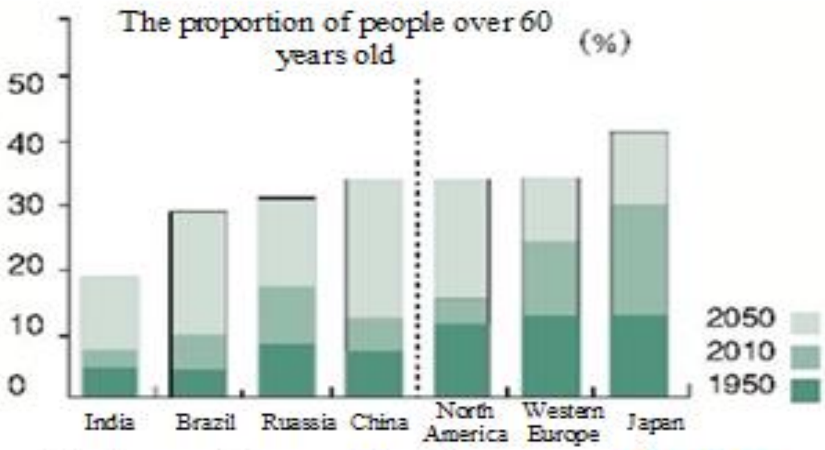
Lecture 12 Typical Intelligent Robots of XJTU2-Rehabilitation Robot based on EEG and EMG

12.1 Rehabilitation robot functions -1

1 Background



Aging of population ——stroke

Accident——brain trauma, spinal injury

- **Illness and accidents cause central nerve injury, which brings about masses of lower limb disorders;**
- **According to the neuro-function remodeling theory, exercise training can restore the patients’ walking abilities.**

12.1 Rehabilitation robot functions -2

Traditional rehabilitation

Lower limb rehabilitation robot

Disadvantages of tradition

- Need assistance of at least 2-3 Rehabilitation specialists;
- Intensive labor work and inadequate amount of training;
- Performance depends on experience of specialists;
- High cost.

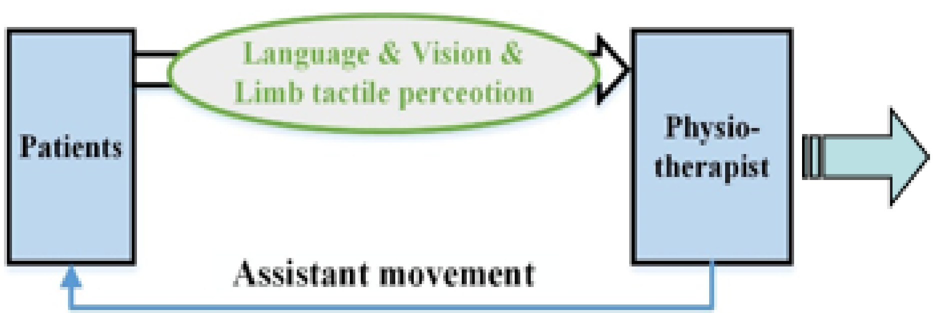
Rehabilitation robot

- No fatigue;
- Training parameters are precisely controlled and recorded;
- One-to-many, remote guidance and lower cost;
- Better rehabilitative performance.

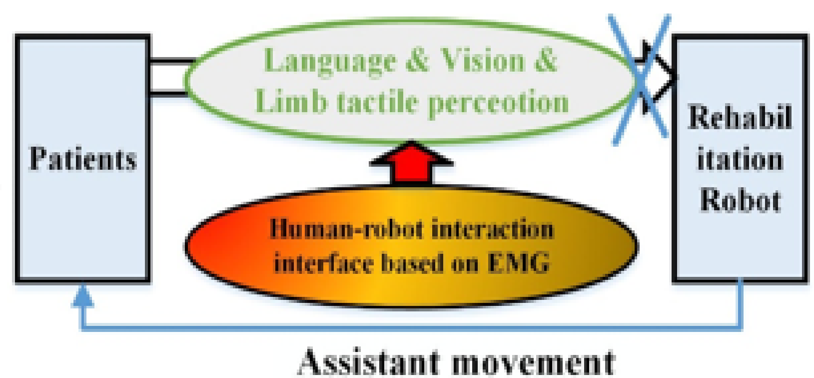
12.1 Rehabilitation robot functions-3

Training timeliness and training frequency;
The orientation of the training task;
The level of patient's involvement;
Assist-as-needed.

Achieving active guidance and assist-as-needed training in the middle and late stages of rehabilitation can greatly improve the rehabilitation effect, and is also a key issue to solve problems of lower limb rehabilitation robots.

