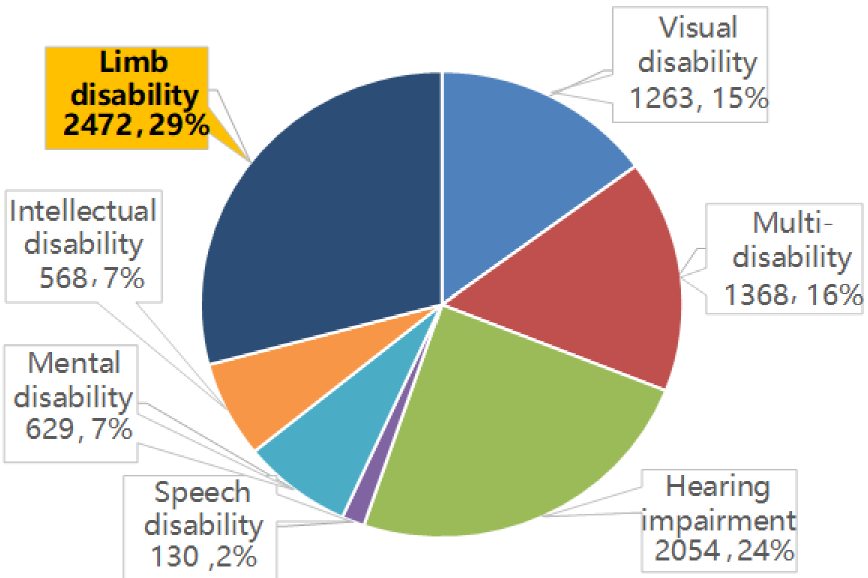
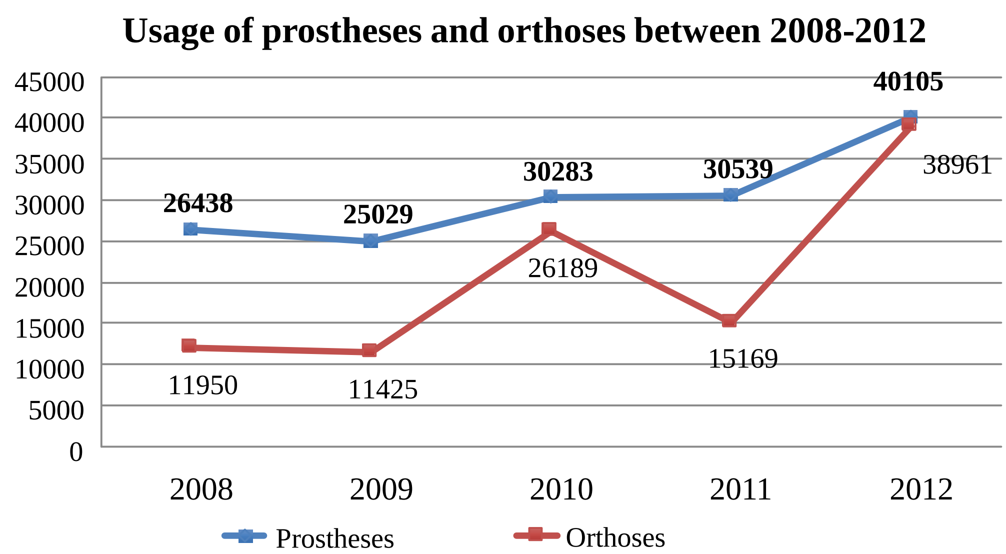
# Lecture 11 Typical Intelligent Robots of XJTU1-Smart neuro-prosthetic hand

# 11.1 Research Backgrounds-1

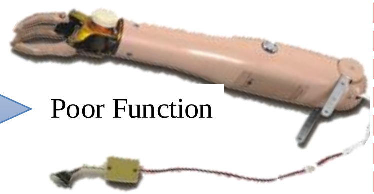



The disabled people in China rose to 85.02 million in total by 2010, limb disability accounting for 29% of it, about 24.72 million; upper limb disability may more than 10 million.

The data in 2012 shows that 40105 prostheses were assembled for disabled people. According to the data in 2010, the number of artificial limbs using was only 0.12% of all disabled people, and there was a huge demand in the prosthetic equipment field.

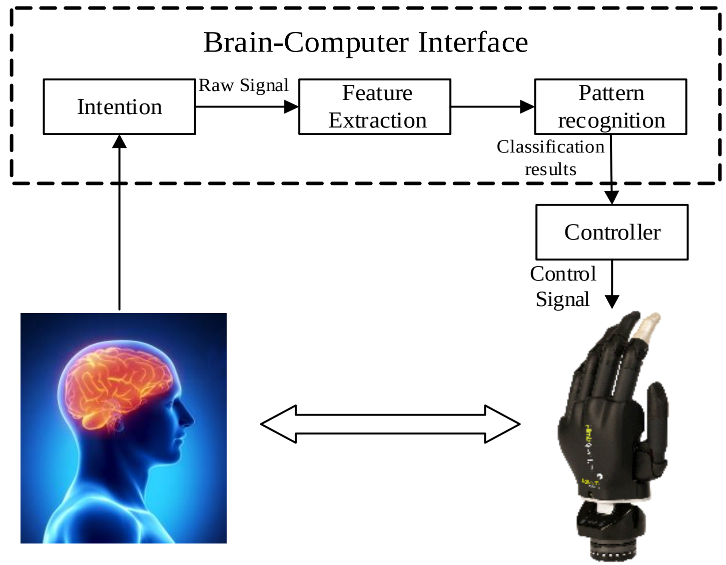
# 11.1 Research Backgrounds-2



| | |
|---|---|
| Decorative Prosthesis | Poor Function |
| Traction Prosthesis | Inconvenient |
| Acoustic Controlled Prosthesis | Limited Application |
| **EMG based Prosthesis** | Poor Performance Under Fatigue |

Current hand prosthesis: Insufficient information used to control, low accuracy, and unable to apply in different amputees such as those with severe nervous system damage & loss the ability to control muscles

The brain-controlled prosthesis presents a method between the brain and the prosthesis based on brain-computer interface technology. It avoids the involvement with peripheral nerve system, so it is suitable for patients with nerve damage, and it is convenient to use. So there are more and more research on this issue.



# 11.2 Development on neural prosthesis hand system driven by BCI

- Principles of System Construction
- Feature Extraction
- Construction of  Control System
- Pattern Recongnition
- System building
- Achievements and main results

