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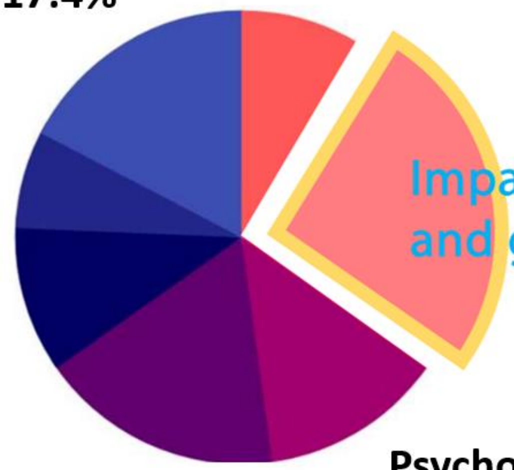
膝伸展筋トレーニングリアルタイム評価のため、非接触式筋活動推定システムの開発

Development of a non-contacting muscular activity measurement system for evaluating knee extension muscles training in real-time

BACKGROUND

- Elderly people fall each year: 28-35% (65 years old~)[1]
- The loss of muscle (Knee Extension Muscles, or KXMs) strength serves as a known factor of the falling[1][2]



Risk Factors for falls in older age

KXMs training is important.

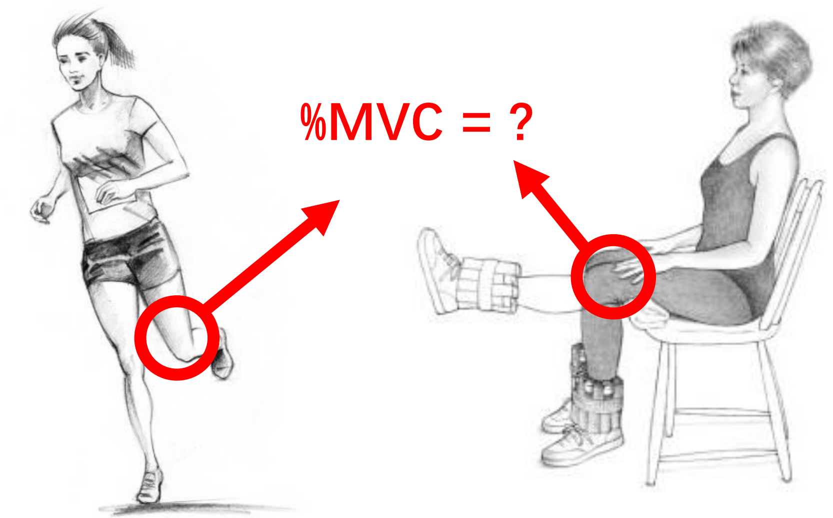
[1]World Health Organization, World Health Organization. Ageing, & Life Course Unit. (2008). WHO global report on falls prevention in older age. World Health Organization.
[2]World Health Organization(Europe), . WHO(2004). What are the main risk factors for falls amongst older people and what are the most effective interventions to prevent these falls?

BACKGROUND

Common Exercises for KXMs training[1][2]:

- Jogging
- Chair extension exercises
- Stair exercises
- …

Problem: KXMs training lacks suitable means to evaluate muscular activity



Exercises for KXMs training

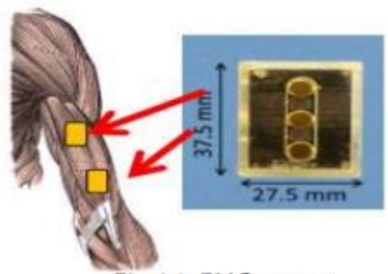
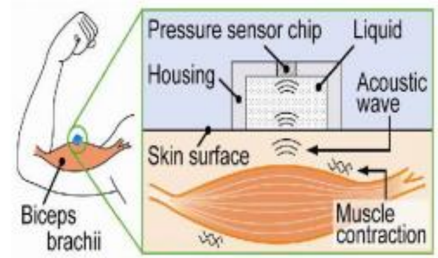
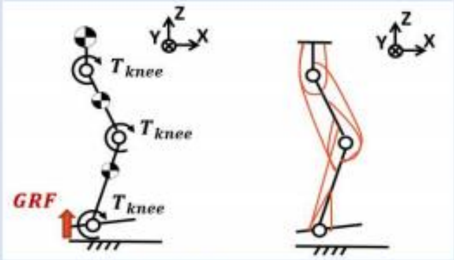
Unable to do quantitative analysis on the muscle

Objective: Developing a real time muscular monitoring system for KXMs training

[1]World Health Organization, World Health Organization. Ageing, & Life Course Unit. (2008). WHO global report on falls prevention in older age. World Health Organization.
[2] https://www.bu.edu/enact/living-well/exercise-and-arthritis/exercises/exercise-3-knee-extension/

STATE OF THE ART

- **Muscular activity evaluation**

	1.Electromyography (EMG)[1]	2.Mechanomyogram (MMG)	3.Kinematics
	 Fig.4.1: EMG sensor	 Fig.4.2: MMG sensor	 Fig.4.3: Kinematics model
Measurement	Electrical signals, Directly	Mechanical signal, Directly	Kinematic parameters, Indirectly
Sensor	sEMG	MMG	Camera, MMG, IMU
Accuracy	$R^2=0.90\pm0.02$[1]	$R^2 = 0.82\pm0.04$[2]	$R^2= 0.58$[3]
Limitation	Placement on skin, Affected by sweat	Inconvenient placement, Affected by sound noise	Affected by model and measurement