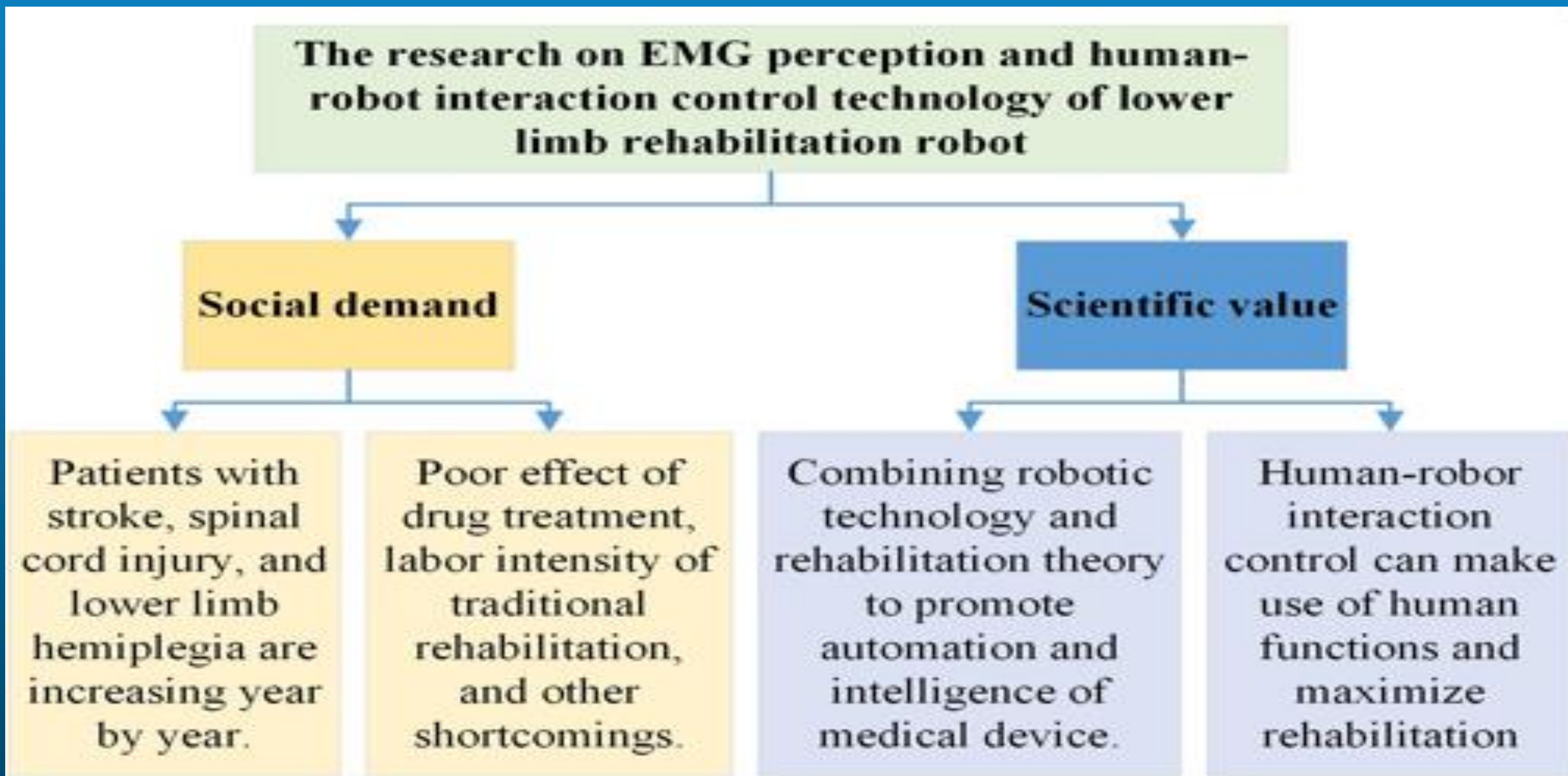


Traditional artificial rehabilitation training



Robot rehabilitation training

12.1 Rehabilitation robot functions -4

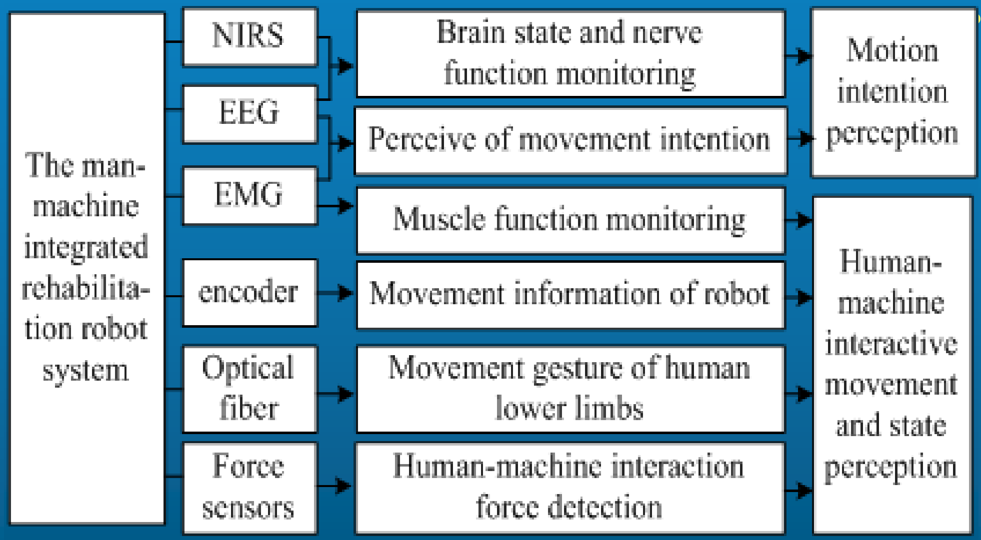


The research of EMG perception method and human-robot interaction control strategy of lower limb rehabilitation robot is an effective way to solve the those problems. From the perspective of social demand and scientific value, the EMG perception and human-robot interaction control technology of lower limb rehabilitation robot has important significance.

12.2 The composition of the perceptual system -1

- The rehabilitation robot we designed is a bed-type rehabilitation robot which is comprised of the robot bed and training mechanism (exoskeleton).
- In the rehabilitation training progress, the patient is lying on the bed whose tilt angle can be adjusted from a horizontal position to 80 degrees.
- The bed will support a portion of patients' weight and the weight supported by the bed will changed with the bed tilt angle for the different training phase.
- The upper body of patient was fixed by security fixtures in chest and the lower limbs are fixed with lower extremity exoskeleton.
- The bed rose mechanism is designed to increase the versatility of the system. The design of the overall system meets the ergonomic requirements and according the principle of non-interference between the bed and the skeletal system. The structure design of lower extremity exoskeleton is a core part in the rehabilitation robot design. Especially, the configuration of exoskeleton directly affects its gait simulation capabilities, and affects the realization of the final function.

12.2 The composition of the perceptual system -2



Previous studies show that the active participation of the patient in the rehabilitation can greatly speed up the rehabilitation. Therefore, in order to get a satisfaction result, we can try to get the active movement intention from the people which used as control commands. In addition, the rehabilitation level of the patient's should be assessed in real-time in order to determine the training model and training parameters.

- **All of the above relies on a strong perception ability of the robot. The perceptual system of lower limb rehabilitation robot can be divided into the human movement intention perception and human-machine interaction movement and status perception.**
- **The perceptual system includes a variety of bioelectrical signals, such as EEG, EMG, oxygen, and physical signals such as the joint's angle and the interaction force between human and machine. Therefore, this perceptual system is a typical multi-source information perception system and effective information fusion algorithms are required. The following describes the signal detection methods and the integration of multi-sensor network.**

12.3 Signals detection methods -1

- The movement intention and behavior of the human brain can be read from the brain electrical signals, so we collect 16-channels EEG single as the source of information.
- Ag/AgCl wet electrodes were used to recoding EEG signals in traditional, it should be used with the conductive glue, not only time consuming but also easy to fall in movement.Therefore, in our project we adopt non-contact capacitive dry electrodes which completely avoid the ohmic contact with the skin. The EEG signals can be collected across the hair by capacitive coupling.
- Except making the electrodes, the signal conditioning circuit through which the electrodes are connected to Neuroscan collector was designed, and finally the signals among the movements are collected reliably.
- This collection method for EEG signals has the merits of simple device, easy to operate, less limited by the use of the environment, and high time resolution, record lossless and so on.
- In addition, the brain oxygen status is detected by near-infrared spectroscopy, which can greatly enhance the perception of the brain state with the EEG and has an important role in the functional assessment after brain injury.

12.3 Signals detection methods -2

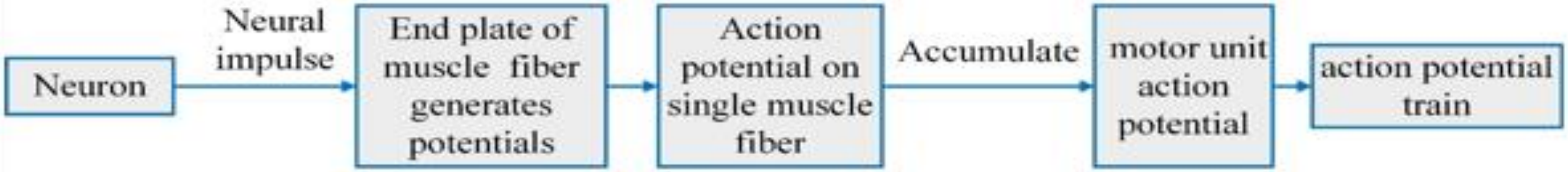
- The man-machine interface based on EMG signal is the main man-machine interface technology. The joint force, position, muscle function can be got through EMG signal detection and analysis, that is useful for the state perception and the assessment of rehabilitation level. The EMG signals can be collected by electrodes on the skin or the electrodes inserted into the interior of the muscle belly. We adapt the skin electrodes for the noninvasive and security of the experiment.
- For the purpose of high motion and posture perception accuracy, the human motion is measured using grating optical fiber. The approach is that, the fiber-optic sensors are fixed to the body's extremities according to the physiological and structure of human; the optical fiber in the fiber optic sensors are bended with the joints' movement, then the bending angles are calculated by measuring the rate of light guide of the optical fiber, based on these, the angle and direction of each joint of the limbs are obtained as well as the move trends of the body.

12.3 Signals detection methods -3

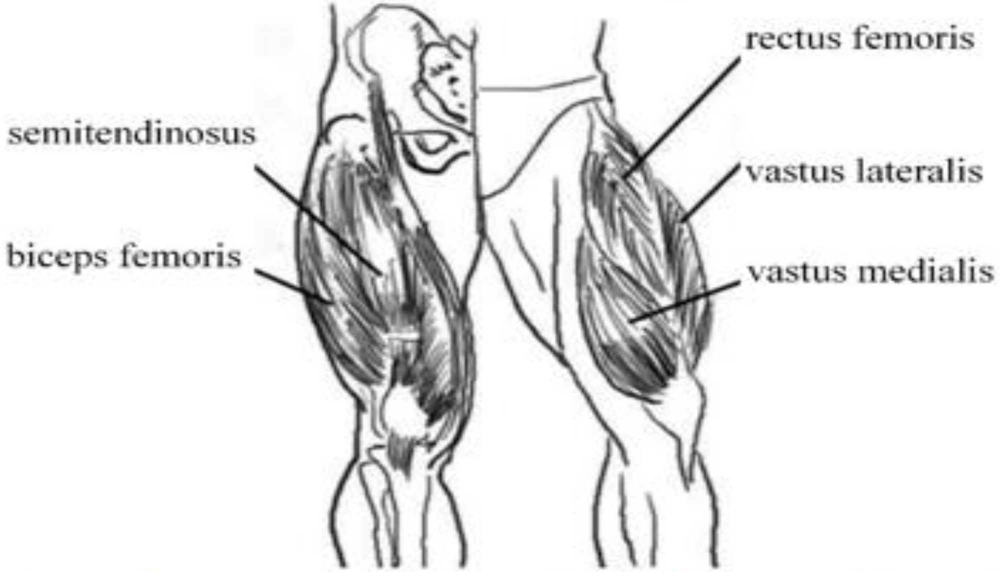
- In the training progress, safe physical interaction between human and machine is the important guarantee to ensure that patients away from harm. The force on patients applied by the robot under any movements must be mild and flexible and can not exceed force that patients could generate for protecting themselves. Therefore, the measurement of interaction forces between human and machine is necessary. In our design of robot, force sensors made of piezoelectric film are installed in all human-machine interfaces where has contact, the sensors used have features of high sampling frequency and high accuracy.
- Besides the signals detected of the above, the motion information of the robot itself is also to be measured. Especially, the robot joints' angles information is measured through photoelectric encoders mounted on the actuators. The encoders we used are incremental encoders, and have the advantages of high reliability, simple structure principle, anti-interference ability, long mechanical life and can be long-distance transmission.