# Principles of System Construction

hand opening and closing
wrist of 360-degree rotation
Elbow flexion

external control object

three degrees of freedom

EMG controlling Circuit is changed to EEG

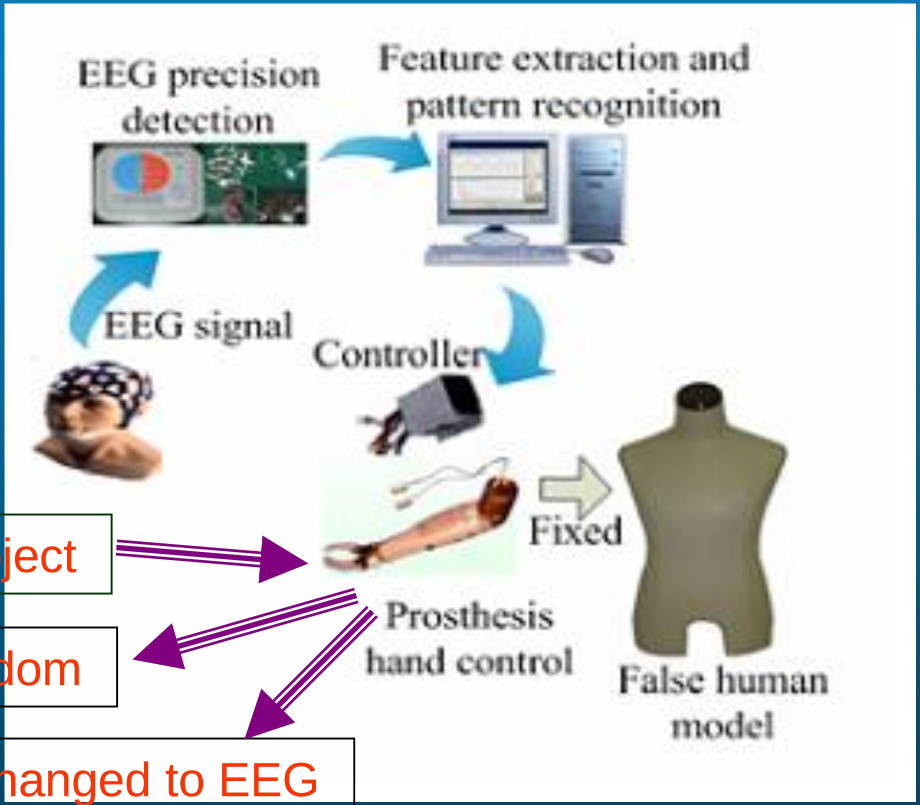
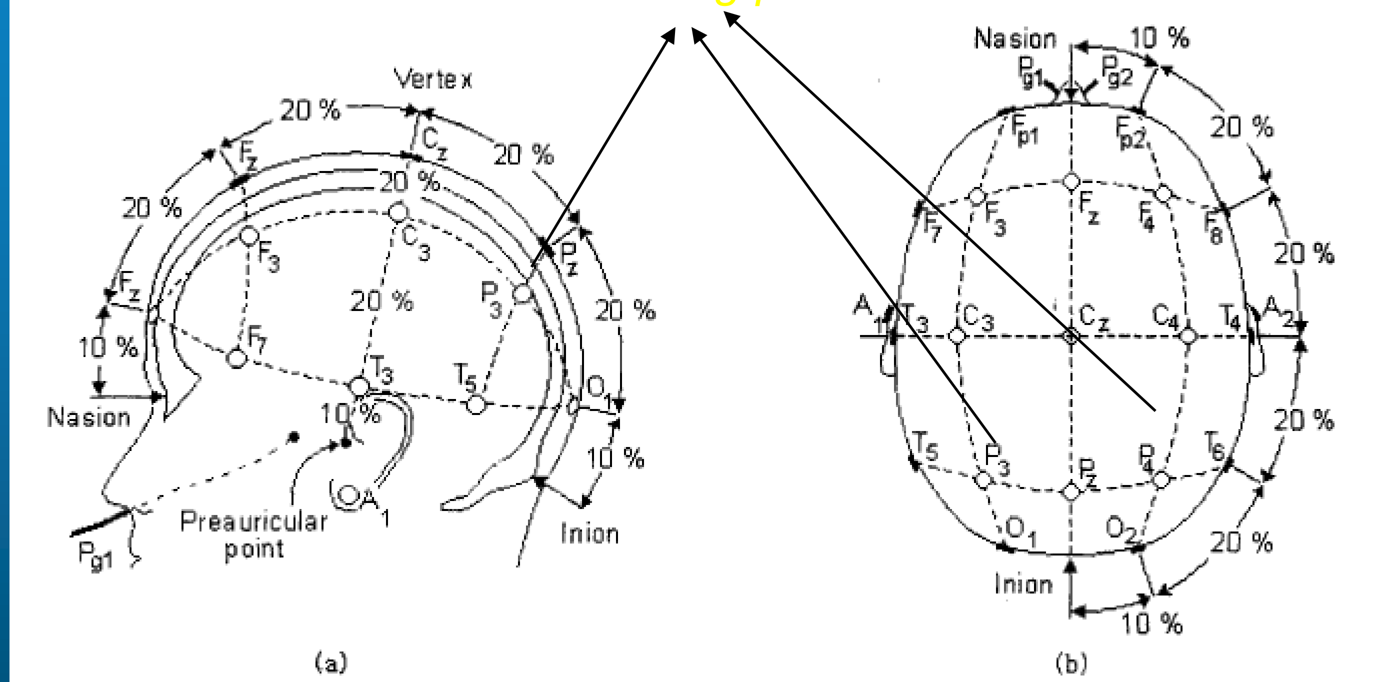



Fig.1 The neural prosthesis hand system driven by BCI

# Feature Extraction

*measuring point*

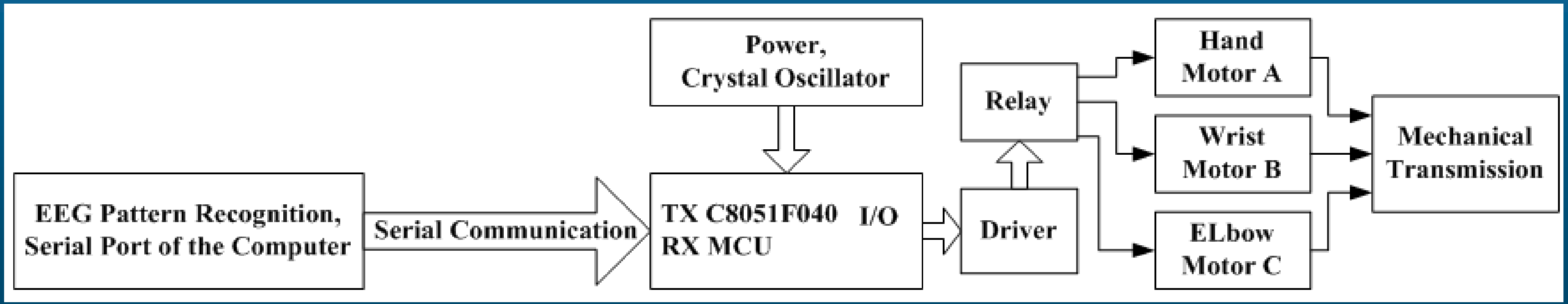



EEG Signal → *wavelet decomposition* → *five useful frequency levels* → *Eigenvector matrix* → *singular value decomposition* → *5-dimensional feature vectors*

# Construction of Control System

the whole control system is mainly consist of prosthetic hand controller, peripheral device, power driver IC, electrical relays and so on.

Through a serial communications PC send the results of recognize to the prosthetic hand drive controller, and the controller processes the corresponding three motor-driver's rotation, stop and turn. And the prosthetic hand movement is achieved through the installation of mechanical.




