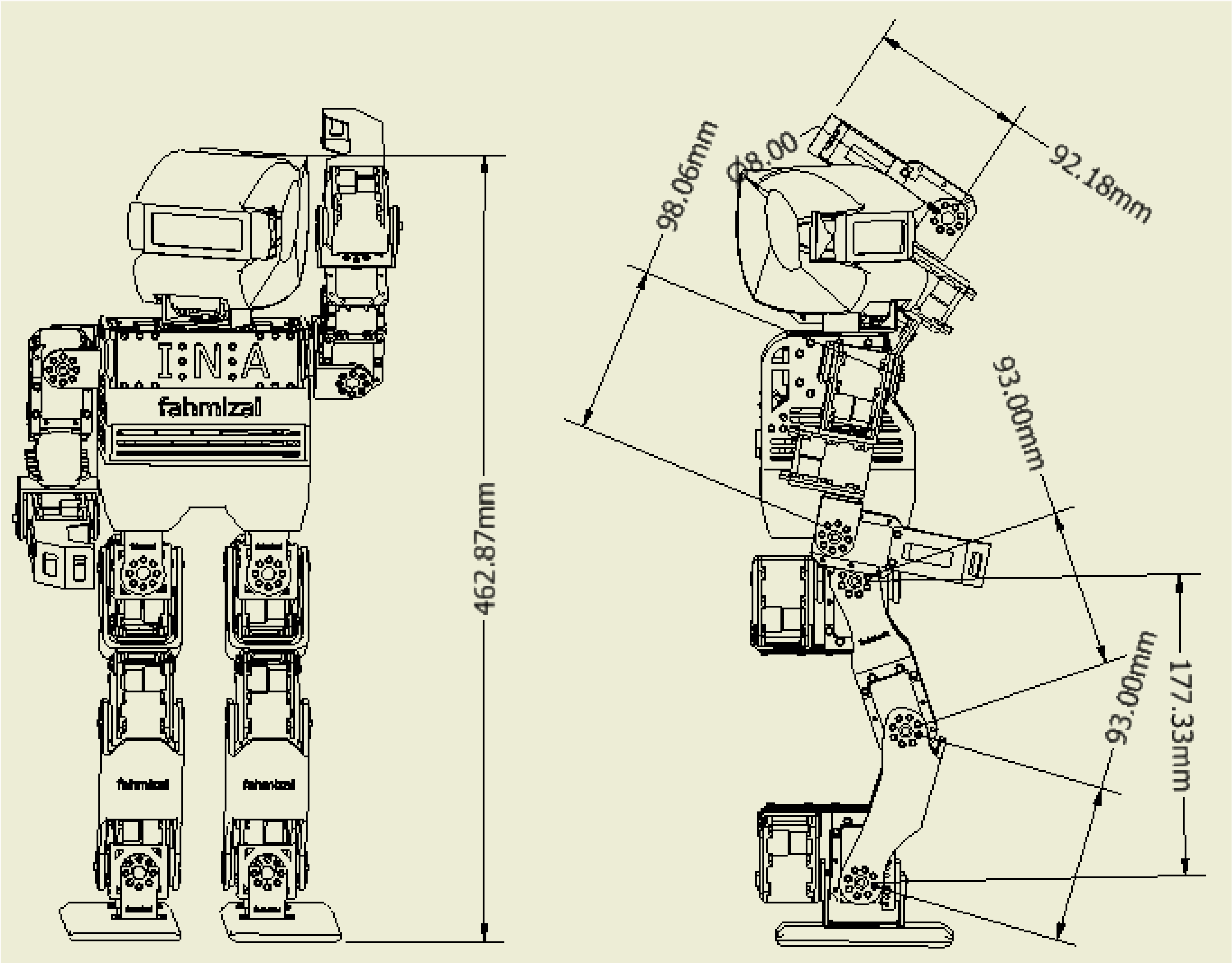
Gait Leg Analysis







Specifications



Specifications

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CPU	Main Controller	UDOO Freescale i.MX 6 ARM Cortex-A9 CPU Dual/Quad core 1GHz
	Sub Controller	ARDUINO DUE Atmel SAM3X8E ARM Cortex-M3
Actuator	Head	1 x 2 Dynamixel MX-28
	Arm	2 x 4 Dynamixel MX-28
	Leg	2 x 6 Dynamixel MX-28
Sensor	FSR	4 sensor per foot
	Magnetic sensor	CMPS-10
	Gyroscope	ITG-3205
	Accelerometer	ADXL345
	Camera	Logitech 15MP HD Pro Webcam C920
Power	Battery LiPo 3 Cell 2200 mAh	
Dimension	Height	462.87 mm
	Foot	66 x 104 mm
	Leg	186 mm
	Arm	190 mm
	Weight	unknown
DOF	Head	1 x 2 DOF
	Arm	4 x 2 DOF
	Leg	6 x 2 DOF
Motion	Walking Speed	unknown

Locomotion Control of Bipedal Robot

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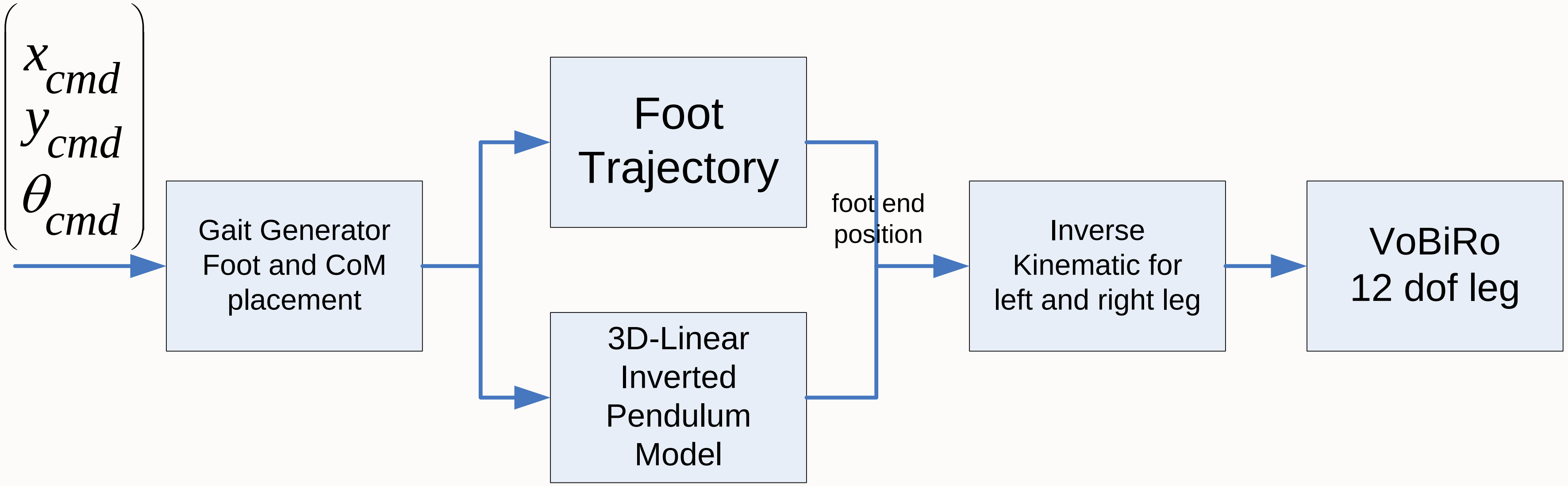