Kinematics method (Easy-to-Place) is a suitable choice for daily KXMs training

[1] Na, Y A study on estimation of joint force through isometric index finger abduction with the help of SEMG peaks for biomedical applications.
[2] Wang, Daqing(2019) Estimation of Human Quadriceps Contraction Strength Using Mechanomyogram Signal
[3] Kasai, Ritaro(2017) Development of a training system to increase knee extension load during walking -Muscular activity estimation by IMU

RESEARCH OBJECTIVE

2017

1.Muscular activity evaluation by IMU + Machine Learning[1]

	Thigh	Calf
Flat walk	✕	○
Stair walk	✕	✕

2018

2.Muscular activity evaluation by IMU[2]

	Thigh	Calf
Flat walk	✕	○
Stair walk	○	○

2019

3. Efficient KXMs training device was developed[3]

Need sensor system to evaluate thigh muscle

2020

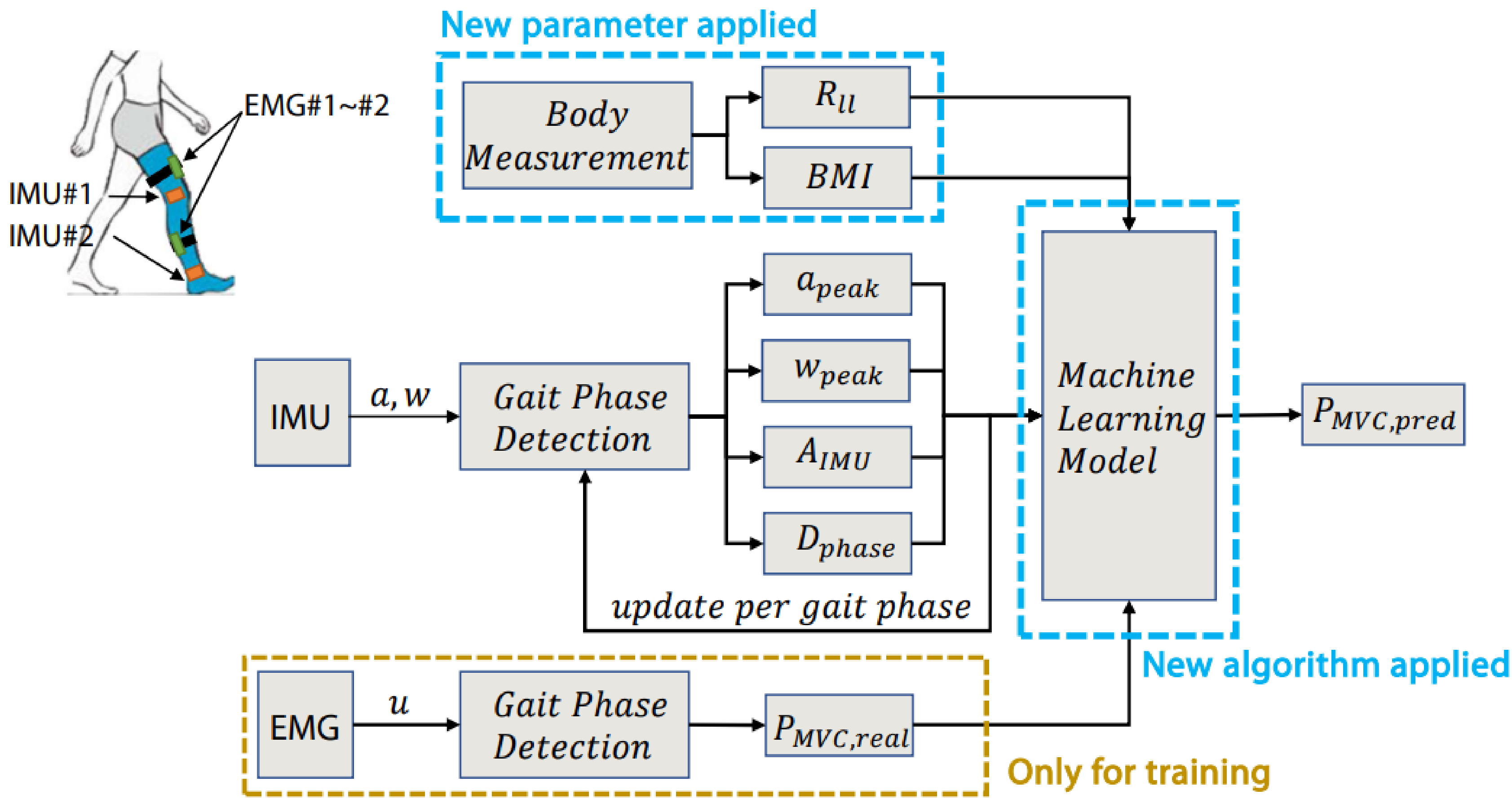
This study

A muscular activity monitoring system with the following features:

- Evaluate **thigh in flat walk**
- Evaluation with higher resolution(0-10%-20%-30%-⋯-100%)
- Real-time evaluation

[1] Kasai, Ritaro Development of a training system to increase knee extension load during walking -Muscular activity estimation by IMU.
[2] Kodama, Takuma(2017)サルコペニア予防のための運動測定システム"慣性センサと機械学習に基づく収縮強度推定手法の提案"
[3]] Z. Gu, M. S. A. Maamari, D. Zhang, Y. Kawakami, S. Cosentino and A. Takanishi, "Design and Evaluation of a Training system to Increase Knee Extension Load During Walking," 2019 IEEE International Conference on Mechatronics and Automation (ICMA), Tianjin, China, 2019, pp. 1288-1293.