The structure of the neural prosthesis hand system

# Pattern Recognition

## A. EEG pattern recognition based on Neural network

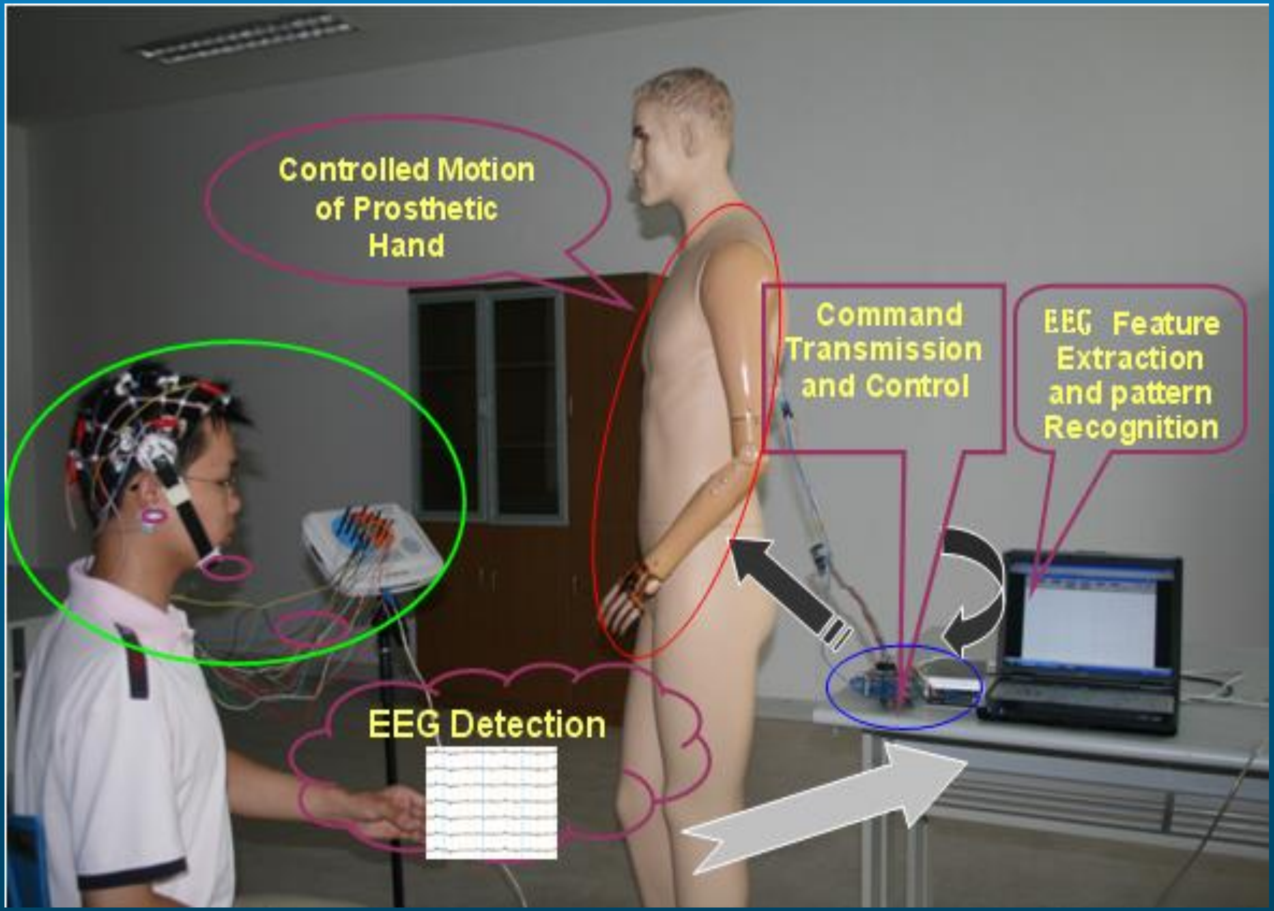
A BP neural network is designed for EEG pattern recognition on hand movement.
In this study, the input layer is set by 12 nodes, corresponding to elements in the normalized wavelet characteristic matrix Tk.
Two neurons (y1 and y2) are set in the output layer, while the output results on the corresponding hand movement patterns as shown in Table 1.

## B.Multi-Classification of EEG Signals based on Support Vector Machine

1) **Structural Risk Minimization principle**: relationship between empirical risk and expected risk in the machine learning early.

2) **C-Support Vector Classification Machine (C-SVC):** Setting the training samples set is: {(xi, yj), i = 1,2, ..., l}, {xi, yj}, 1, ..., l, xi is a d-dimensional vector, yiЄ{-1, +1}. The original problem of classification is that the process of solving Optimal Hyper plane and that is to maximize the distance. As shown in Fig.3.

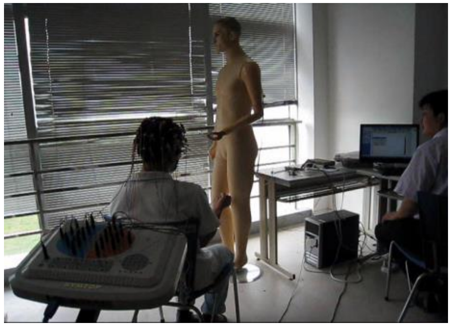
# System building




The neural prosthesis hand system driven by BCI

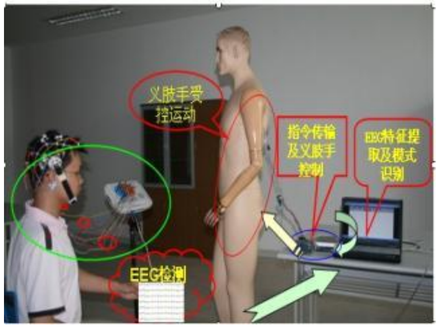
# Achievements and main results

Hand moving



Hand opening

Hand closing




The whole system

- Recording EEG signal from motor imagine area
- Feature extraction： wavelet transform and singular value decomposition
- Recognition : the BPNN to classified the three hand gesture: hand moving, hand opening and hand grasping . The highest accuracy was up to 85%.
- 3 actions can be recognized with the application of BP neural network , and the recognition rate is up to 85%.

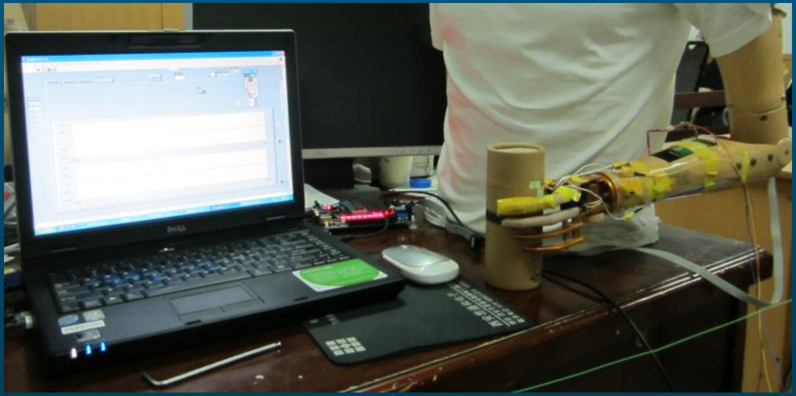
# 11.3 Development on wearable smart prosthesis

A potential application of BCI(Brain Computer Interface) is the way of prosthesis control.

We consider the spontaneous EEG of motor imagery as the control signals for the prosthesis.

Unlike the SSVEP(Steady State Visual Evoked Potentials), motor imagery just have three or four patterns that can be recognized.

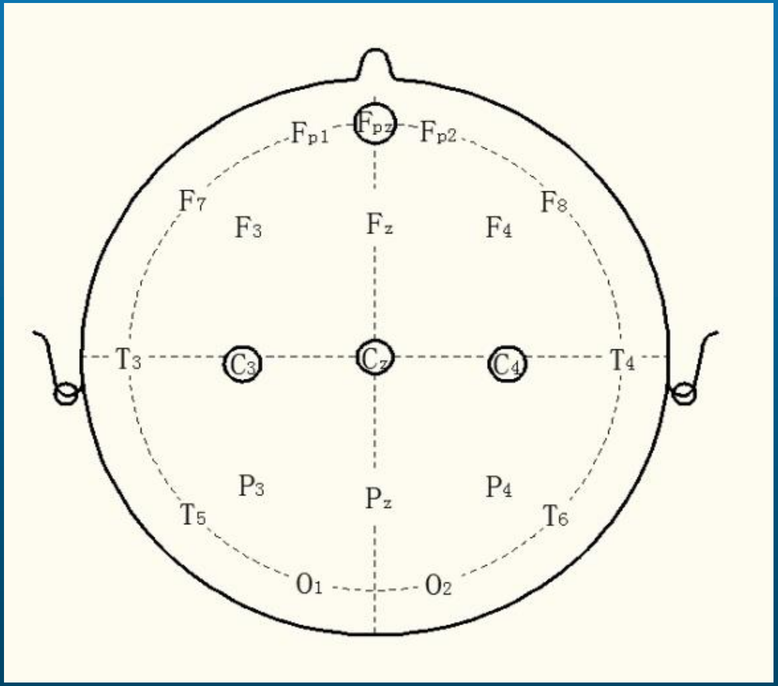
So the strategy that we designed in this paper can easily complete the controlling of 3 joints prosthesis.