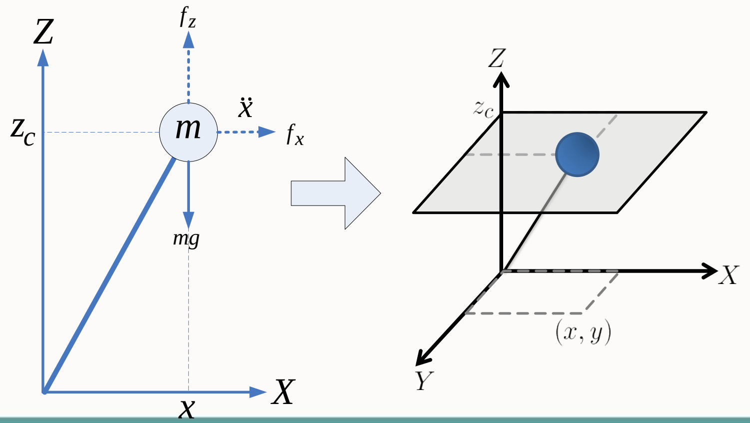
Foot Trajectory

$$x_s(t) = \frac{Shift}{2\pi}\left[2\pi\frac{t}{T_s} - \sin\left(2\pi\frac{t}{T_s}\right)\right], \qquad 0 \le t \le T_s$$

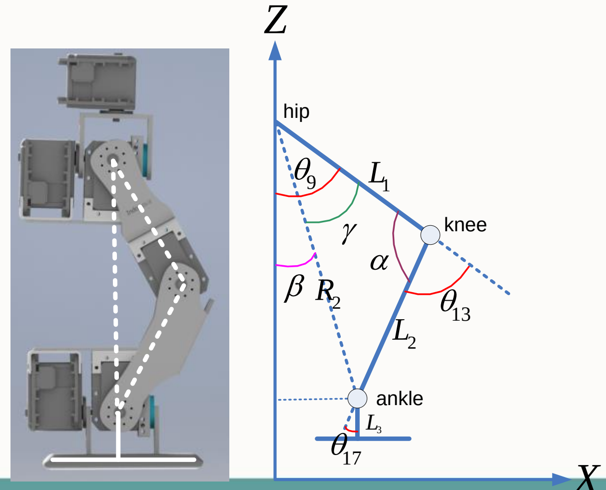
$$y_s(t) = \frac{Length}{2\pi}\left[2\pi\frac{t}{T_s} - \sin\left(2\pi\frac{t}{T_s}\right)\right], \qquad 0 \le t \le T_s$$

$$z_s(t) = \begin{cases} \frac{Height}{2\pi}\left[2\pi\frac{t}{\rho T_s} - \sin\left(2\pi\frac{t}{\rho T_s}\right)\right], & 0 \le t \le \rho T_s \\ Height - \frac{Height}{2\pi}\left[2\pi\frac{t-\rho T_s}{(1-\rho)T_s} - \sin(2\pi)\frac{t-\rho T_s}{(1-\rho)T_s}\right], & \rho T_s < t < T_s \end{cases}$$

CoM Trajectory use LIPM

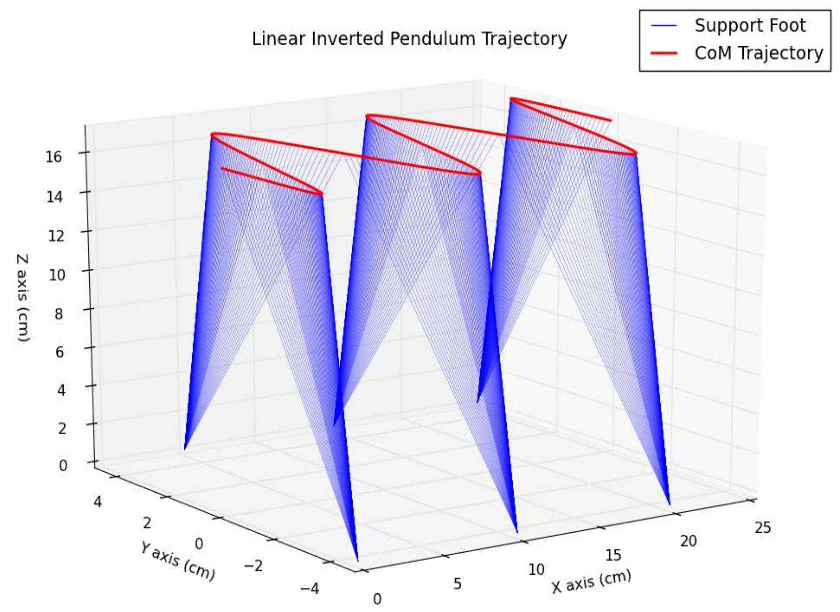


Inverse Kinematic

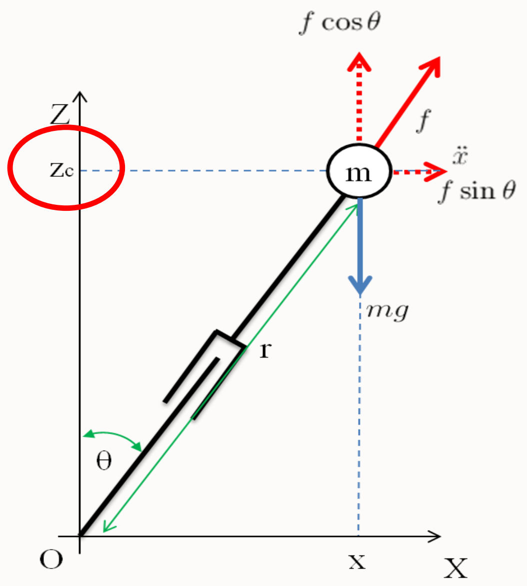


Linear Inverted Pendulum Model (LIPM)