SYSTEM OVERVIEW-MODEL

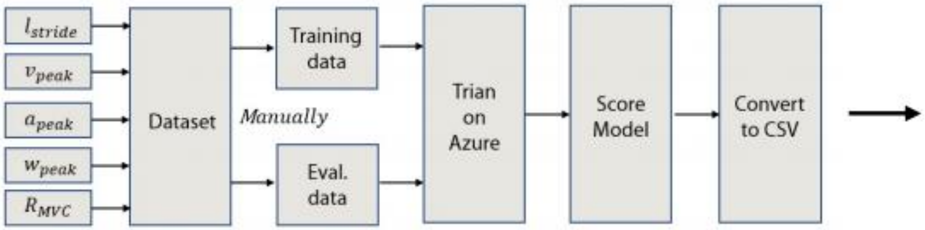


a	: Acceleration $[m/s^2]$	R_{ll}	: Lower limb ratio
w	: Angular verocity $[rad/s]$	BMI	: Body Mass Index
		a_{peak}	: Peak acceleration$[m/s^2]$
u	: $Voltage[mV]$	w_{peak}	: Peak angular verocity$[rad/s]$
		A_{IMU}	: *Area under IMU signal curve*
MVC	: *maximum voluntary contraction*	D_{phase}	: *Duration of the gait phase*$[ms]$

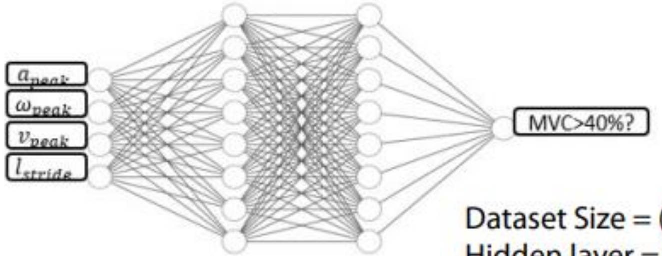
TRIAL EXPERIMENT

- Azure [1](previous) vs Local training(this study) using previous database

Previous: Train on Cloud(Azure, ANN)



This time: Train on Local(Tensorflow, ANN)



Dataset Size = (92, 5)
Hidden layer = 16

In this study, local training applied as it is more feasible for adjusting training parameters.

Result

	Platform	Cycle	Result(RMSE*)
Previous	Azure	80	9.4%
Re-do 1	Local (Tensorflow r1.15)	100	9.6%
Re-do 2		1000	3.4%
Re-do 3		100	9.3%(BMI)

$$^{*}RMSE(X,h) = \sqrt{\frac{1}{m}\sum_{i=1}^{m}(h(x_i) - y_i)^2}$$

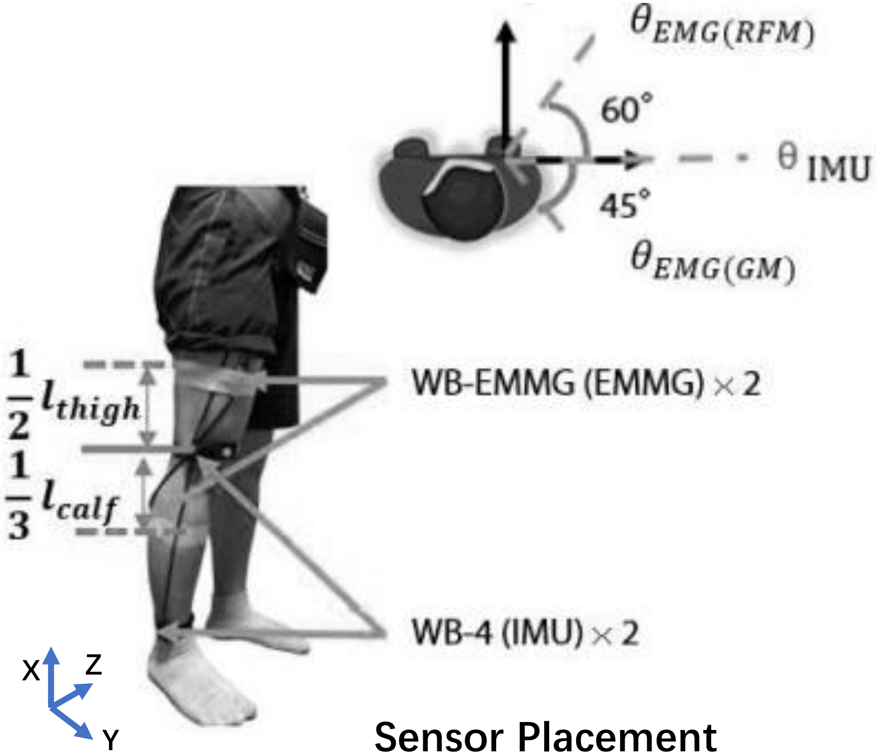
smaller is better

① Better result when consider individual difference.
② Overfitting happened when learning cycle increase.
③ More database is need.

[1] Kodama, Takuma(2017)サルコペニア予防のための運動測定システム "慣性センサと機械学習に基づく収縮強度推定手法の提案"