# EEG Acquisition

Three Ag/Agcl circular electrodes were mounted on the C3, Cz, and C4 with the references at the both mastoids and the ground at the Fpz over the forehead according to the 10-20 system.

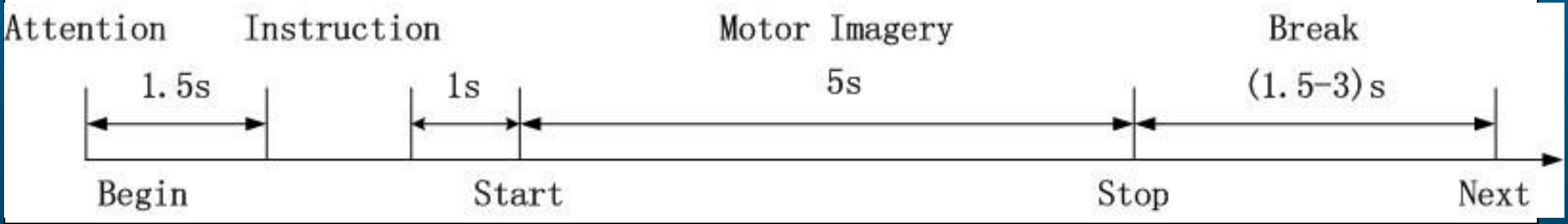
The sampling frequency was 256Hz with 60Hz lowpass filtering including a notch filtering at 50Hz.



# Auditory Paradigm

Participants had to perform three types motor imagery according to the instruction which they heard including left/right hand and feet movements.

the kinesthetic motor imagery of definite actions will help participants for better motor imageries.



# Signal Processing and Classifying

The signals $S_{cj}$ acquired from the 1s before start to the 1s after stop were analyzed for establishment of classifier. The data was 3 channels and 7s of length. The time-frequency map[18] calculated by a sliding window of 1s length and 0.25s step, while the power spectrum $P_{cj}^{t_n}(f)$ was saved from 6Hz to 30Hz

$$P_{cj}^{t_n}(f) = F(S_{cj})$$

# Signal Processing and Classifying

Then the relevance coefficient about the power between $t_k$ and $t_{k-1}$ was presented as $R_{cj}^{k}$ and the regularized $Rr_{cj}^{k}$ .

$$R_{cj}^{k}(\tau)=\frac{1}{N}\sum_{k=1}^{N-1}P_{cj}^{t_k}(f)P_{cj}^{t_{k+1}}(f+\tau)$$

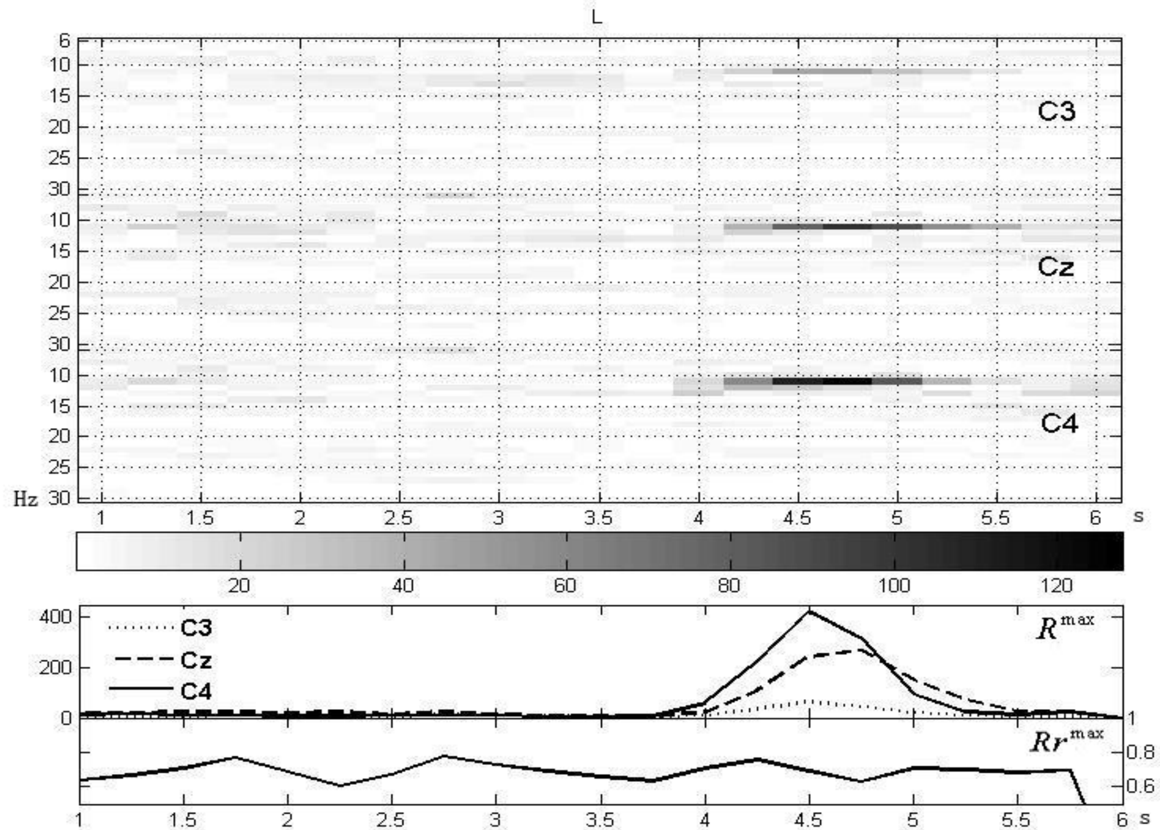
$$Rr_{cj}^{k}(\tau)=\frac{2}{N}\sum_{k=1}^{N-1}\frac{P_{cj}^{t_k}(f)P_{cj}^{t_{k+1}}(f+\tau)}{(P_{cj}^{t_k}(f))^2+(P_{cj}^{t_{k+1}}(f+\tau))^2}$$