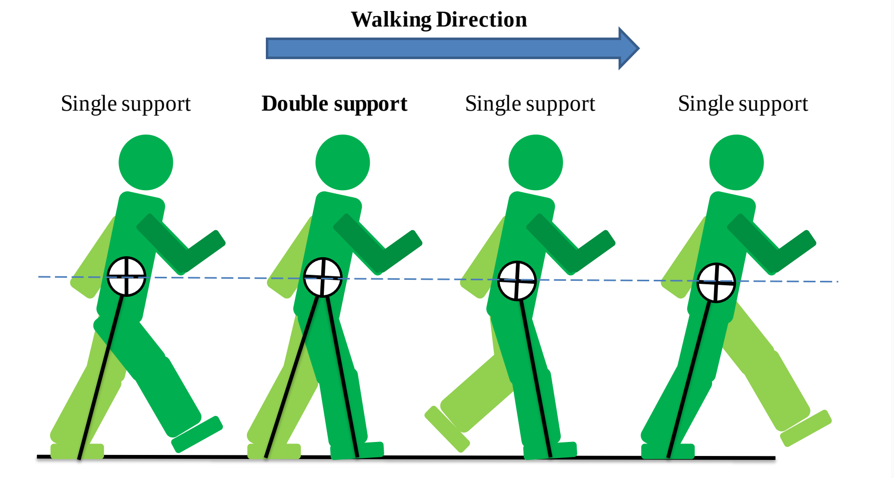
- Mainly used for trajectory generation robot walking to the center of mass (CoM)
- The robot CoM is assumed to be an inverted pendulum



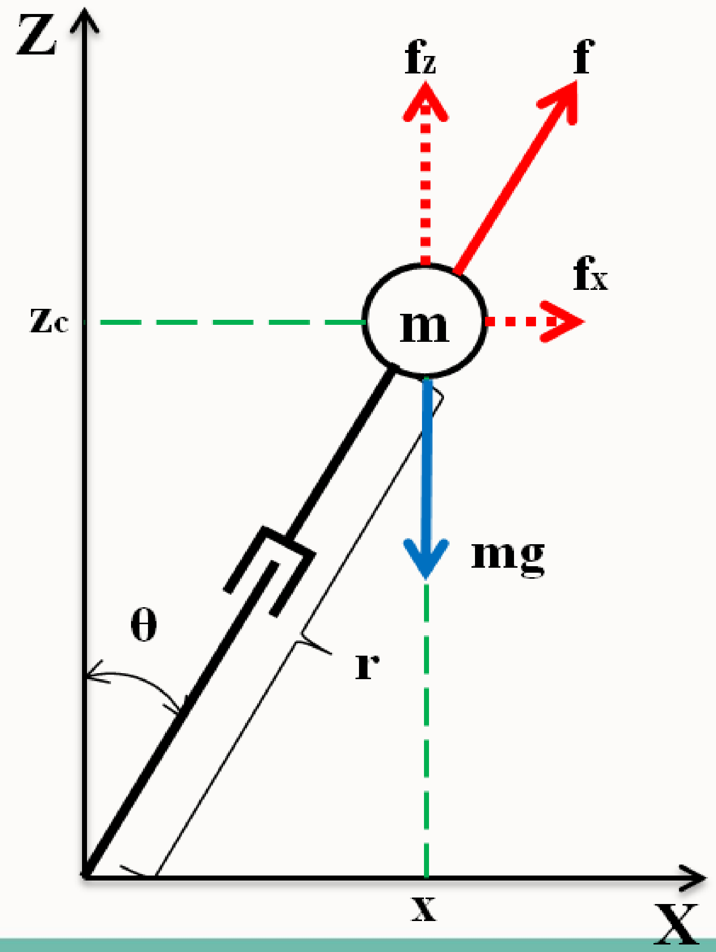
One-Dimensional Linear Inverted Pendulum Model



$$f\cos\theta = mg$$
$$f\sin\theta = m\ddot{x}$$
$$\frac{\ddot{x}}{g} = \frac{\sin\theta}{\cos\theta}$$
$$\frac{\ddot{x}}{g} = \tan\theta \Rightarrow \ddot{x} = \frac{g}{z_c}x$$



One-Dimensional Linear Inverted Pendulum Model



$$\ddot{x} = \frac{g}{z_c}x$$

Solutions $x(t)$ can be obtained by the differential equation

$$x(t) = x(0)\cosh(\frac{t}{T_c}) + T_c\dot{x}(0)\sinh(\frac{t}{T_c})$$

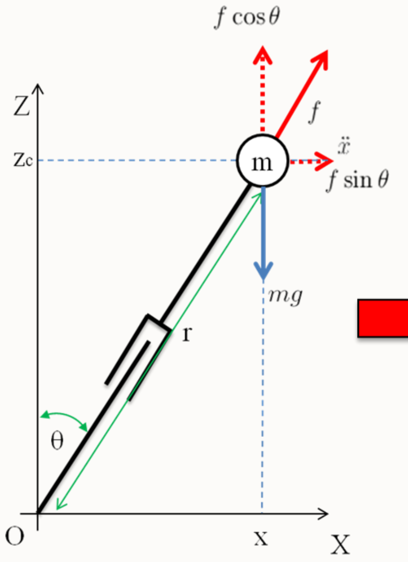
Which is T_c a linear inverted pendulum time constant