EXPERIMENT

❑ Objective:
- Extend database
- Evaluate algorithm

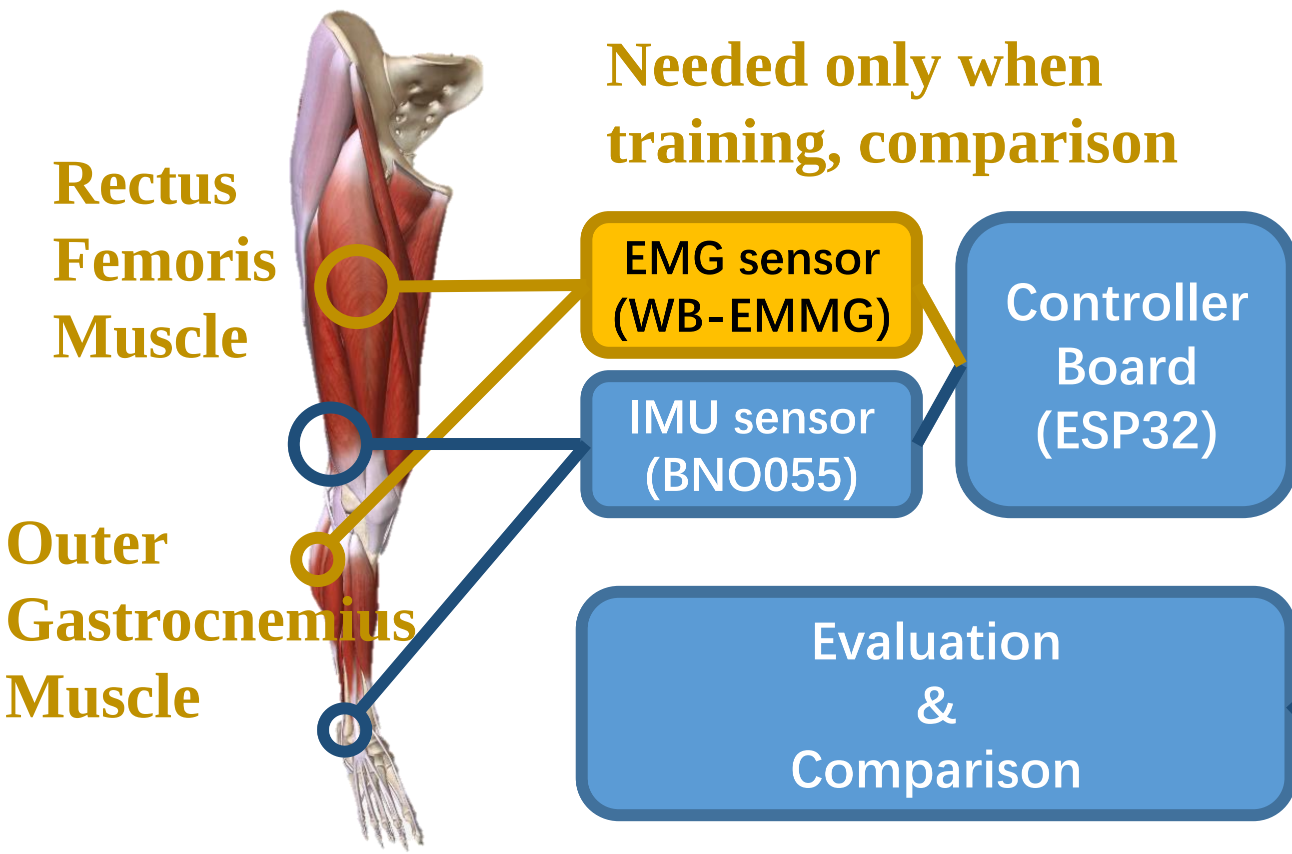


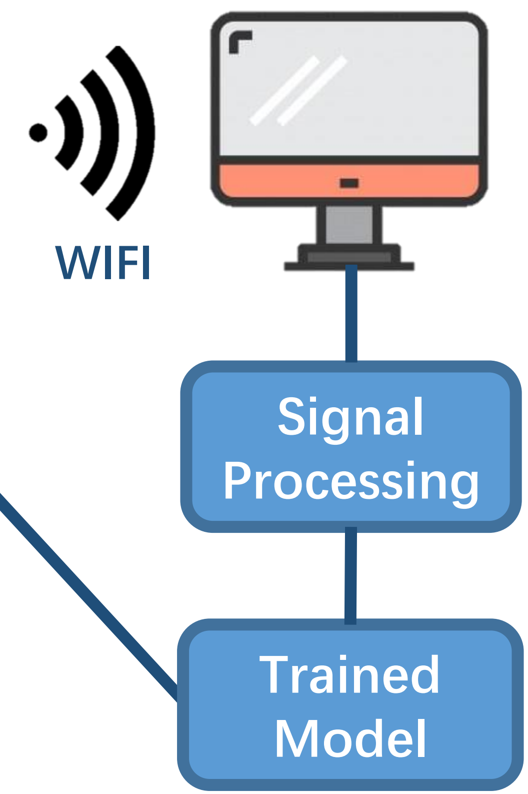
Sensor Placement

❑ Participants:
14 healthy young adults
(8 male + 6 female,
21-44 years old)

❑ Protocol:
- Body measurement(Lower limb ratio & BMI)
- Normal walk, 5[m] * 5 [times] back and forth walk: 4 [groups]
- Fast walk, 5[m] * 5 [times] back and forth walk: 4 [groups]
- MVC measurement