$$k=1,2,\ldots..24.$$

$$R_{cj}^{\max}(k)=\max(R_{cj}^{k})$$

$$Rr_{cj}^{\max}(k)=\max(Rs_{cj}^{k})$$

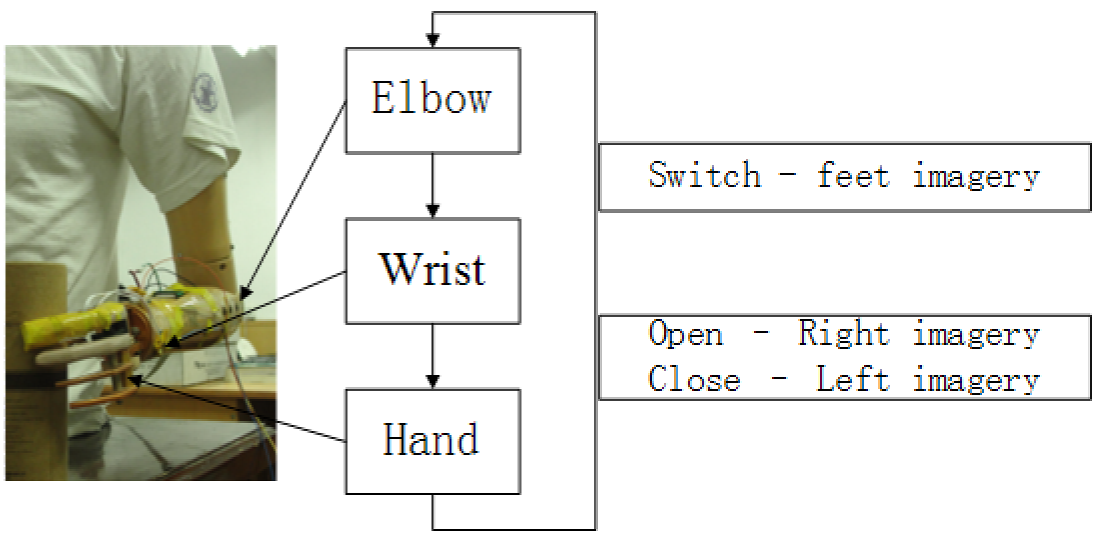
# Signal Processing and Classifying




The ERD/S emerged when the $R_{cj}^{max}$ augment，we supposed when the $Rr_{cj}^{max}$ increase sharply, the power spectrum show the ERD/S.

# Prosthesis Control Strategy

The specific control strategies are as follows. Three joints were controlled separately, thus, there is only one joint in control in the same time. The switch between them was controlled by the motor imagery with highest recognition rate. For instance below.



# Training of Prosthesis Control

The training of prosthesis control is a feedback control process of separate prosthesis movement using the classifier obtained from the auditory paradigm. The purpose is to make participants accomplished several basement assignments of controlling prosthesis separately by visual feedback of prosthesis movements. According to the control strategy, the tasks of training contains switching the current controlling joint, rotating forward or reverse of any joints.

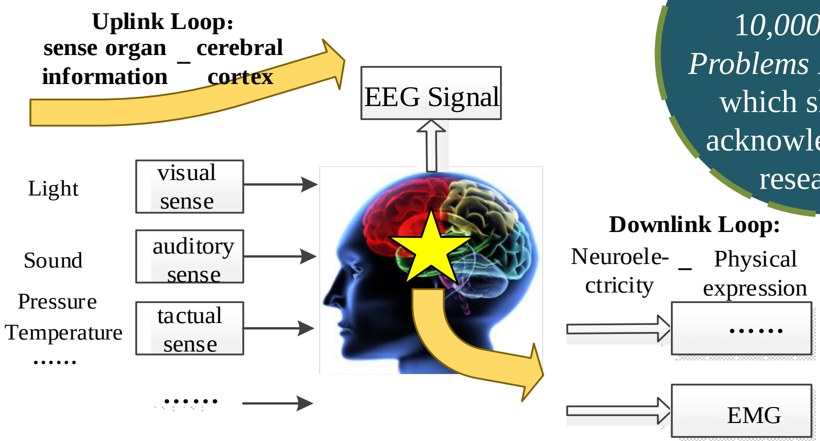
# Evaluation of Prosthesis Control

An experiment is designed to evaluate the prosthesis control system in the last part. The sequence of prosthesis movements was given below: no action, elbow bending, switching, wrist clockwise rotation, switching, hands clenched, hands open, switching, wrist anticlockwise rotation, switching, elbow extending, and no action. The subjects were required to remember the sequence and completed the whole process as fast as possible by performing the motor imagery.

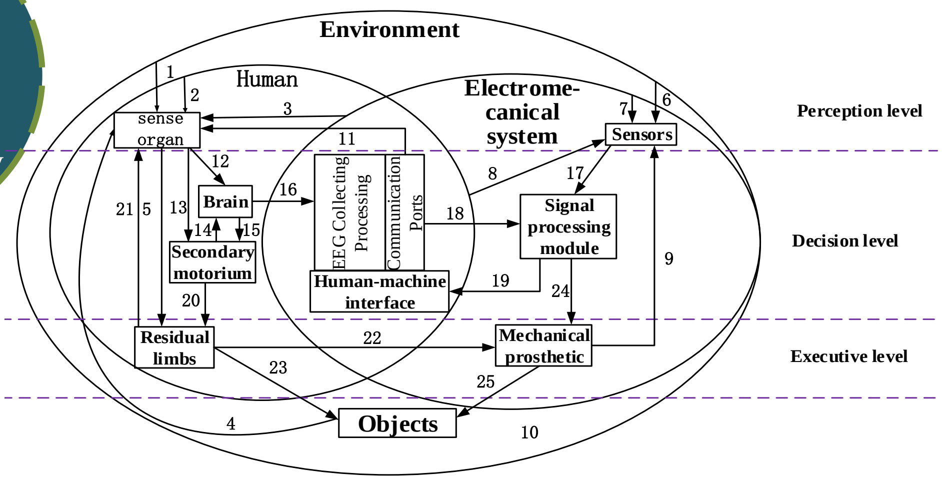
# 11.4 Brain-controlled Paradigm-1

**Brain control mechanism: MIMO cognitive model**

The thoughts have been accepted by *10,000 Selected Problems In Science*, which showed the acknowledgment by researchers.




**Human-machine-environment interaction mechanism**

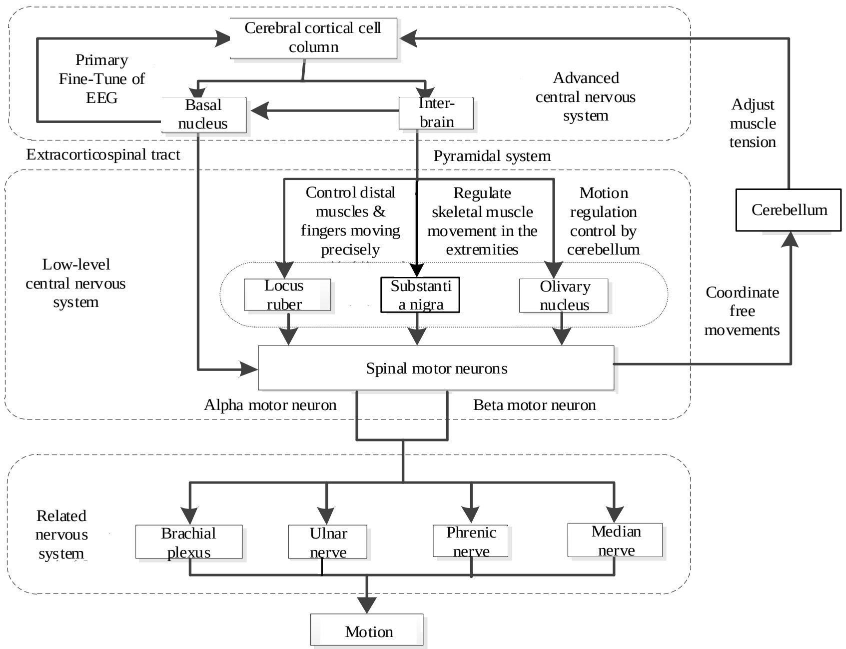



**First**, combine the information acquired from vision and tactual sensation with the existed knowledge in brain, to understand the generating process of nerve pulse. **Then**, nerve pulse delivered through the nervous system and muscle tissue, and with the help of bioelectricity and limbs, so the EEG or EMG can be seen as actions.