12.3 Signals detection methods -4

1 The detection system and method of EMG



Principle of EMG generation



Selection of measurement points for human lower limb muscle

12.3 Signals detection methods -5

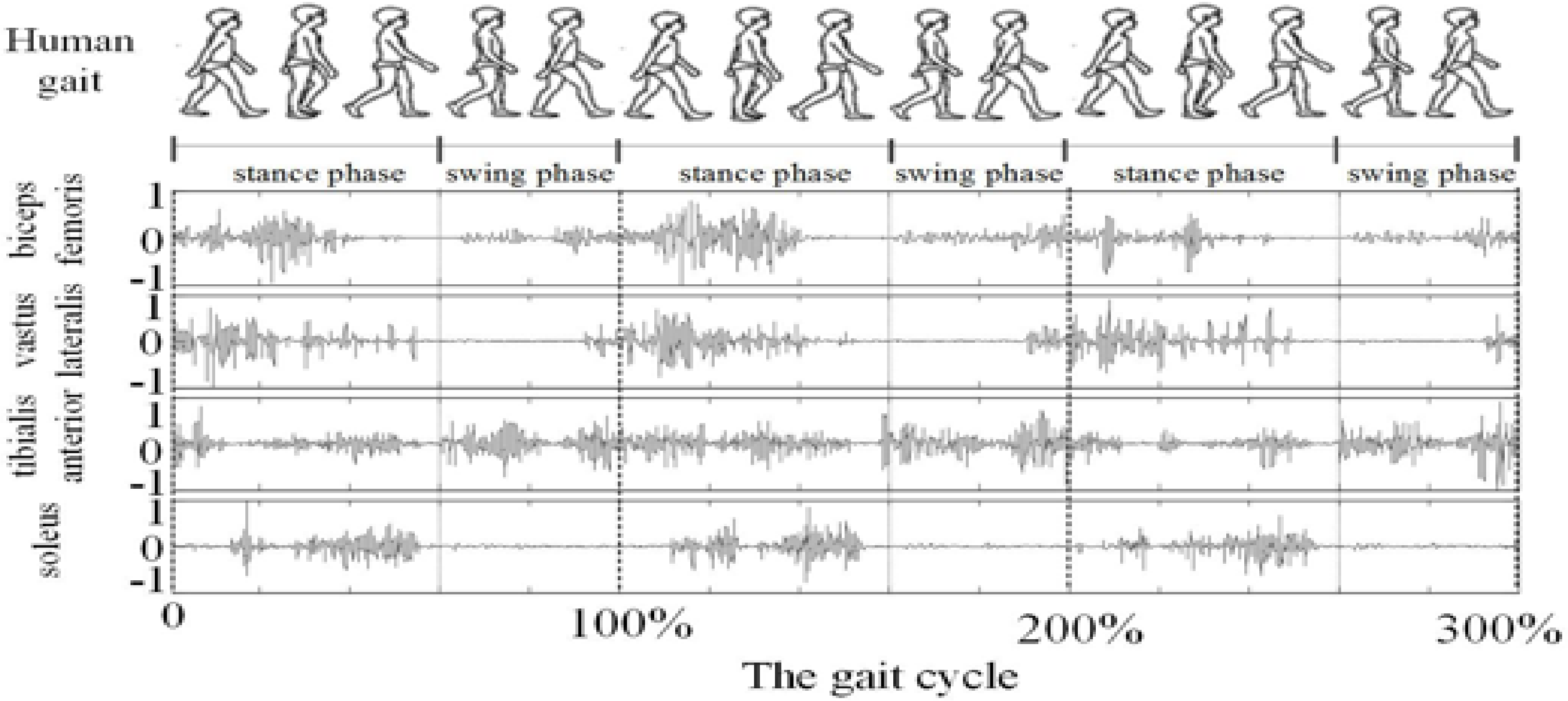
Hardware composition of the EMG acquisition system

Notice

To ensure the conductivity between the skin and the electrode, rub the skin surface repeatedly with medical alcohol to remove grease before pasting the electrodes. Besides, preheat the sEMG equipment for 30 minutes.

12.3 Signals detection methods -6

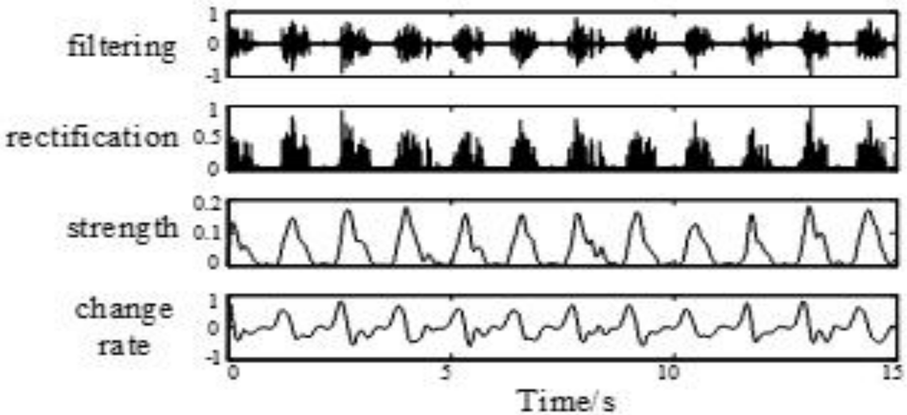
Fast recognition of gait events



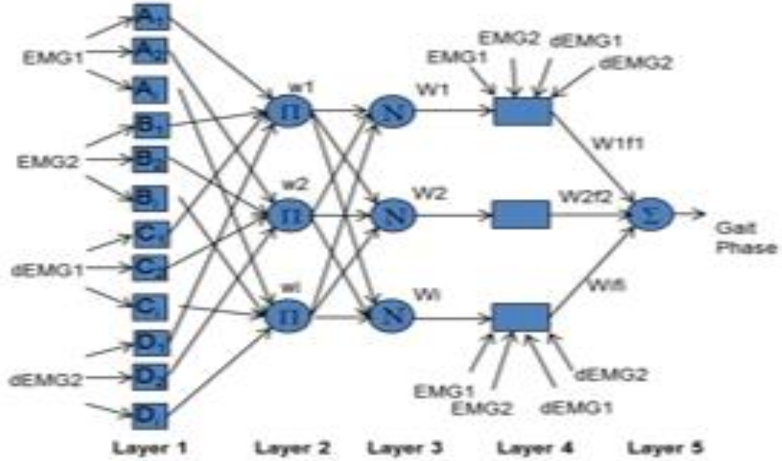
The typical sEMG on skeletal muscle and gait event in gait cycle