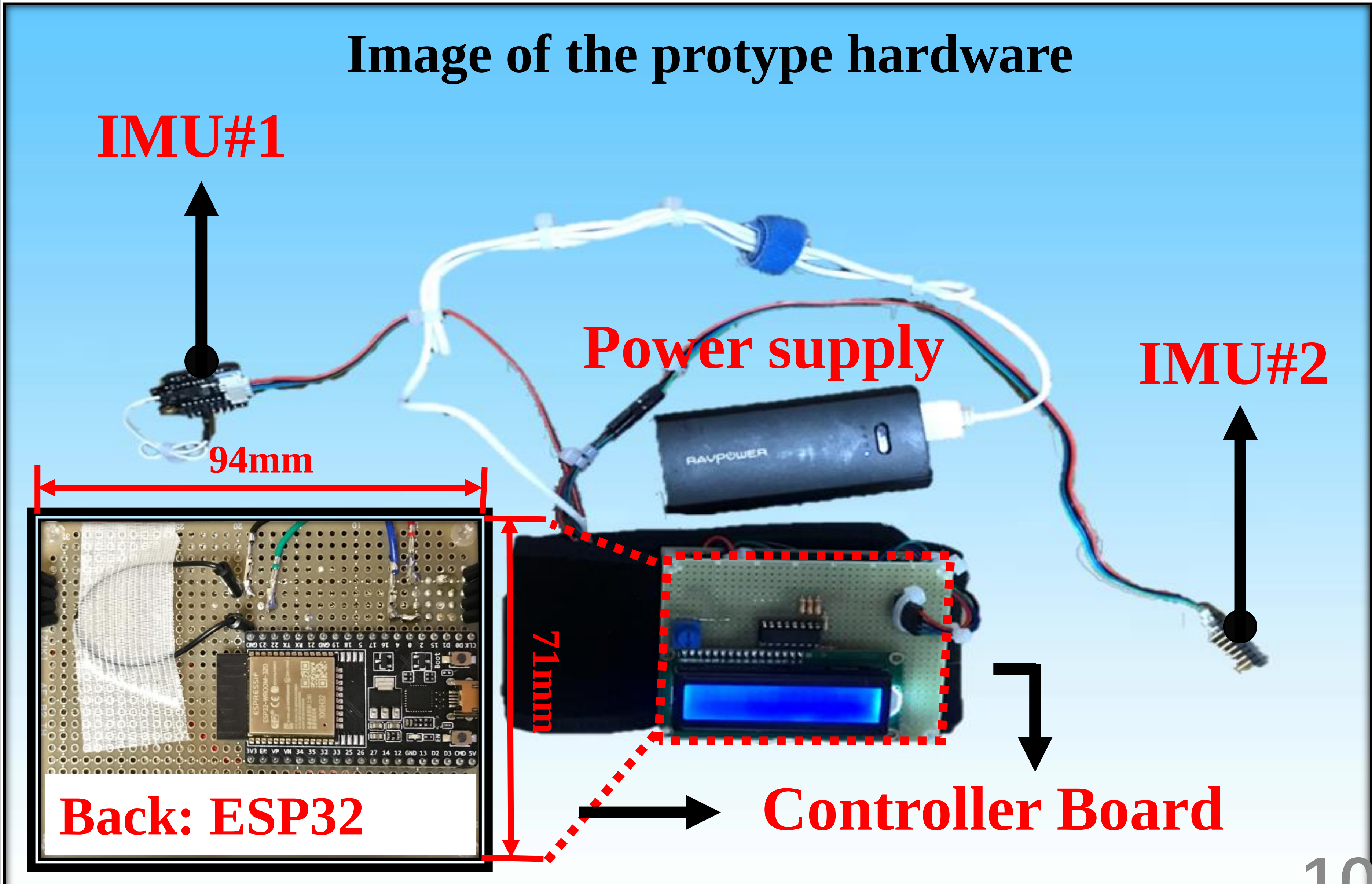
❑ Results: 649 Phases available for model training.