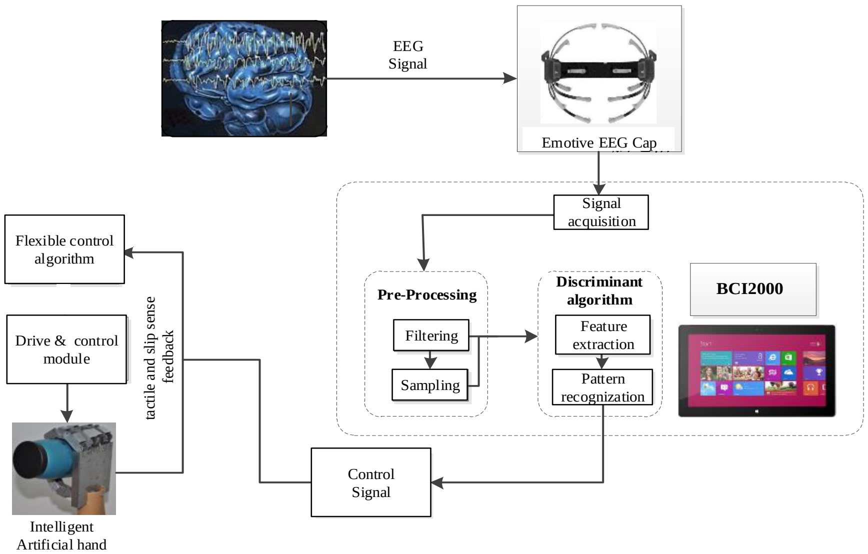
Decision-making mechanism under human-machine-environment system is built firstly, then the comprehensive information of machine-environment are used to correct decision-making mistakes and improve efficiency. So the performance in complex and changing environment are improved by the human-machine collaboration system with human intelligence.

# 11.4 Brain-controlled Paradigm-2

## Upper limb prosthesis control theory




Brain control mechanism and nerve conduction in hand movement



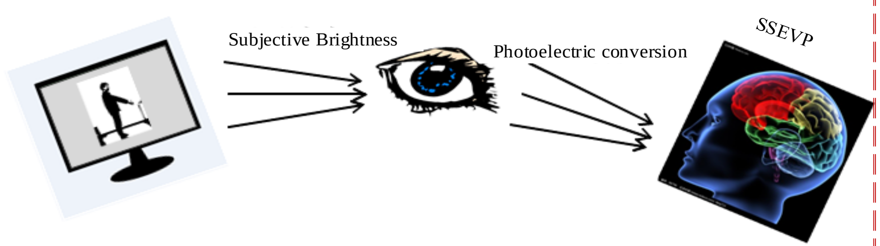

Brain control system model of intelligent prosthesis

# 11.4 Brain-controlled Paradigm-3

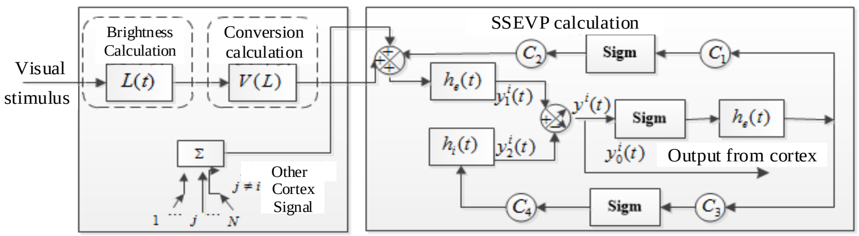
## Brain-controlled Paradigm I

### Scene-Graph SSVEP EEG Paradigm

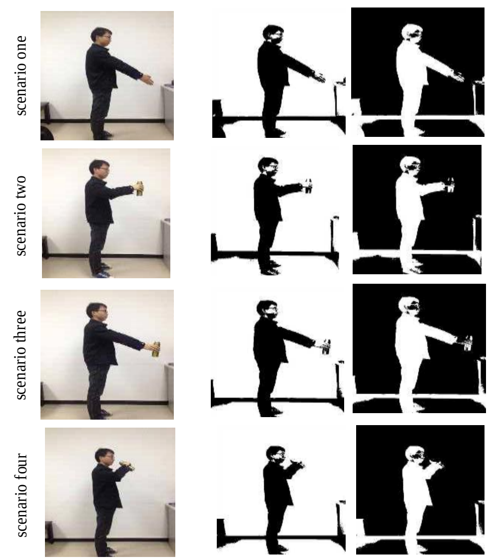
According to the control target, the daily life scene can be decomposed into corresponding independent stimulation maps, and gray-scale image processing is performed to form a scene based on SSVEP paradigm that uses sinusoidal modulation flickering.