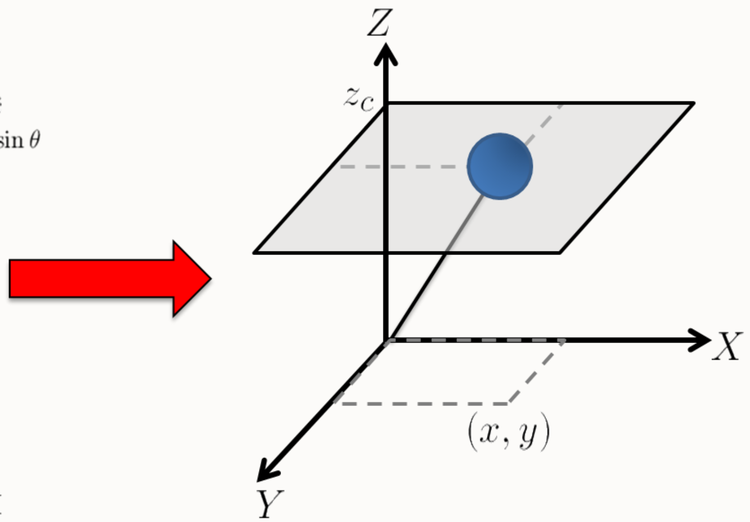
$$T_c = \sqrt{\frac{z_c}{g}}$$

g is gravity

We have the initial velocity $\dot{x}(0)$
and initial position $x(0)$
through this equation, Available to any position of a point of time $x(t)$

Three Dimensional Linear Inverted Pendulum Model





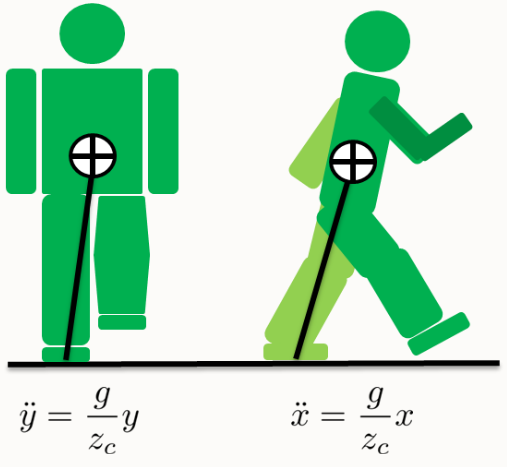
$$\ddot{x} = \frac{g}{z_c}x \begin{cases} x(t) = x(0)\cosh(\frac{t}{T_c}) + T_c\dot{x}(0)\sinh(\frac{t}{T_c}) \\ \dot{x}(t) = \frac{x(0)\sinh(\frac{t}{T_c})}{T_c} + \dot{x}(0)\cosh(\frac{t}{T_c}) \end{cases}$$

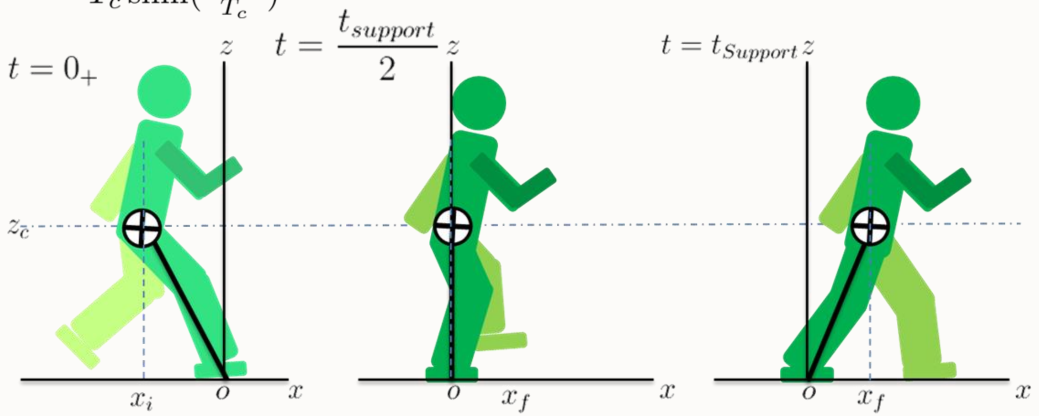
$$\ddot{y} = \frac{g}{z_c}y \begin{cases} y(t) = y(0)\cosh(\frac{t}{T_c}) + T_c\dot{y}(0)\sinh(\frac{t}{T_c}) \\ \dot{y}(t) = \frac{y(0)\sinh(\frac{t}{T_c})}{T_c} + \dot{y}(0)\cosh(\frac{t}{T_c}) \end{cases}$$