Perception principle of gait event

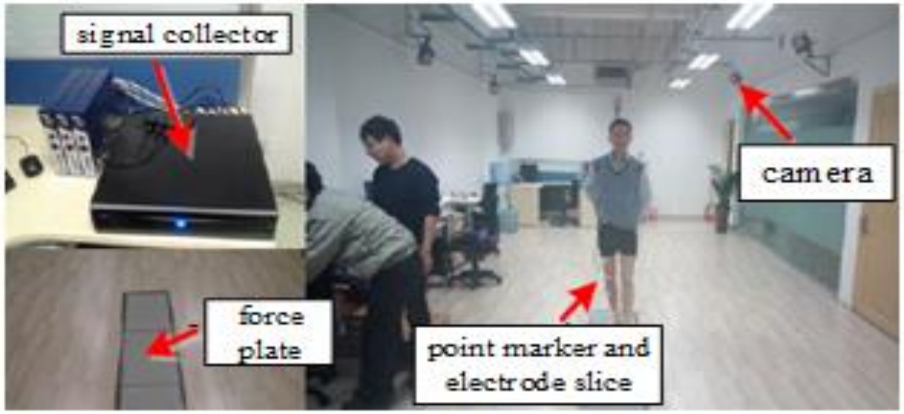
12.3 Signals detection methods -7



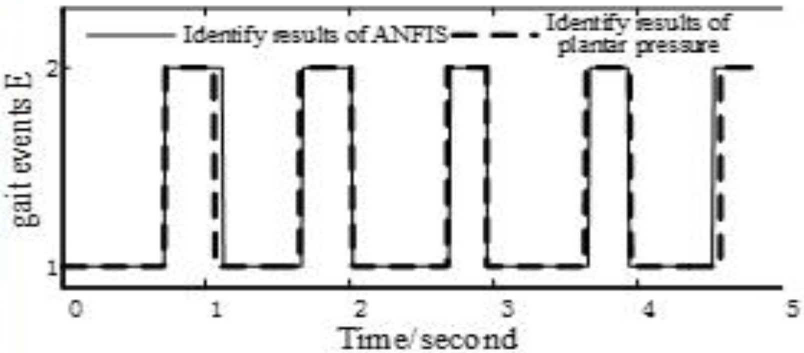
Feature extraction



Fast recognition of gait events based on NAFIS



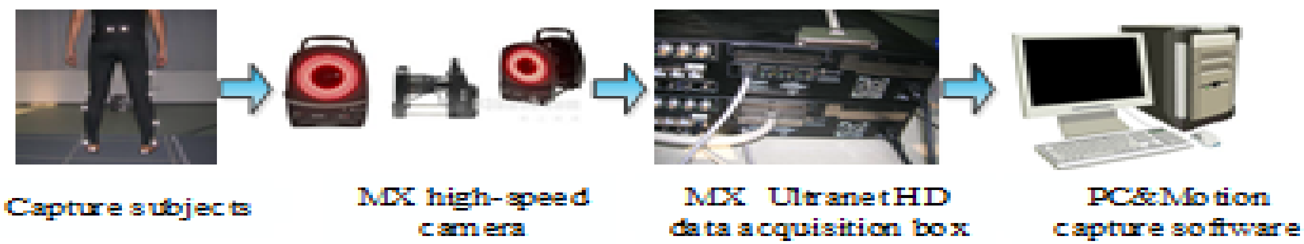
Experimental scene



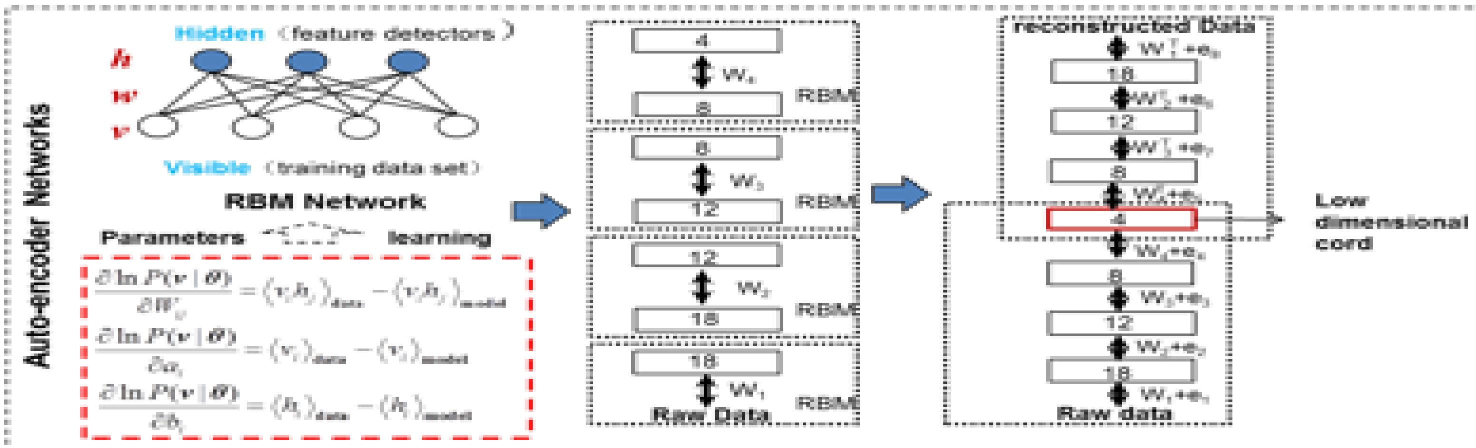
Results

12.3 Signals detection methods -8

3 Continuous Decoding of Lower Limb Joint Angles

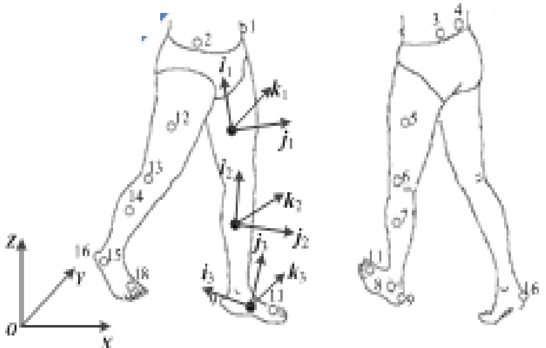


Optical capture method for lower limb movement



Dimension reduction of multi-channel semg
Based on deep learning

12.3 Signals detection methods -9

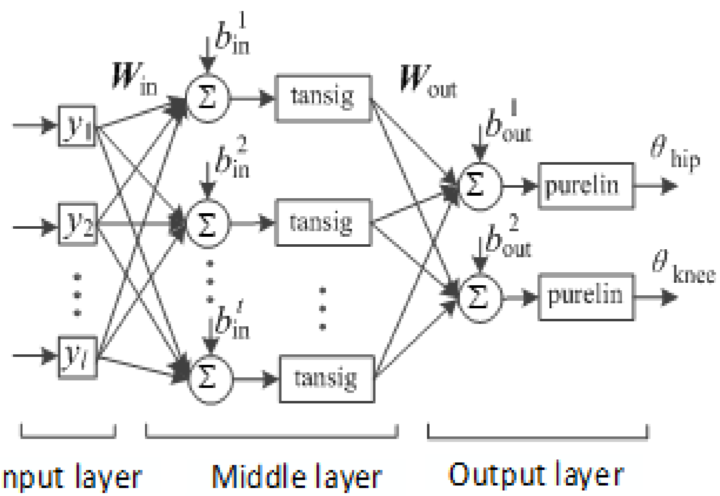


$$\alpha_{hip} = \sin^{-1}[\boldsymbol{l}_{hip} \cdot \boldsymbol{i}_{pelvis}]$$
$$\beta_{hip} = -\sin^{-1}[\boldsymbol{k}_{Pelvis} \cdot \boldsymbol{i}_1]$$
$$\gamma_{hip} = \sin^{-1}[\boldsymbol{l}_{hip} \cdot \boldsymbol{k}_1]$$

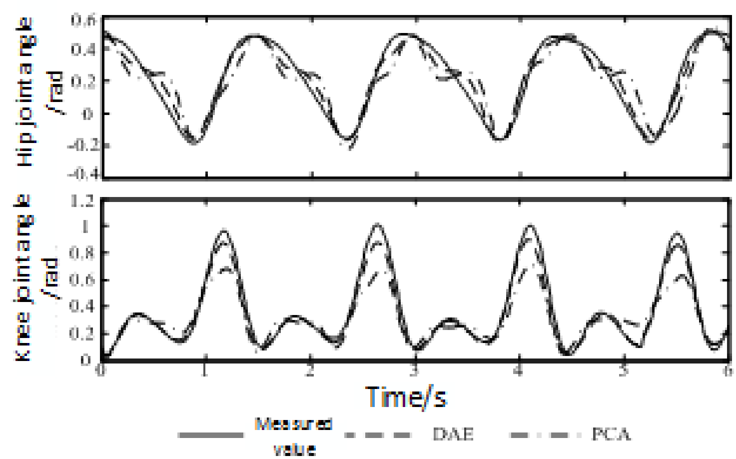
$$\alpha_{knee} = -\sin^{-1}[\boldsymbol{l}_{knee} \cdot \boldsymbol{i}_1]$$
$$\beta_{knee} = -\sin^{-1}[\boldsymbol{k}_1 \cdot \boldsymbol{i}_2]$$
$$\gamma_{knee} = \sin^{-1}[\boldsymbol{l}_{knee} \cdot \boldsymbol{k}_2]$$

$$\alpha_{ankle} = \sin^{-1}[\boldsymbol{l}_{ankle} \cdot \boldsymbol{j}_2]$$
$$\beta_{ankle} = -\sin^{-1}[\boldsymbol{k}_2 \cdot \boldsymbol{i}_3]$$
$$\gamma_{ankle} = \sin^{-1}[\boldsymbol{l}_{ankle} \cdot \boldsymbol{k}_3]$$

Local coordinate of lower limbs | Hip joint angle | Knee joint angle | Ankle joint angle



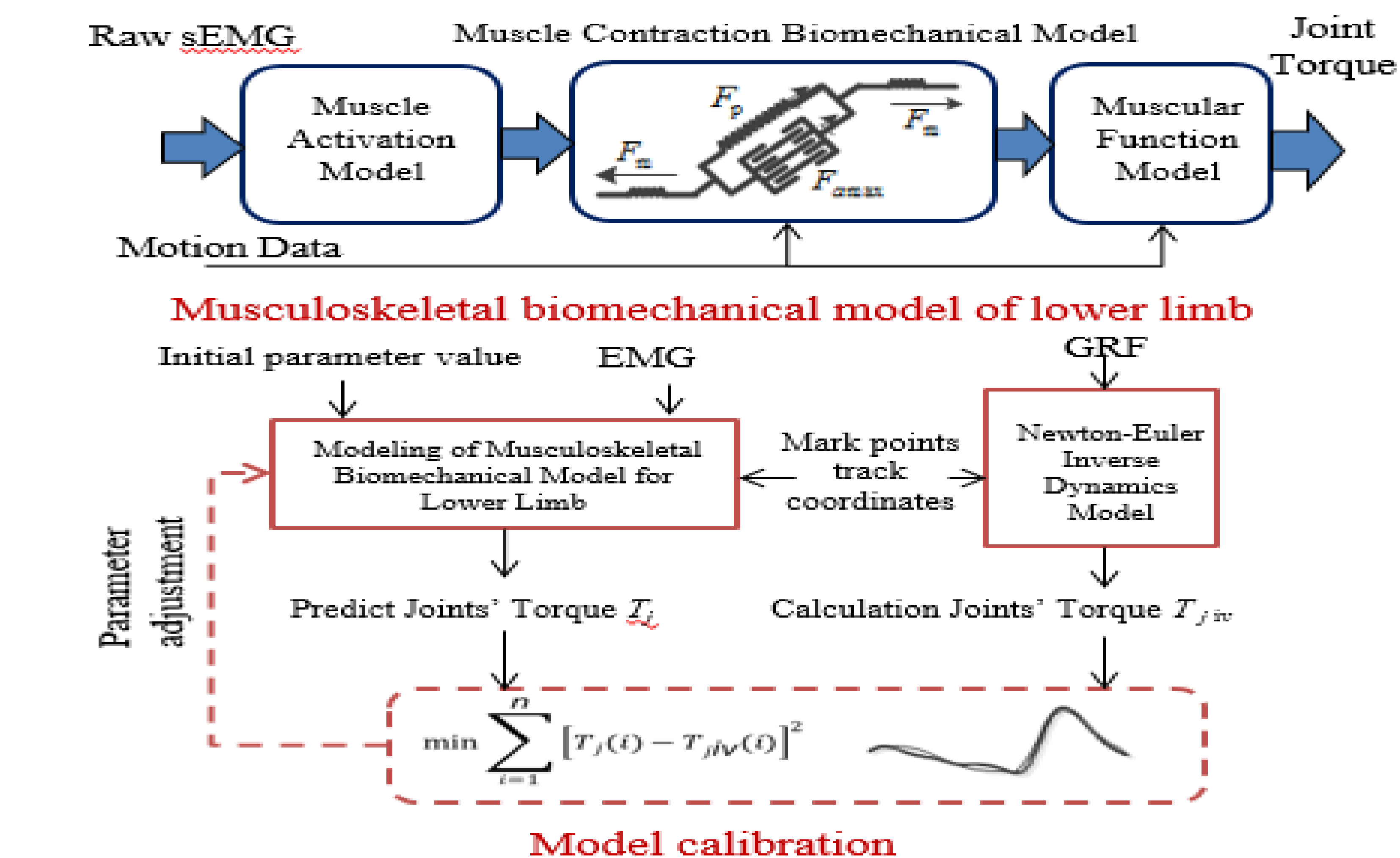
Model for determining the relationship between Semg and joint angle based on BP network