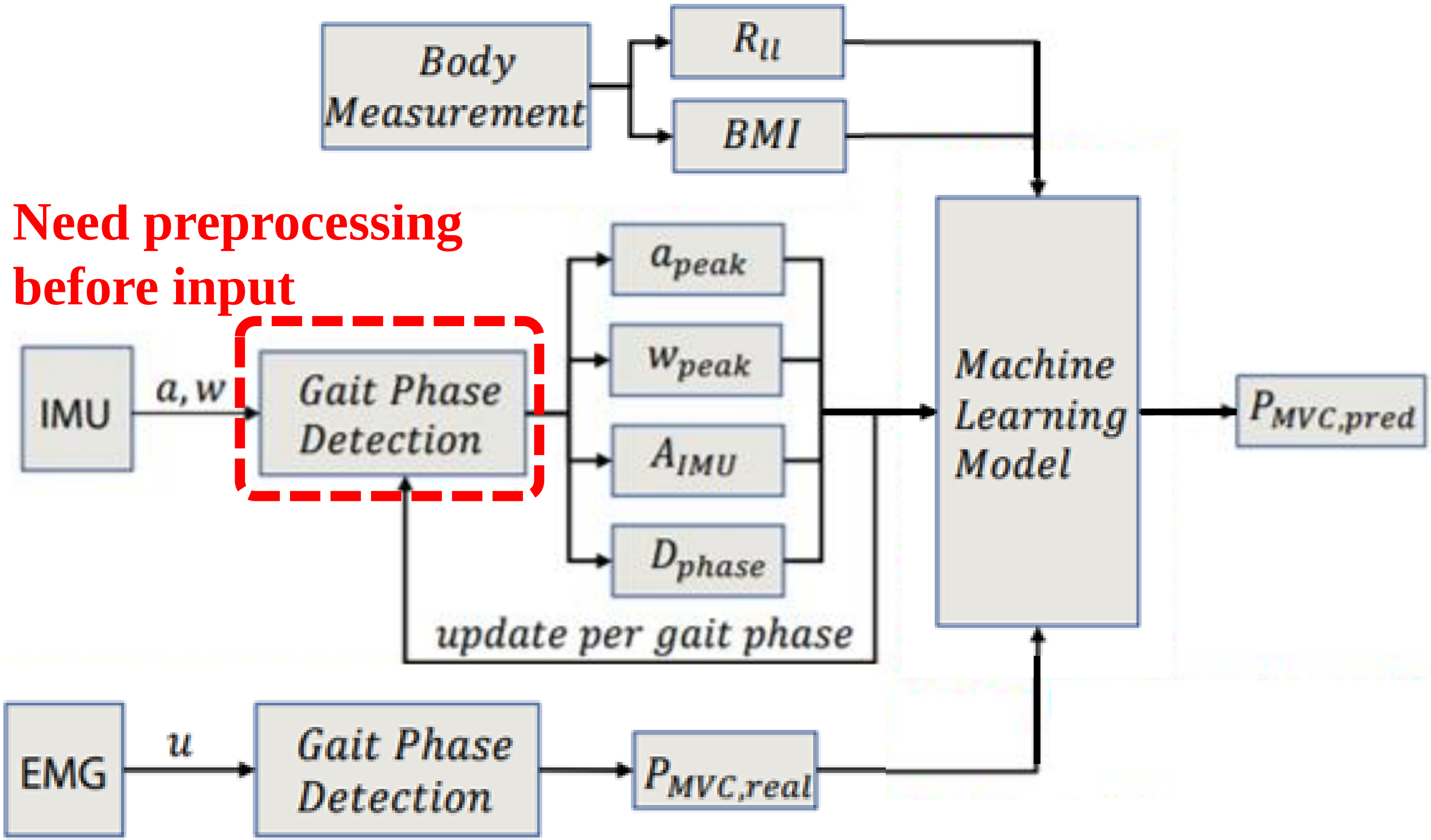


Thigh	Rectus Femoris Muscle
Calf	Outer Gastrocnemius Muscle

SYSTEM OVERVIEW-HARDWARE

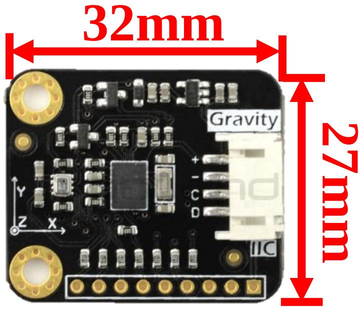


PREPROCESSING



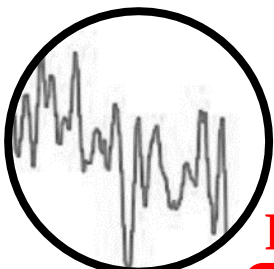
PREPROCESSING

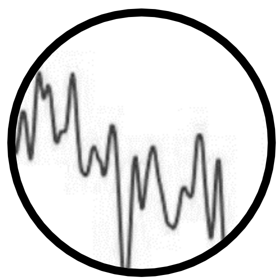
1. Signal Processing(IMU: BNO055)



Sensor	DOF	Accelerometer		Gyroscope	
		Range	Bandwidth	Range	Bandwidth
BNO055	9	±2g/±4g/±8g/±16	1k~<8 [Hz]	±125~2000 [deg/s]	523~12 [Hz]

IMU $\xrightarrow{IMU_{raw}}$ *Gaussian Smoothing Filter* $\xrightarrow{IMU_{gaus}}$ *Polynomial detrending Filter* $\xrightarrow{IMU_{detrend}}$

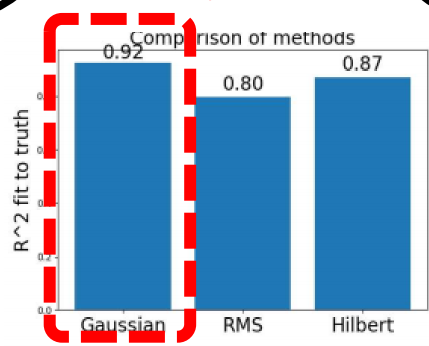




*IMU signal change

Denoising Filter Performance Comparison

$R^2 = 0.92$



Gaussian Smoothing Filter:

$$Kernel:\ g = e^{\frac{-4\ln(2)t^2}{w^2}} \quad Filter:\ y_t = \sum_{i=t-k}^{t+k} x_i g_i$$