$$x_f = x_i\cosh(\frac{T_{sup}}{T_c}) + T_c x_y\sinh(\frac{T_{sup}}{T_c})$$

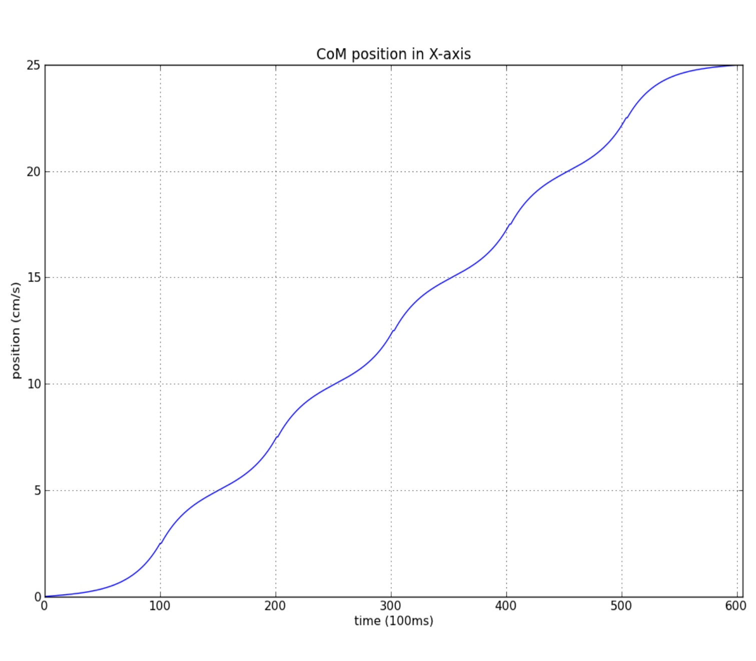
$$x_f = -x_i$$

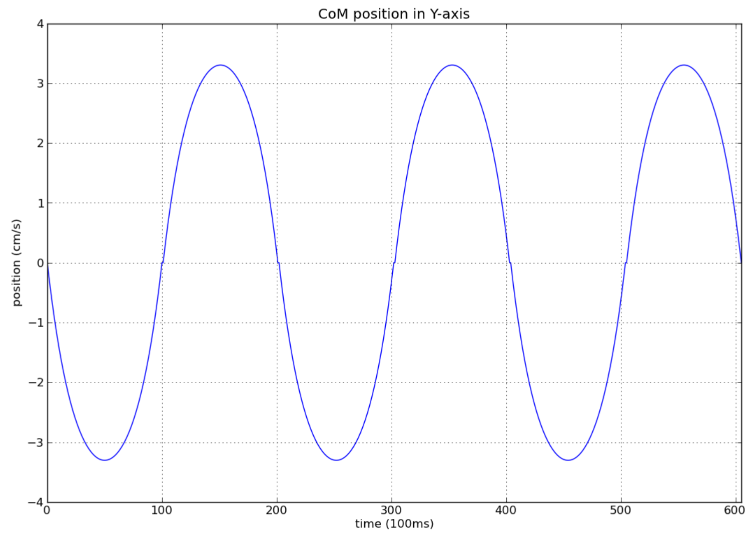
$$v_x = \frac{x_f + x_f\cosh(\frac{T_{sup}}{T_c})}{T_c\sinh(\frac{T_{sup}}{T_c})}$$

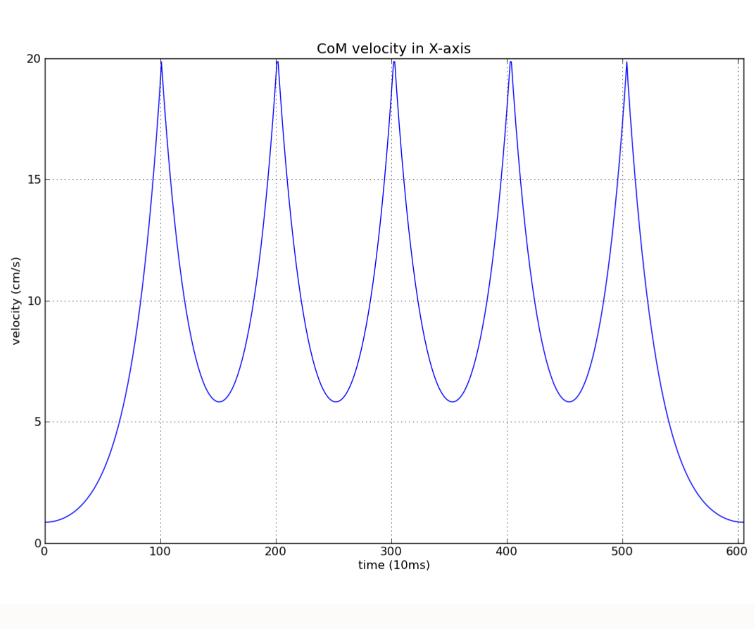


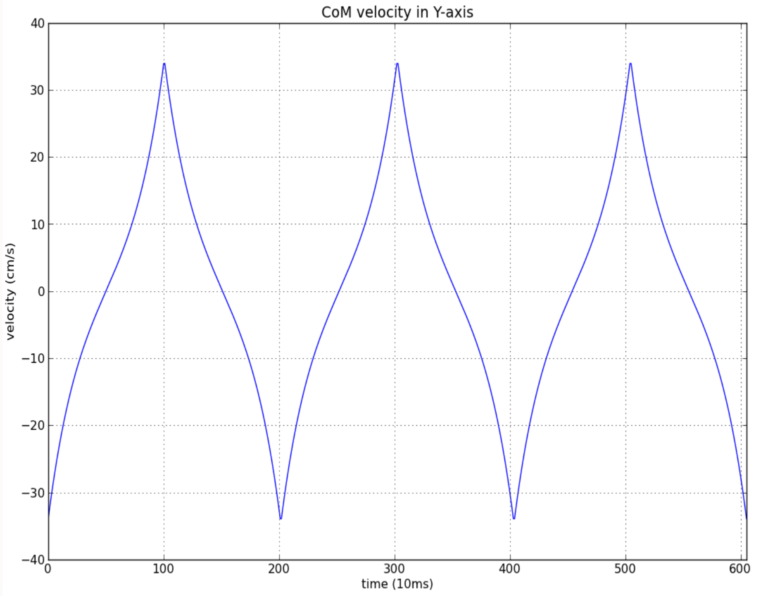


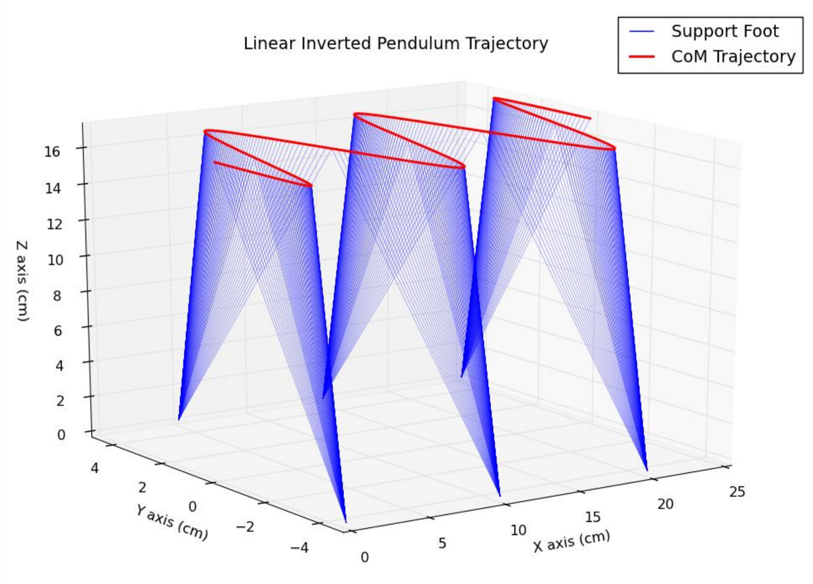
Kajita, S., Kanehiro, F., Kaneko, K., Yokoi, K. and Hirukawa, H.,"The 3D Linear Inverted Pendulum Mode: A simple modeling for a biped walking pattern generation". In Intelligent Robots and Systems, 2001. Proceedings. 2001 IEEE/RSJ International Conference on IEEE, 2001