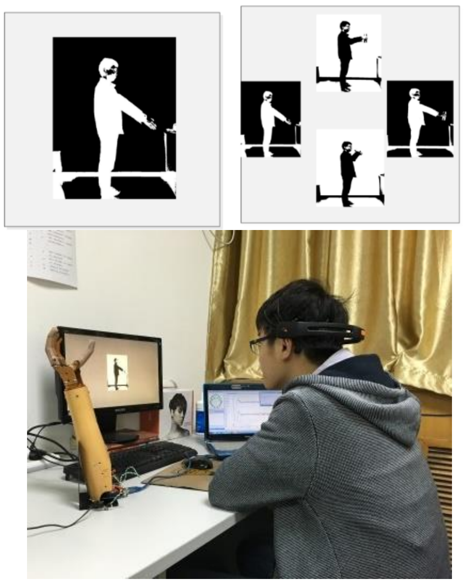

(a) SSEVP generation mechanism based on scene animation




(b) Modeling method based on scene animation




(a) Original photo (b) Black and white reverse color picture

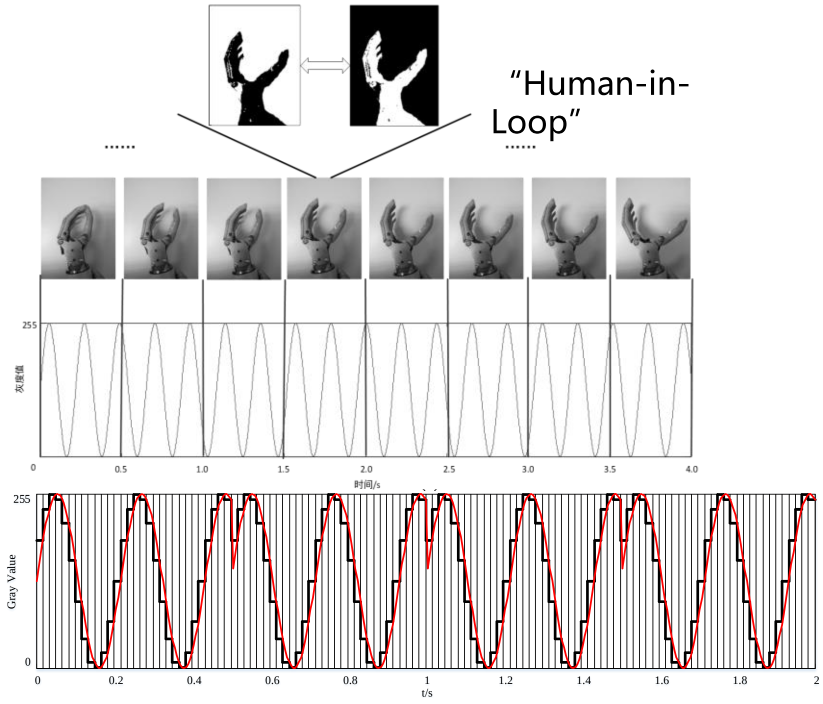


Stimulus Scene

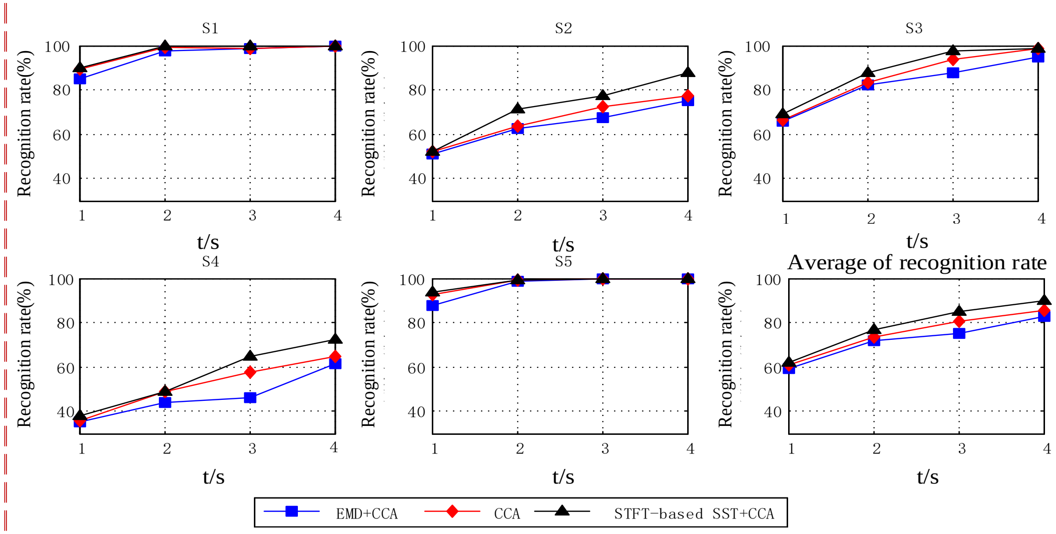
# 11.4 Brain-controlled Paradigm-4

## Brain-controlled Paradigm Ⅱ

### Object Continuous Movement SSVEP EEG Paradigm




### Synchro squeezing Short-Time Fourier Transform Method

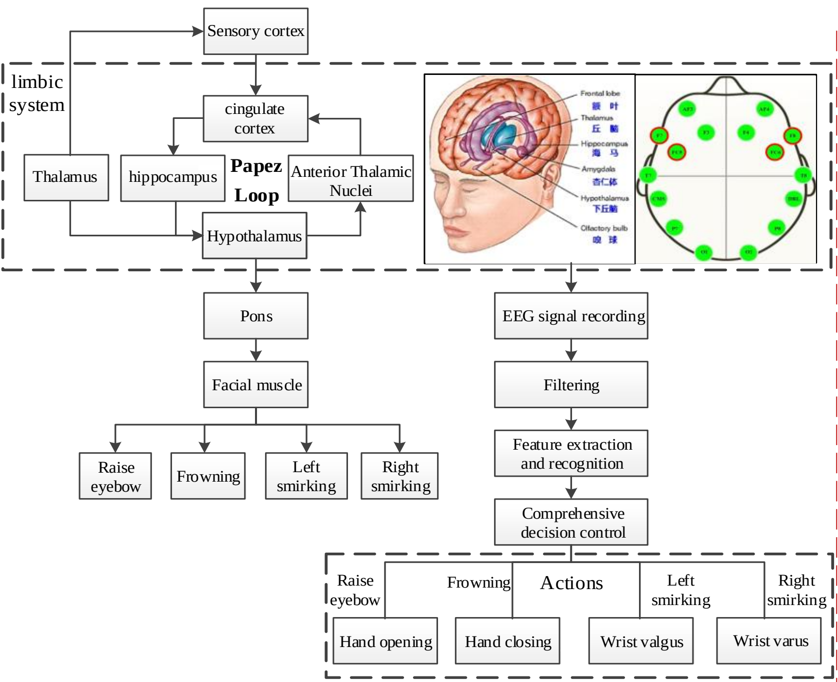



Greatly improve the SNR, and has good anti-noise performance and signal extraction accuracy. Compared with the Empirical Mode Decomposition (EMD) and conventional filter method, the average recognition accuracy of the method is increased by 9.98% and 4.38% respectively.

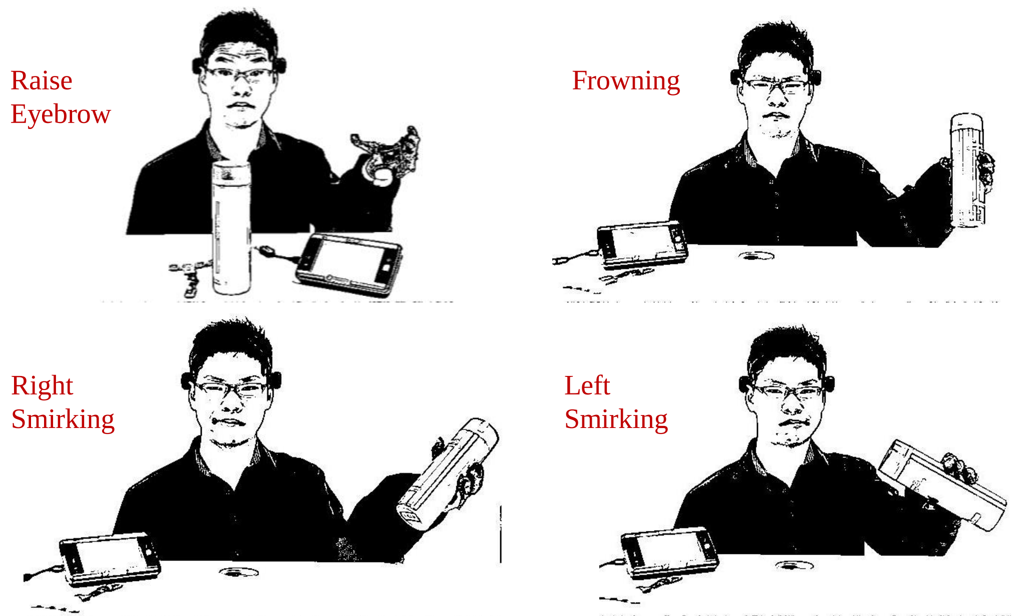
# 11.4 Brain-controlled Paradigm-5

## Brain-controlled Paradigm Ⅲ

### EEG paradigm of expression driven



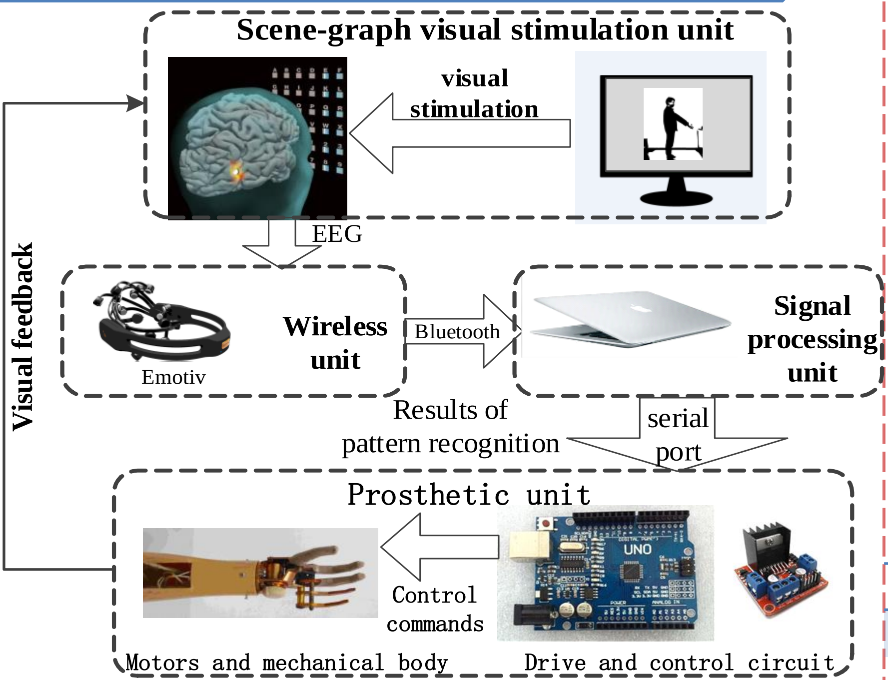

The BCI technology based on expression driven is used to achieve the control of the prosthesis including hand open, hand close, wrist valgus, wrist varus and rest state to help amputee complete some daily operations independently.