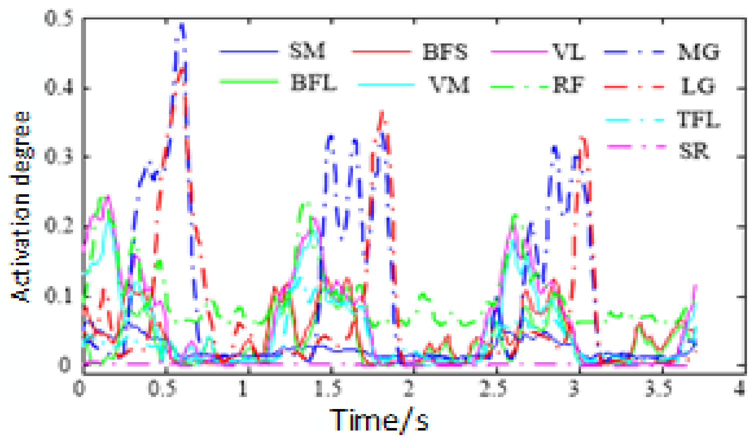
Joint angle estimation results at 1.2 m/s

12.3 Signals detection methods -10

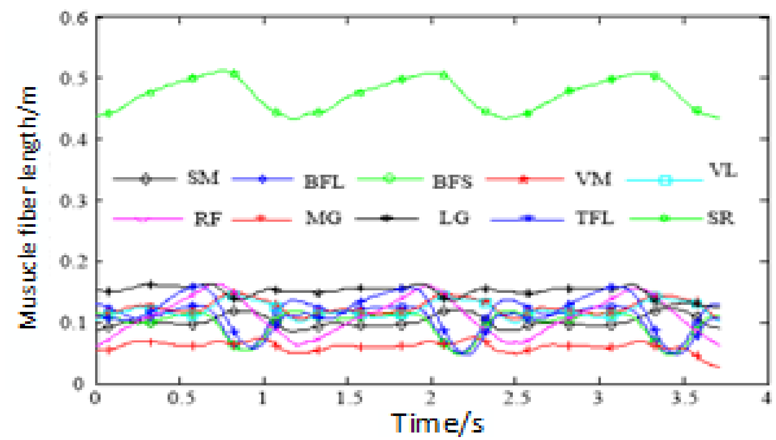
4 Quantitative prediction of active joint torque



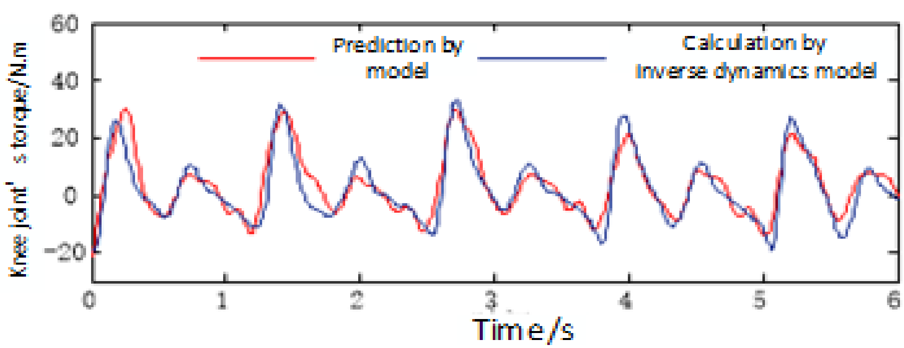
12.3 Signals detection methods -11



The muscle activation curve of the three gait cycles of the subject



The muscle fiber length curve of the three gait cycles of subject



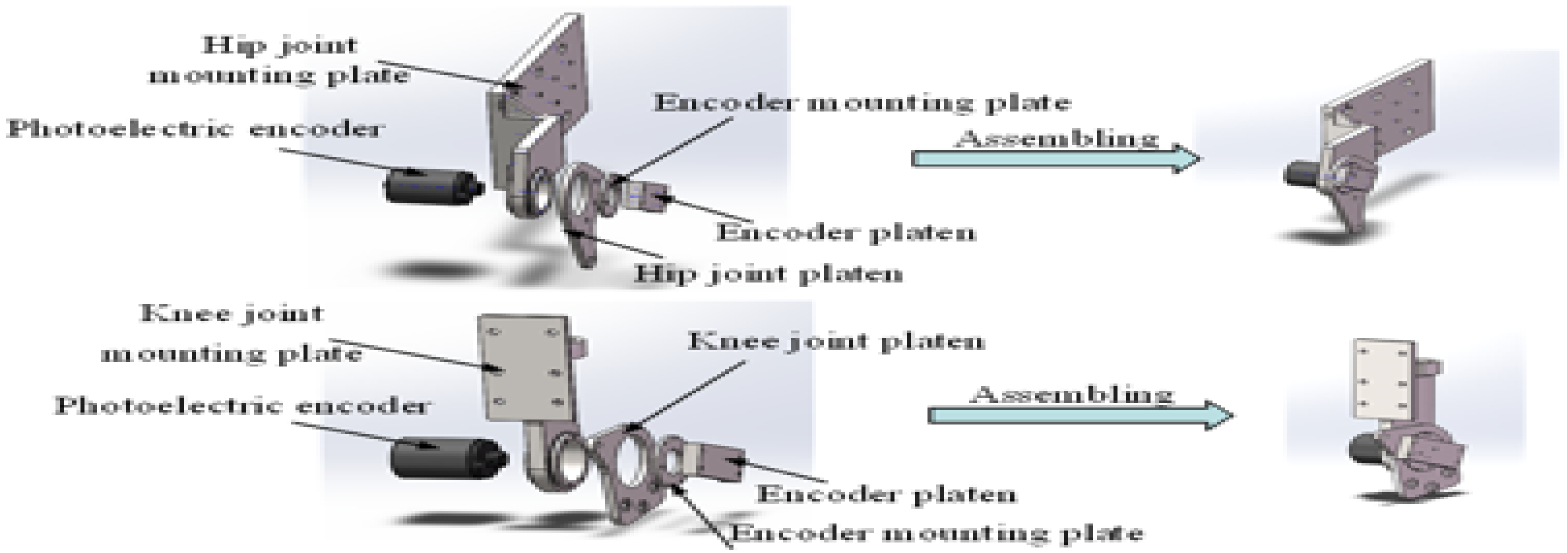
The prediction result of subject knee joint dynamic joint torque

Subjects	MAE（N·m）	MRE（N·m）	R
A	10.8	4.81	0.987
B	12.6	3.86	0.897
C	9.40	3.59	0.921
D	11.2	5.01	0.901
Mean	11.0	4.43	0.927
S.D	1.32	0.698	0.042

The statistics of joint torque prediction results based on EMG

12.3 Signals detection methods -12

System of posture and interaction force detection



Joint angle encoder layout diagram

RIH3808G-1000BZ1-5L, an incremental photoelectric angle encoder provided, is installed at the joint of the lower limb rehabilitation exoskeleton robot. It is used to detect the joint rotation angle of robot during working , and sense the position and posture in real time, which is regarded as feedback elements in closed-loop control .