CoM position in X-axis
position (cm/s)
time (100ms)

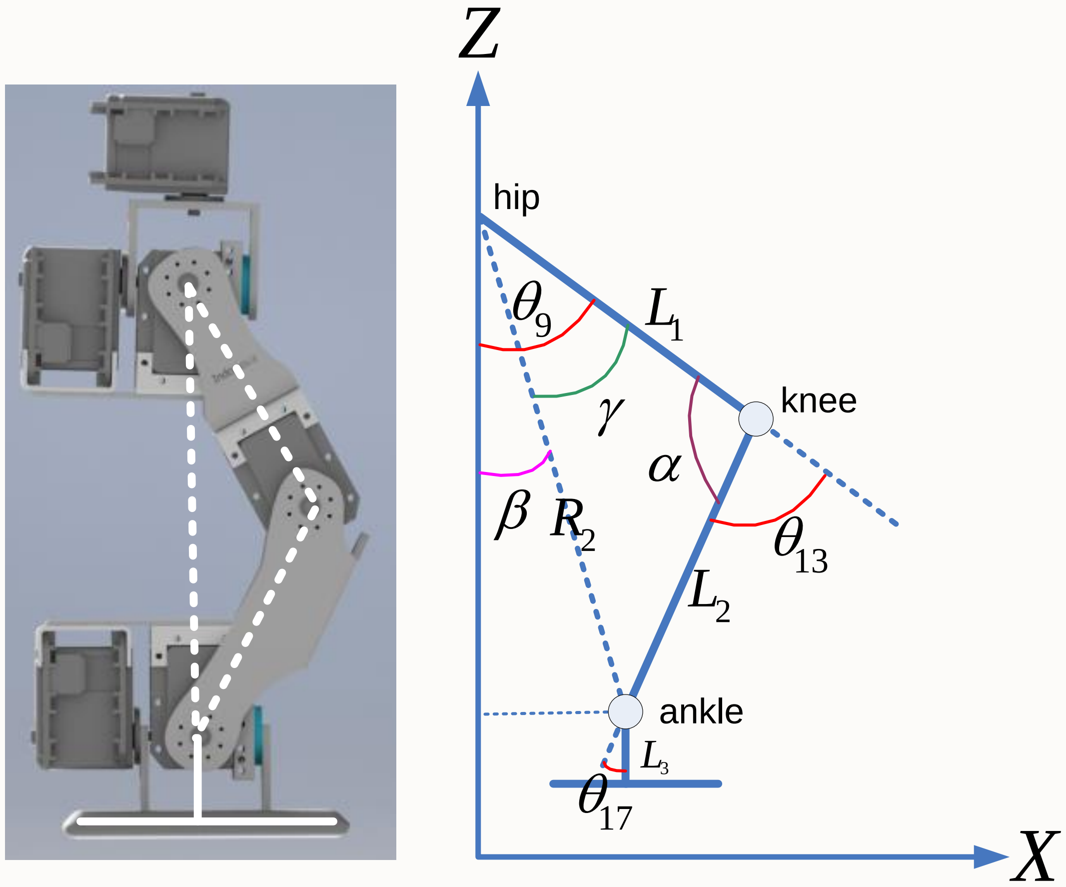

CoM position in Y-axis
position (cm/s)
time (100ms)


CoM velocity in X-axis
velocity (cm/s)
time (10ms)

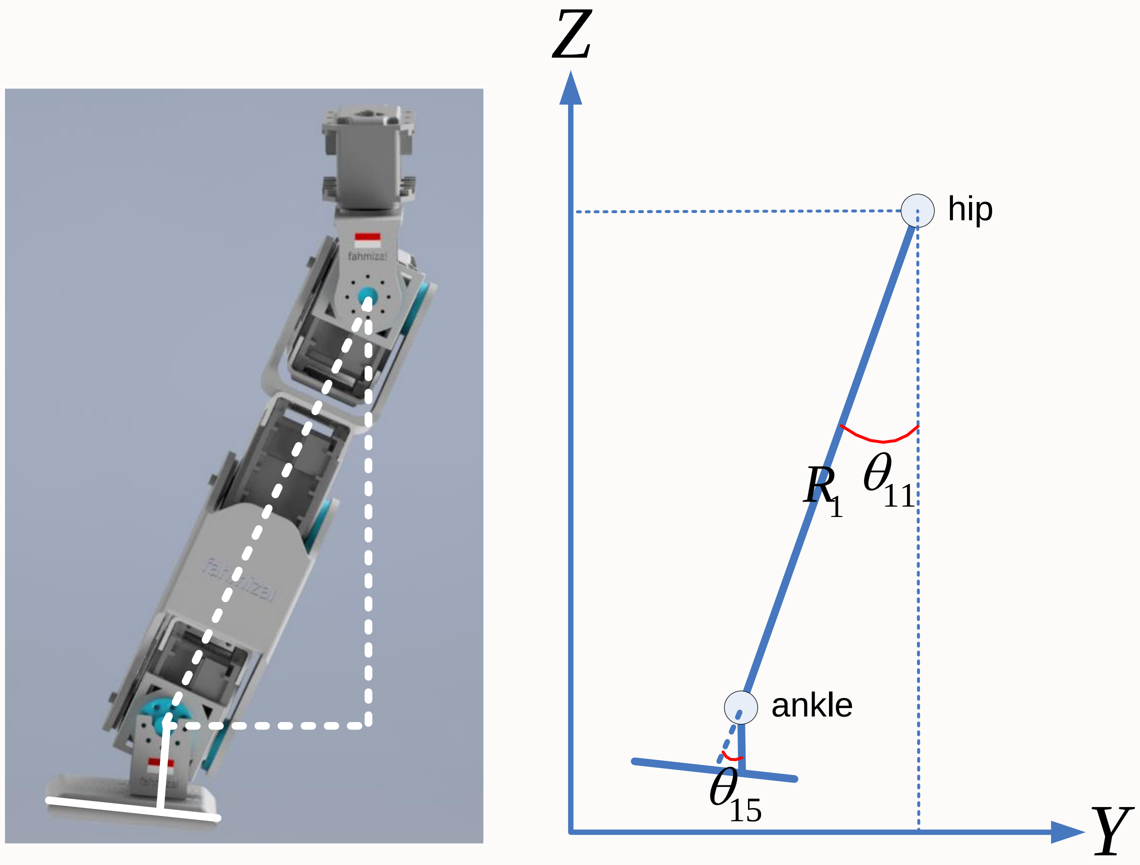

CoM velocity in Y-axis
velocity (cm/s)
time (10ms)