PREPROCESSING

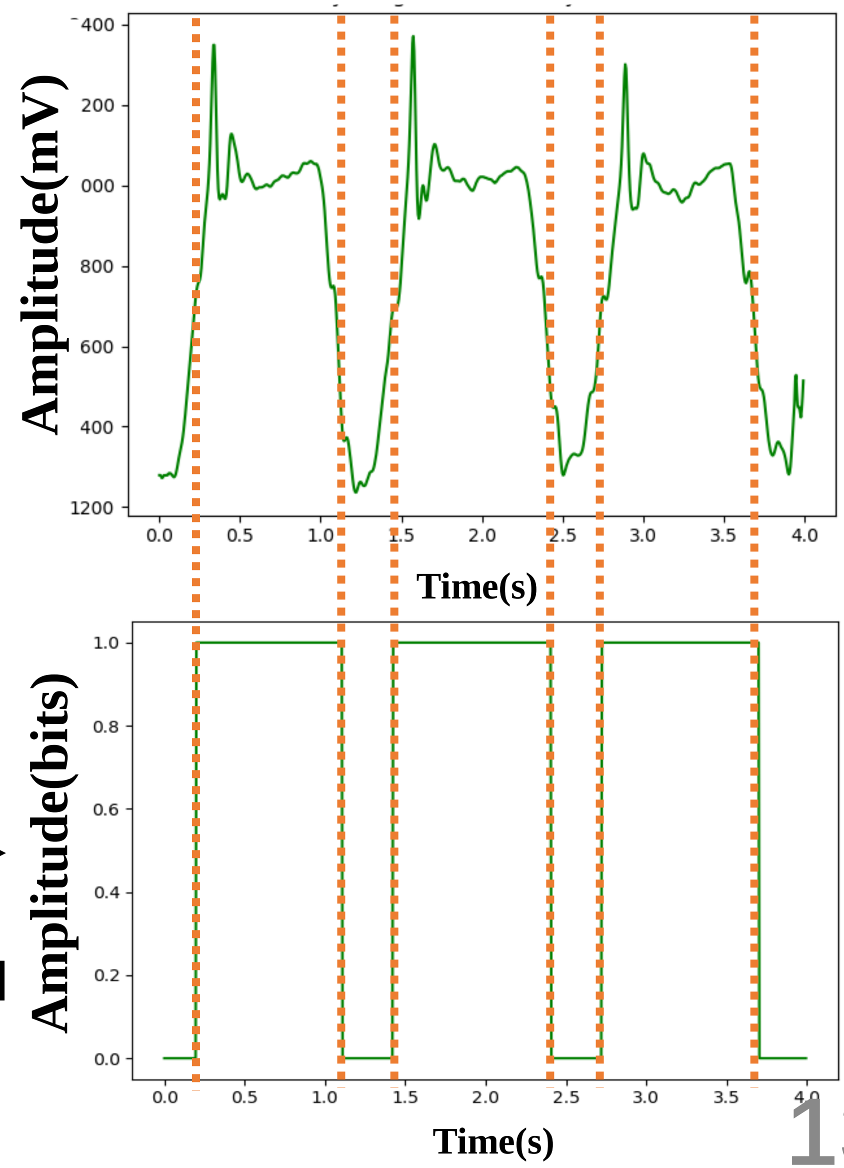
2. Gait Phase detect

Gait phase separated by Threshold, Then turn to digital signal

Featured parameter calculation

a_{peak}	**Peak acceleration [m/s²]**
w_{peak}	**Peak angular velocity [rad/s]**
A_{IMU}	**Area under IMU signal curve[mV*s]**
D_{phase}	**Duration of the gait phase [ms]**

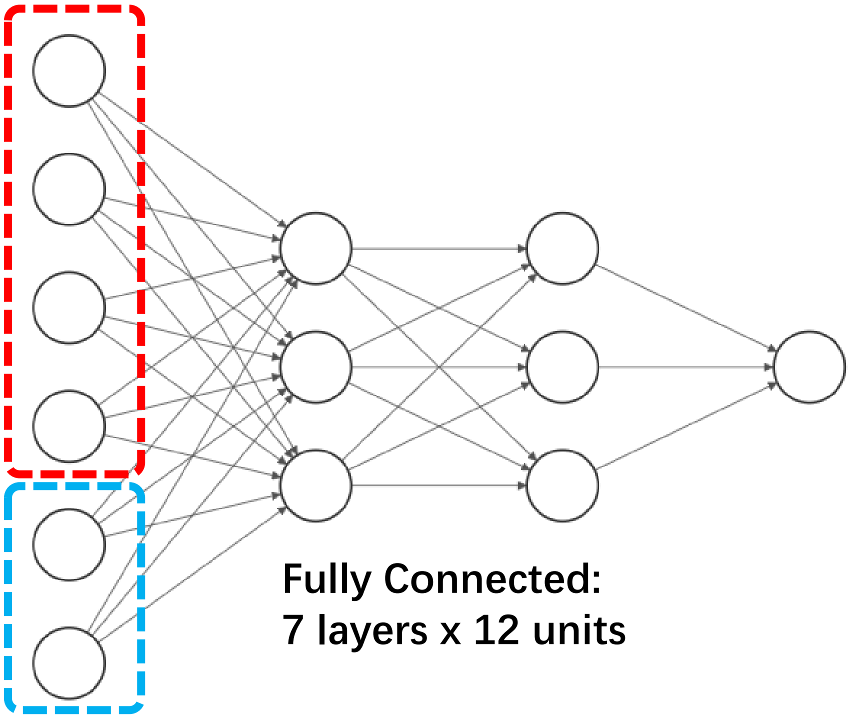
GyrZ signal collected by IMU



MODEL OPTIMIZATION

1. Hyper-parameter Selection

Featured kinematics inputs(via IMU): [4,649]



Fully Connected:
7 layers x 12 units

Individual Differences(via Body measurement): [2,649]

Objective: optimize model's performance by adjusting hyper-parameter

Hyper-Parameter adjusted with *GridSearchCV* method

n_HiddenLayer	7
n_NeuronUnit	12
act_Func	'relu'
Optimizer	'Adam'
loss_Func	' logcosh'

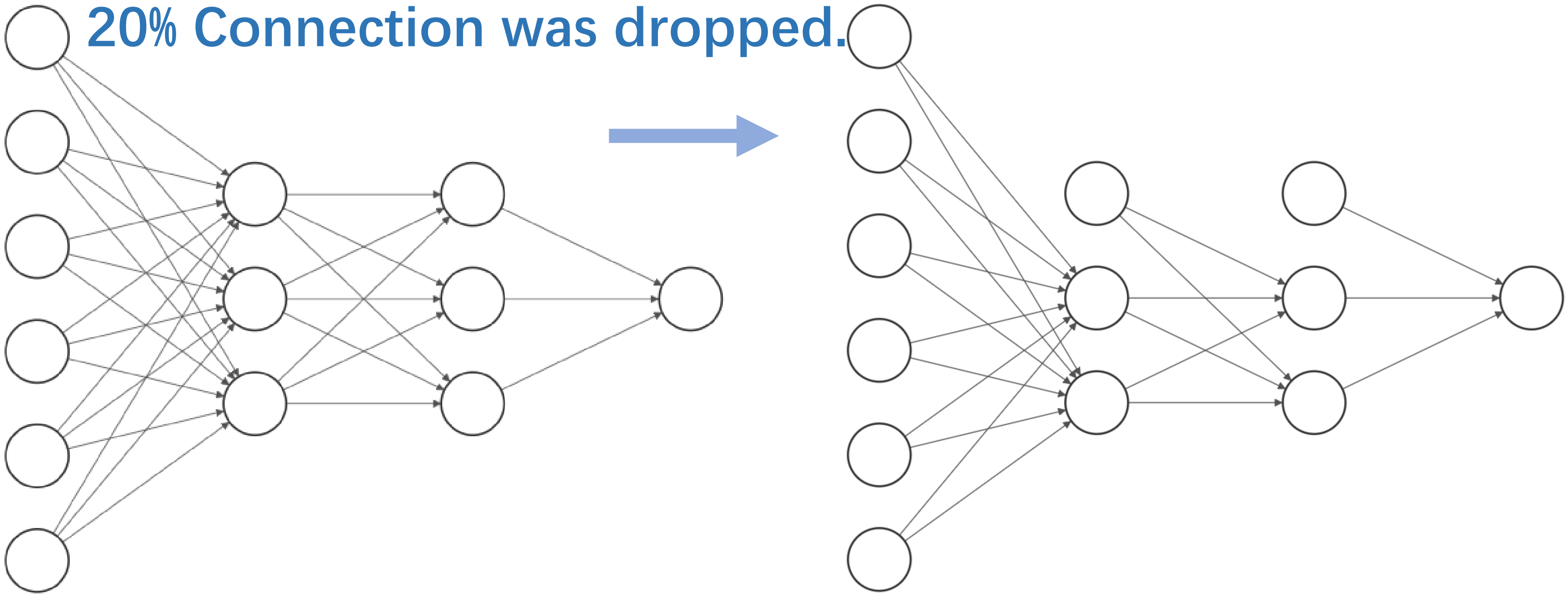
*Environment:
-Python 3.6.5
-CUDA 10.0
-Tensorflow 2.0.0
-Keras 2.3.1