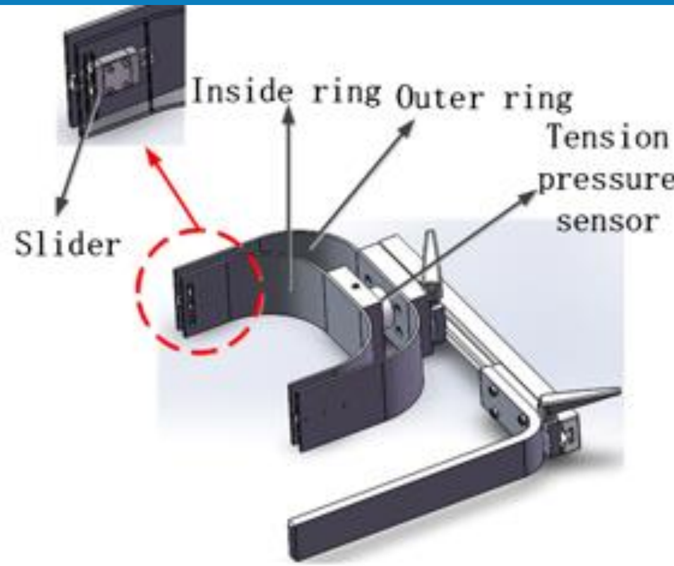
12.3 Signals detection methods -13

$$\Delta F = F_{ai} - F_{a1}$$

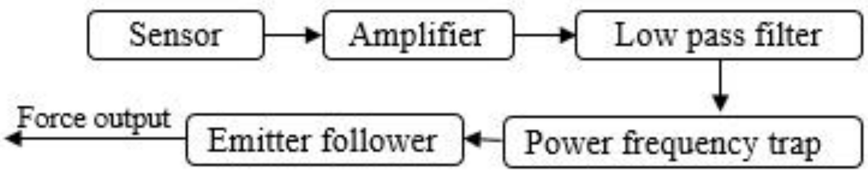
Perception of subjects' active interaction force

Calculate the average human-computer interaction force of passive rehabilitation training F_{al}, and which of each period is regarded as F_{ai}("i"is the i gait cycle), then the active force of patients could be obtained by calculating the error of F_{ai} and F_{al}

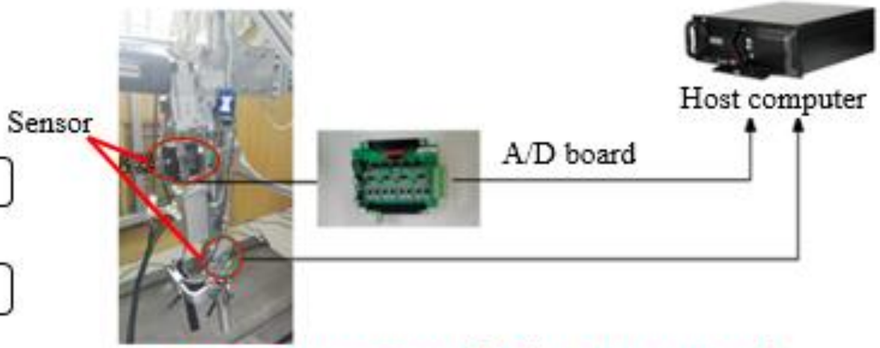
Human-robot interaction force sensor



Installation diagram of Human-robot interaction force

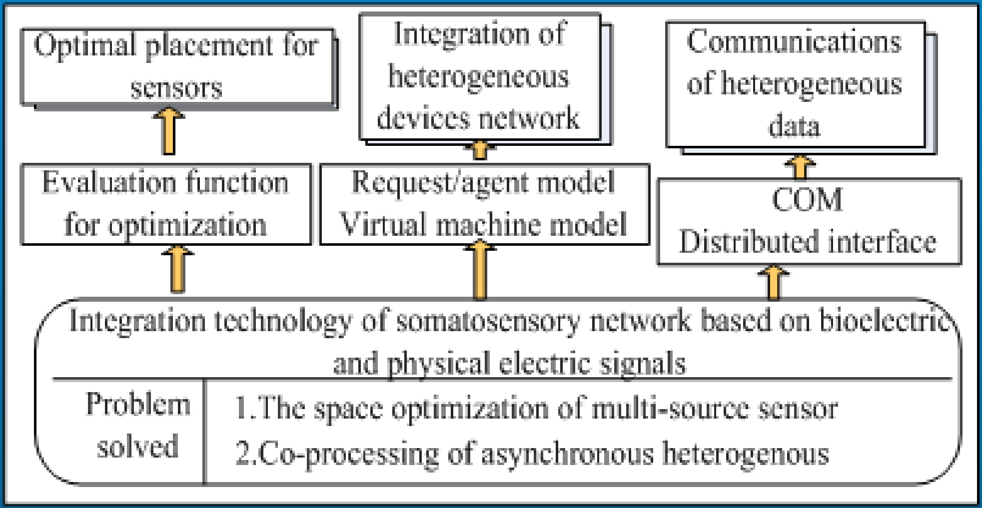


Interactive force signal amplification conditioning flow chart



Detection system of robot posture and interaction force

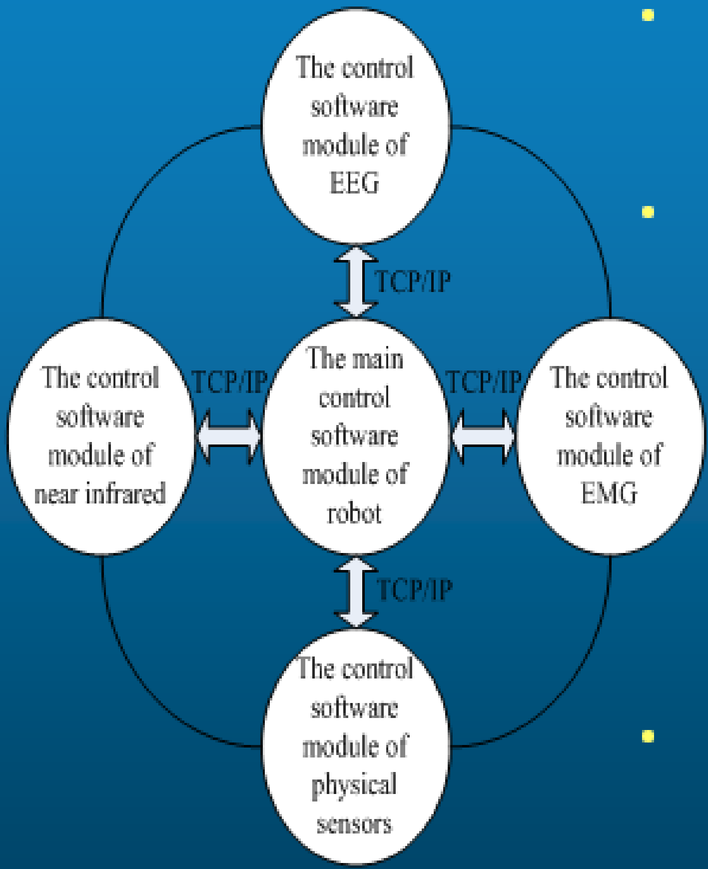
12.4 Integration of multi-sensor network -1



- The most important feature of the rehabilitation robot is that it has a strong ability of human-machine interaction, which depends on the developed perceptual system.
- The integration of perceptual system involves EEG, EMG, near infrared, and a variety of physical sensors and their respective software and data communication protocols.

- Firstly, in order to maximize the information involved in the EEG and EMG, the sensors, electrodes, are optimal layout in the spatial through cresting the corresponding optimization evaluation functions and experiments. Take the EEG sensors as an example.
- Based on the experiment of EEG detection on the whole brain area in the process of lower limbs movement, the fully connected network model for EEG detection is established with the electrodes as the nodes and with the correlation coefficients of the signal change as the connection weights.
- Then in accordance with the timing variation of internal related weights in the EEG detection network during patients' exercise and combine with the principle of identification error minimization, the key acquisition nodes for electrodes and the steady for the network are determined.