Linear Inverted Pendulum Trajectory
Support Foot
CoM Trajectory
Z axis (cm)
Y axis (cm)
X axis (cm)

Inverse Kinematic

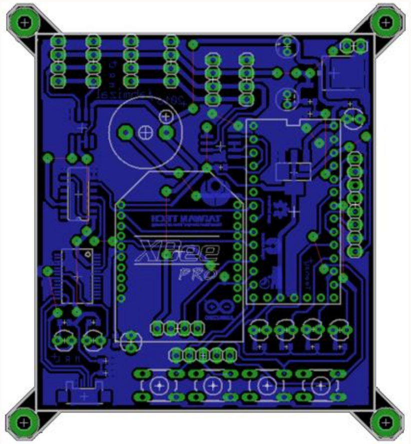


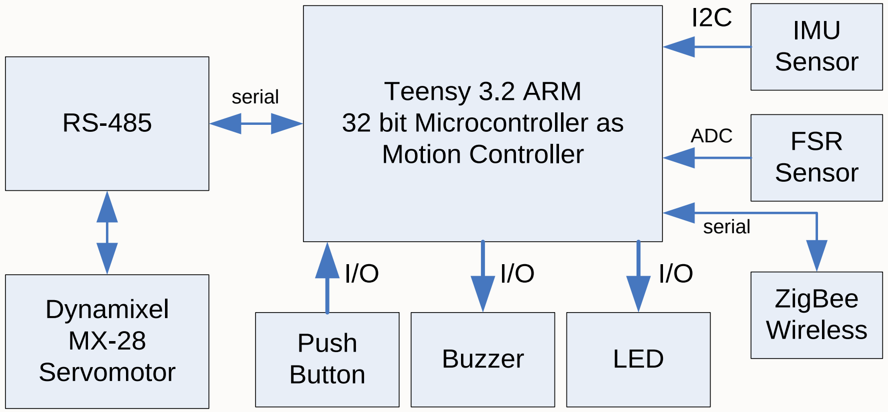
side view



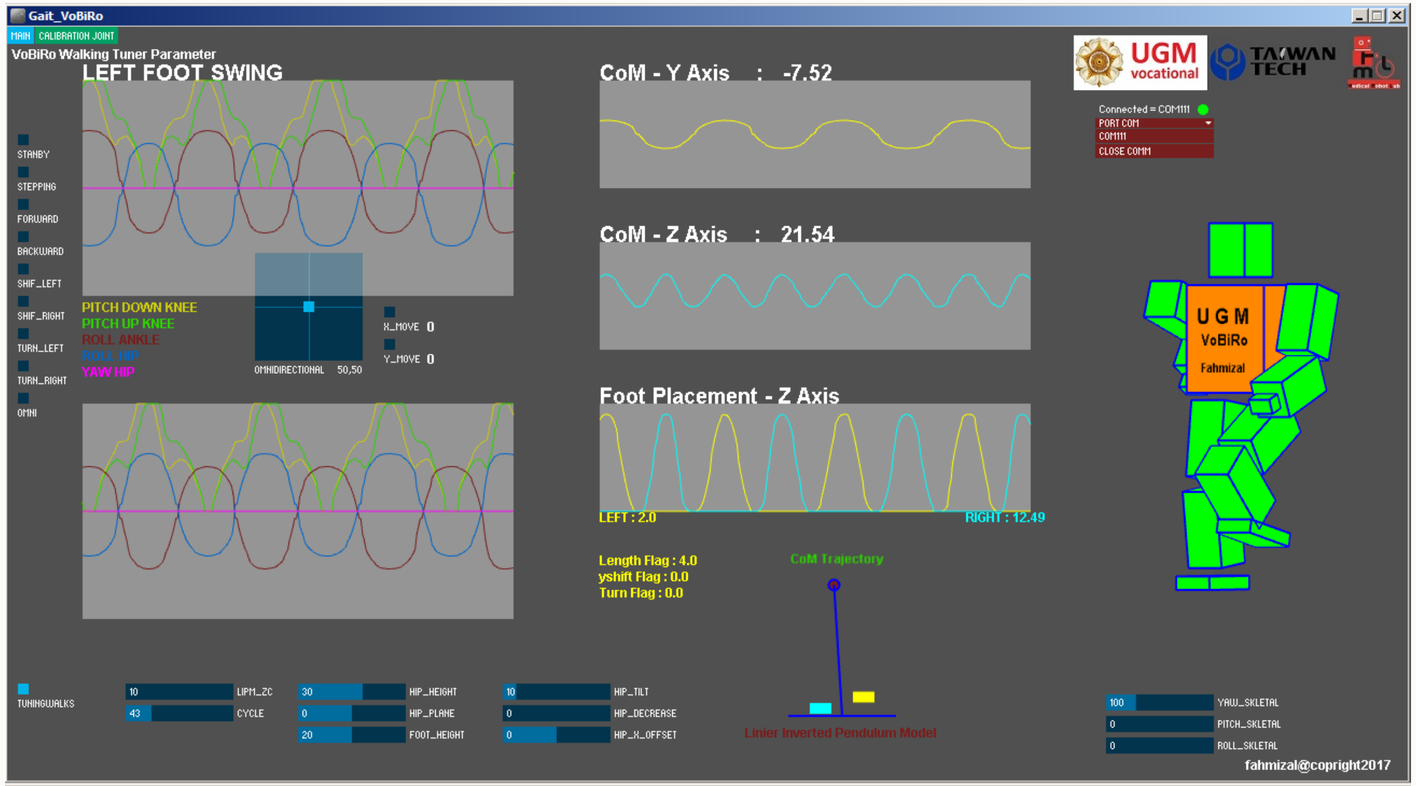
front view

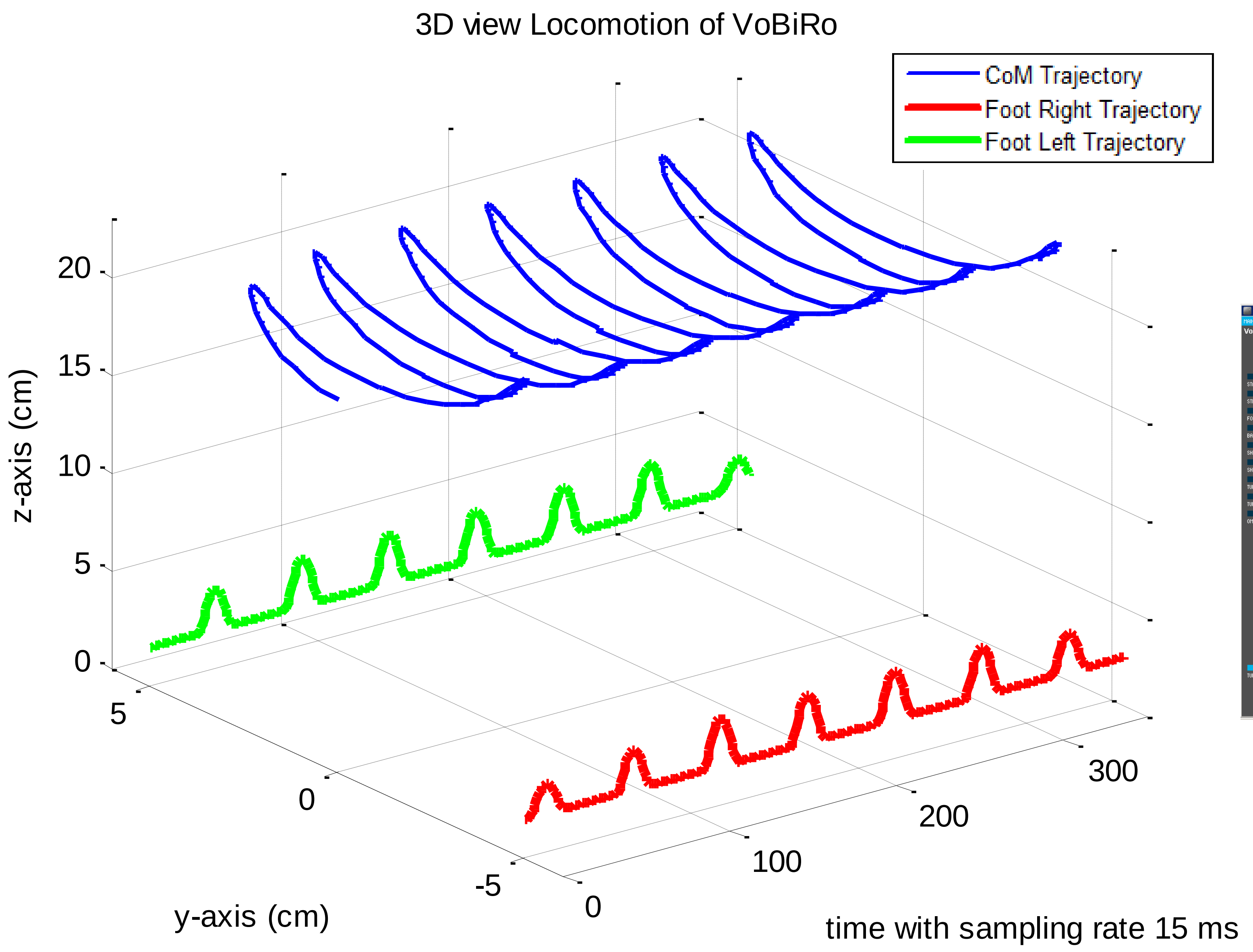
Electronic design