Result: Performance was improved by 6.4% in average

MODEL OPTIMIZATION

2. Random Connection Dropping(Dropout)

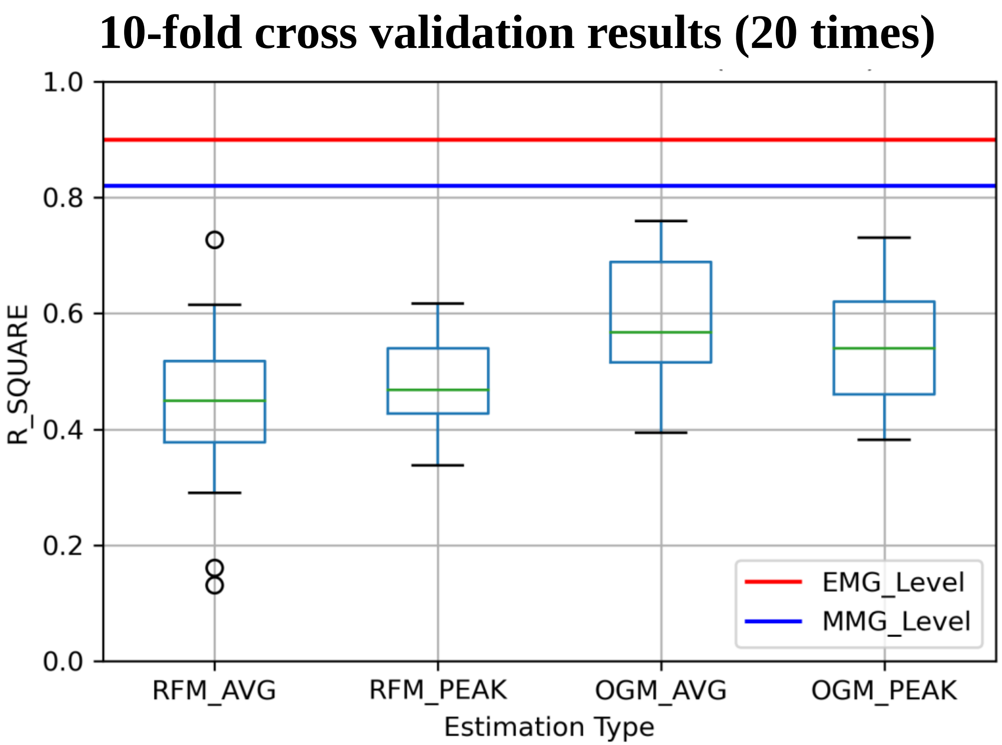
Objective: prevent over-fitting happened (generalization ability reduce)



Result: performance difference between training data and testing data drop from 20%~40% to < 5%

Results

1.Model Performance boxplot



2.Real-time Performance(Latency):

For 1 gait phase

Processing (PC)	Wireless	Total
72 [ms]	120 [ms]	192 [ms]

*Regular frequency of human stride:

1[Hz] ~ 4[Hz]

=>

250 [ms] ~ 1000[ms]

		2021.1 Model (BNO055)	EMG sensor	MMG sensor
MVC value estimation (Regression) Evaluation index: R Square (10-Fold cross validation, higher R^2 shows better results)	MVC_{AVG}(RFM)	0.48	0.90 ±0.02	0.82 ±0.04
	MVC_{Peak}(RFM)	0.47		
	MVC_{AVG}(OGM)	0.58		
	MVC_{Peak}(OGM)	0.55		

Results

Conclusion:

- Quantitative estimation for lower limb muscular activity (flat walk) in a high accuracy($r^2 > 0.5$).
- Real time estimation

Limitation:

- Model trained by EMG sensor data, data scale & EMG accuracy limit further performance improvement.
- Preprocessing calculation made the system need powerful hardware or latency increase.

Future work

- Performance improvement:
  - 1. Merge multiple sensor data to break the limit of only using single type sensor(Not just EMG).
  - 2. Extend application scenario(more complicate exercise & specific object group).
- Real time estimation:
  - 1. Simplifying algorithm to decrease calculation difficulty.
  - 2. Trying model no need gait phase detection.

THANK YOU FOR YOUR ATTENTION