12.4 Integration of multi-sensor network -2

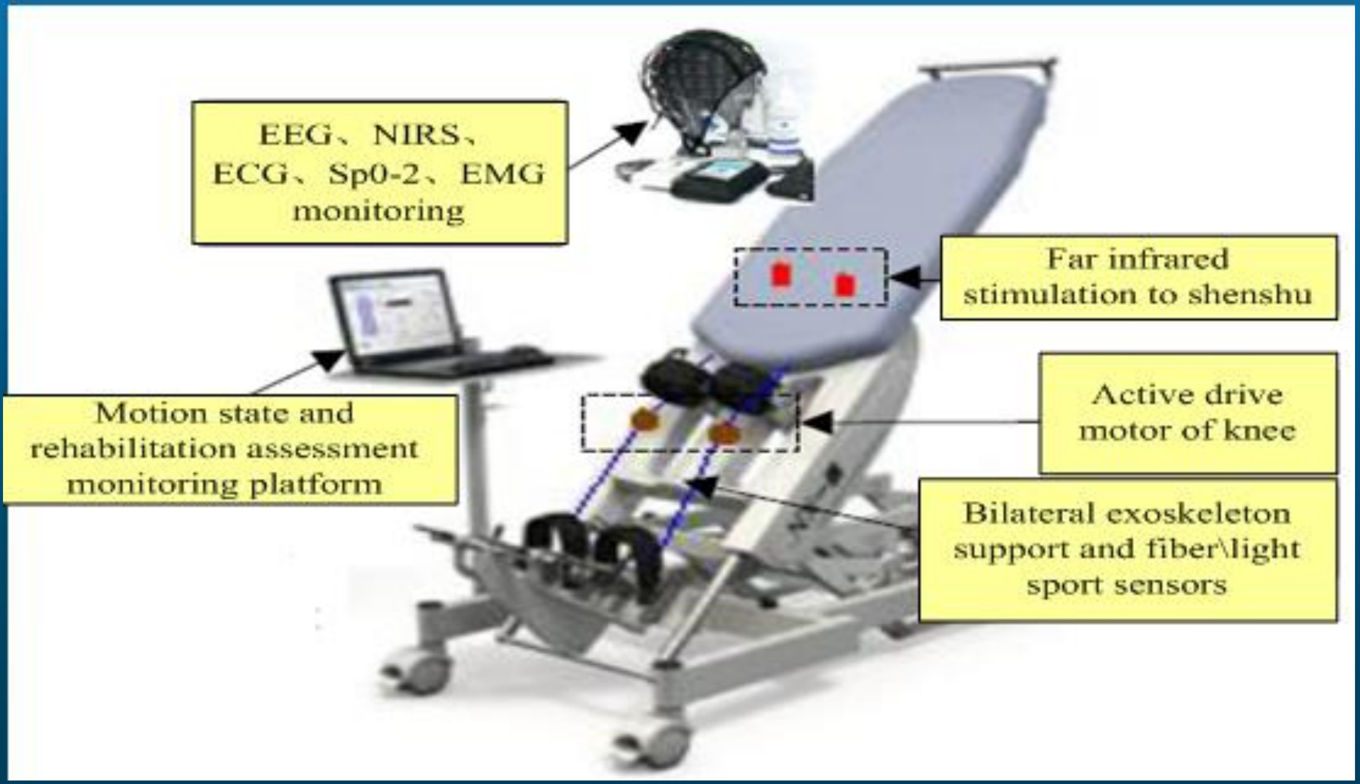


- Additionally, the measurement and analysis system of EEG, EMG, and fiber-optic signals are both relatively independent but also interrelated, and the data communication between each module is required.
- Therefore, in order to achieve the integration between several control software and a variety of data and different communication protocols, we have established a multi-Agent software system with which communication and processing are possible between the asynchronous heterogeneous data, such as the EMG, EEG, cerebral near infrared signal and physical sensor signals. Moreover, each subsystem using a modular design method and data transfer and communication between software is achieved based on TCP/IP.
- As a result, program module calls parameter passing, data sharing, functional mutual support and supplement are possible between each sub-module.

- In addition, considering that the biological perception system and the sensing devices of electromechanical system are typical isomerism devices and have different data structure, we defined the asynchronous data communication format and fault-tolerant mechanism, developed COM-based interface for distributed heterogeneous devices and built an Ethernet-based integration framework for heterogeneous devices.

12.5 Development on lower limb rehabilitation robot-1

- Compared to the previous lower extremity rehabilitation robot, the lower limb rehabilitation robot has more features and advantages because of its very good and complete perceptual system.



12.5 Development on lower limb rehabilitation robot-2

- **1) The robot can maintain detailed records of physiological and locomotion parameters during the rehabilitation training, which provide means for exploring recovery law of the nerve function and lower limbs locomotion and benefit for the mechanism research of brain control movement of lower limbs.**
- **2) Through the detection of bioelectric signals such as EEG, EMG, and advanced signal processing techniques and pattern recognition techniques, it is possible to recognize the movement intention and state of patients. The patients' movement intention was used to control the rehabilitation robot, so that the patents can actively participate in the training which would accelerate the rehabilitation process.**

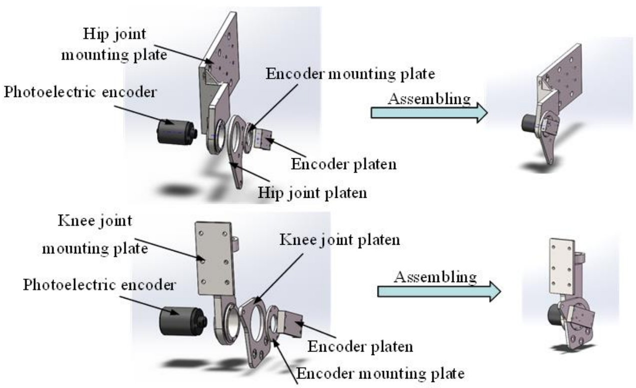
12.5 Development on lower limb rehabilitation robot-3

- 3) Real-time assessment of rehabilitation level of brain and lower limb motor function can be achieved based on the analysis of record data. As a result, the training parameters can be changed according the results of assessment which make it possible to determine the training programs according to the actual situation of the patient.
- 4) Biofeedback technique is used in the training, including visual feedback and far infrared stimulation feedback, which can accelerate the reconstruction of central nervous system's control function to the lower limbs.

12.6 Lower Limb Exo-skeleton Rehabilitation Training Robot-1

Lower limb rehabilitation exoskeleton robot | **Robot Perception**

System of posture and interaction force detection



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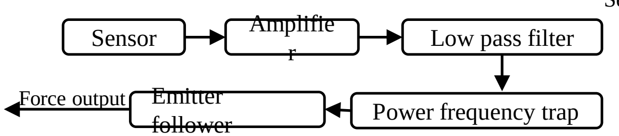
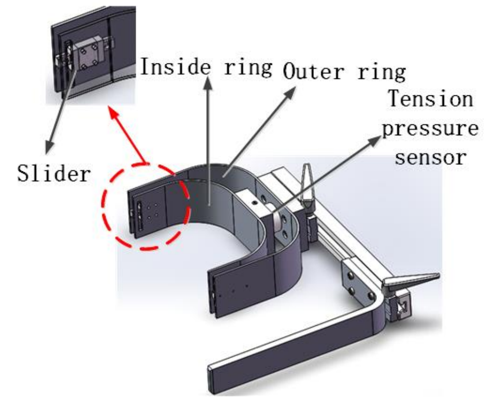
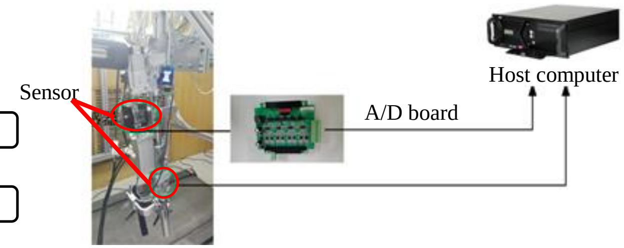
Human-robot interaction force sensor



Interactive force signal amplification conditioning flow chart



Installation diagram of Human-robot interaction

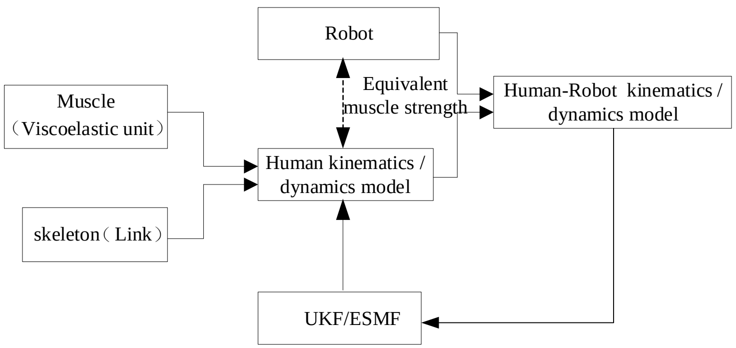


Detection system of robot posture and interaction force

12.6 Lower Limb Exo-skeleton Rehabilitation Training Robot-2

Lower limb rehabilitation exoskeleton robot **Robot Perception**

System of posture and interaction force detection



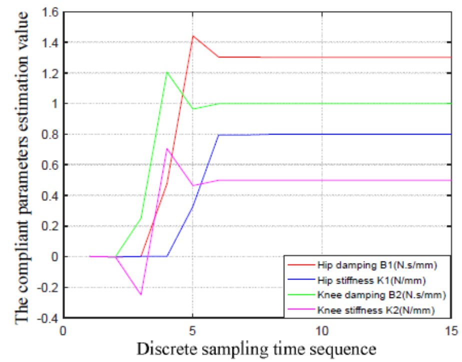
Human-robot system dynamics modeling technology route

$$M_{hw}(\theta)\ddot{\theta}_i+\left(C_{hw}(\theta,\dot{\theta})+B\right)\dot{\theta}_i+G_{hw}(\theta)+K\theta=T_{hw}\quad i\in[1,2]$$