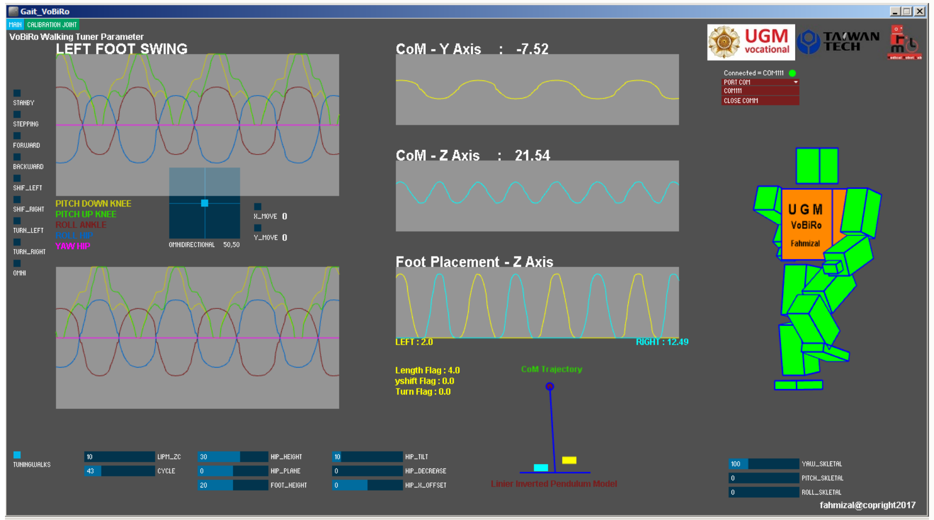




GUI




3D view Locomotion of VoBiRo
CoM Trajectory
Foot Right Trajectory
Foot Left Trajectory
z-axis (cm)
20
15
10
5
0
5
0
-5
y-axis (cm)
0
100
200
300
time with sampling rate 15 ms


LEFT FOOT SWING
CoM - Y Axis : -7.52
CoM - Z Axis : 21.54
Foot Placement - Z Axis
UGM
VoBiRo