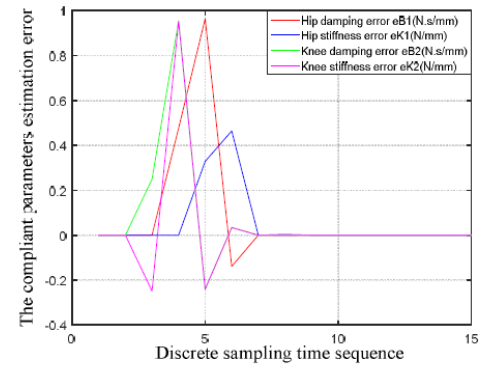
$$M_m(\theta)\ddot{\theta}_i+\left[C_m(\theta,\dot{\theta})\right]\dot{\theta}_i+\left[G_m(\theta)\right]=T_{robot}\quad i\in[1,2]$$

$$\left[M_m(\theta)+M_{hw}(\theta)\right]\ddot{\theta}_i+\left[C_m(\theta,\dot{\theta})+C_{hw}(\theta,\dot{\theta})+B\right]\dot{\theta}_i+\left[G_m(\theta)+G_{hw}(\theta)+K\theta\right]=T=T_{robot}+T_{hw}\quad i\in[1,2]$$

Dynamics modeling of Compliant human-robot system



Parameter estimation of human-robot system model based on compliance characteristics



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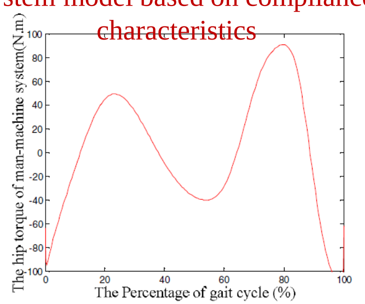
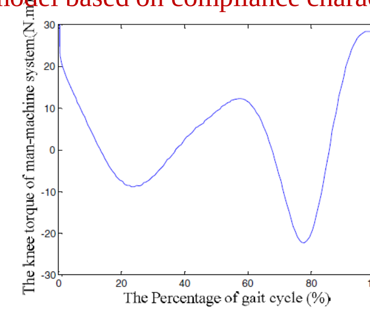


Hip torque of human-robot



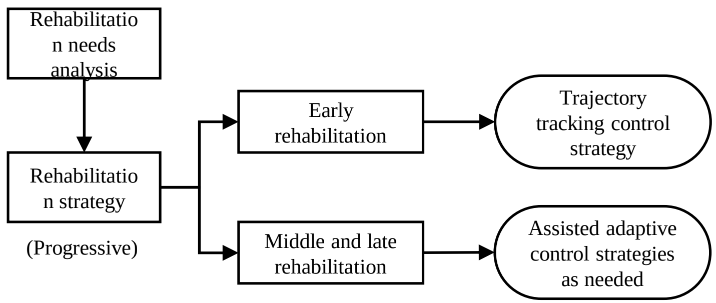
Knee torque of human-robot

12.6 Lower Exo-skeleton Limb Rehabilitation Training Robot-3

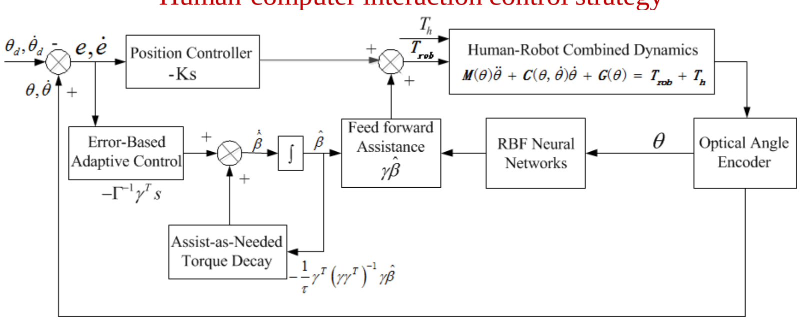
Lower limb rehabilitation exoskeleton robot

Human-computer interaction control theory

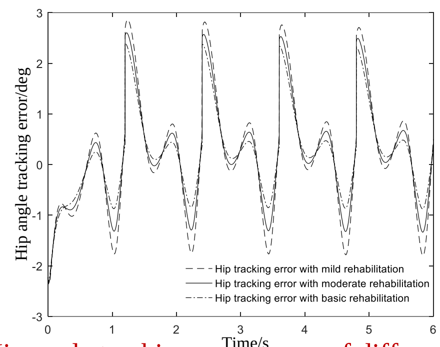
Assist in adaptive control as needed



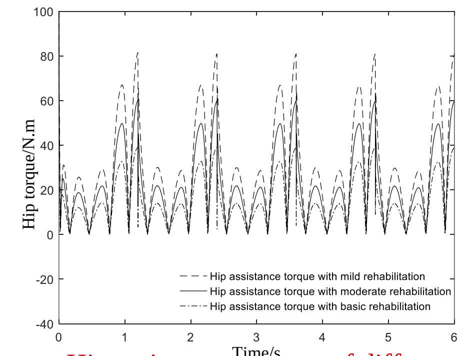
Human-computer interaction control strategy



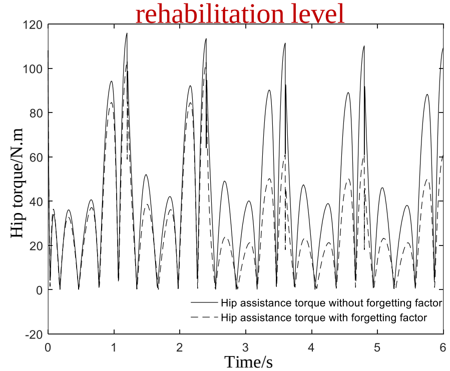
Adaptive assist-as-needed control block diagram for lower limb rehabilitation robot



Hip angle tracking error curve of different rehabilitation level



Hip assist torque curve of different rehabilitation level



Assist torque of hip without forgetting factor

Results of adaptive assist-as-needed control

Gait trajectory parameter	Forgetting factor is infinity	Forgetting factor is 0.5
Hip maximum angular deviation	1.86° ±0.24	3.26° ±0.32
Knee maximum angular deviation	0.48° ±0.10	1.18° ±0.15
Hip maximum assist torque	116N·m±2.6	60N·m±1.8
Knee maximum assist torque	28N·m±2.2	15N·m±1.6

Adaptive assist-as-needed control of lower limb rehabilitation robot is realized with forgetting factor.

12.6 Lower Limb Exo-skeleton Rehabilitation Training Robot-4

Lower limb rehabilitation exoskeleton robot » **Experimental platform construction**

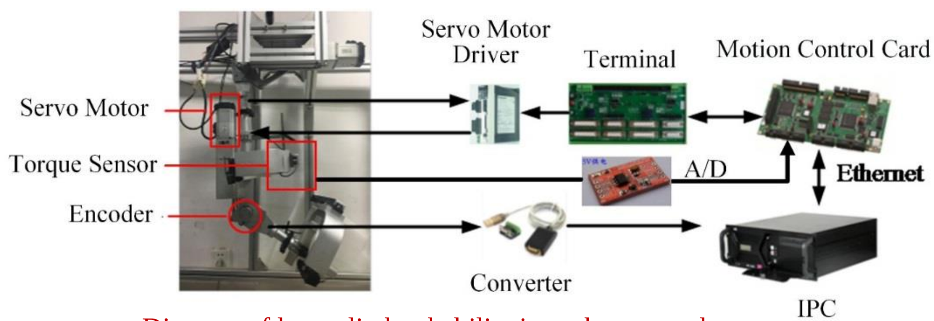
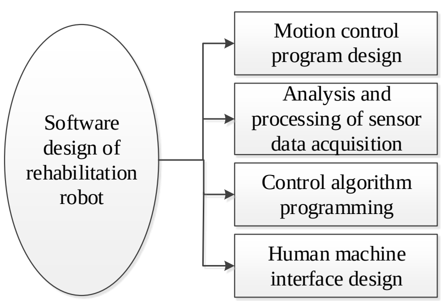
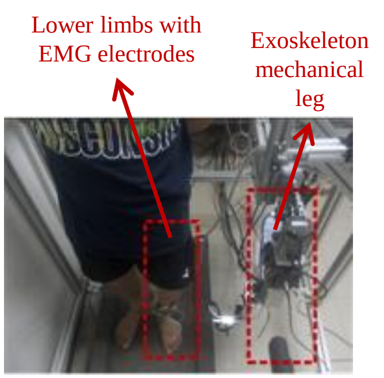


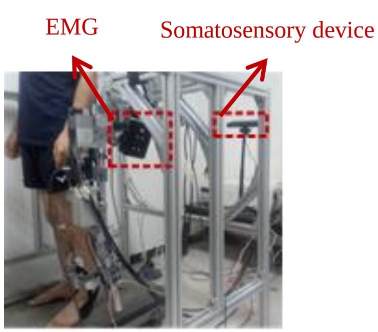
Diagram of lower limb rehabilitation robot control system



Design of control software for lower limb rehabilitation robot

Control interface of lower limb rehabilitation robot





That is all for today.

Thank you very much for your attention!


ann d. martin
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