# 11.4 Brain-controlled Paradigm-6

## Brain-controlled System I

### Brain-controlled system of scene-graph based




With the EEG signal collected from the occipital lobe , a method based on typical correlation analysis (CCA) was proposed, and the recognition rate was up to 94.5%.

| | |
|---|---|
| Recognizable amount | 4 |
| On-line recognition rate | 94.58±11.05% |
| The information transfer rate | 19.55±3.07bit/min |

# 11.4 Brain-controlled Paradigm-7

## Brain-controlled System II

### Brain-controlled system of expression driven

With the EEG signal of the prefrontal lobe ,limbic system and motor cortex, the five facial expression was successfully realized by the time-frequency.

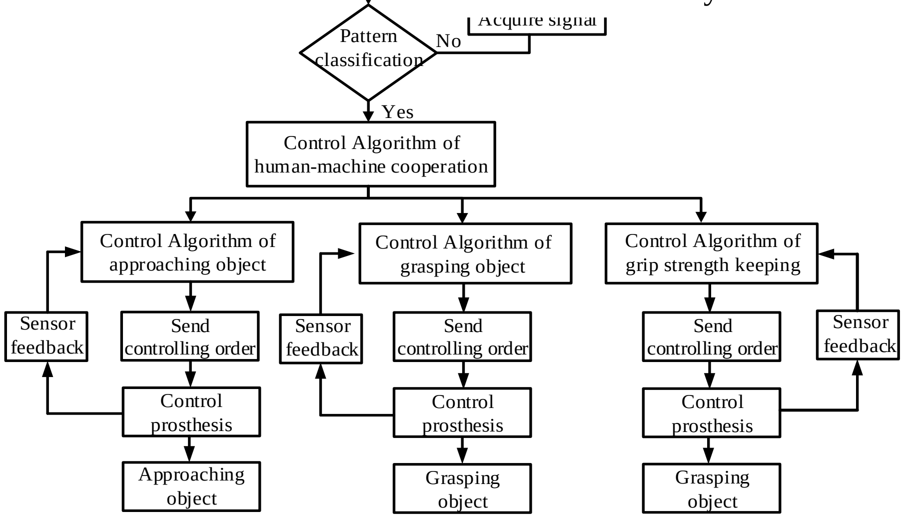

| | |
|---|---|
| Off-line recognition rate | 88.3±3.5% |
| The information transfer rate | 36.10±4.2bit/min |

# 11.4 Brain-controlled Paradigm-8

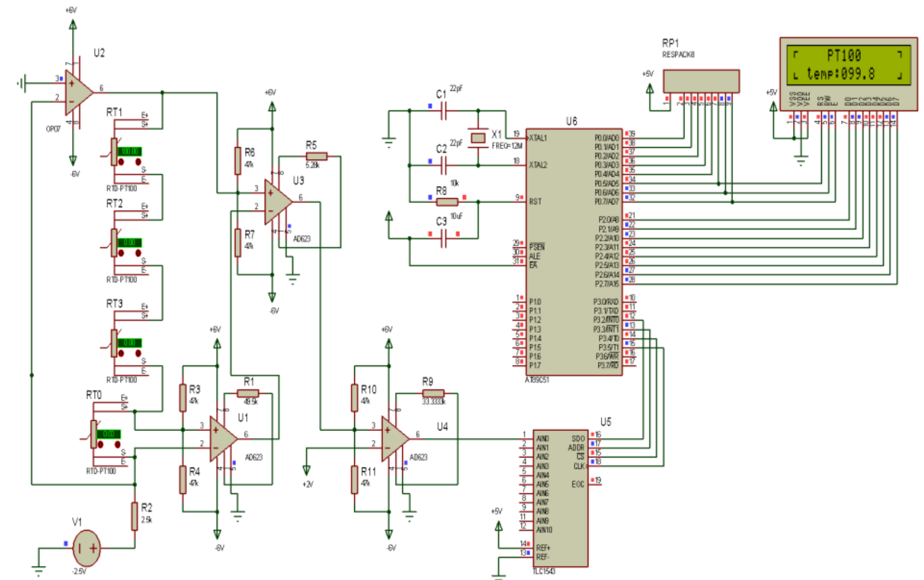
## Cooperative Control and Perception of Prosthesis

### The control with Man-machine Cooperation

The cooperative control in the approaching and stable control of grasping and respond control of grasping strength keeping that based on Tau theory

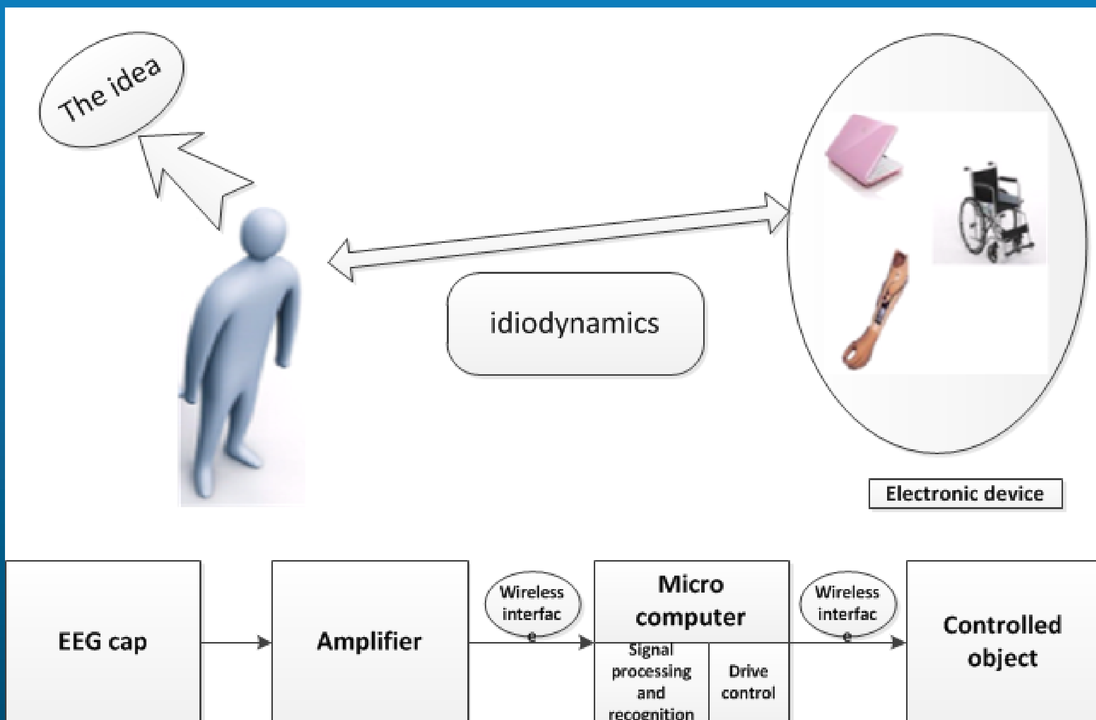



### Intelligent Perception



Grasping control system based on PVDF tactile and slip sensor Temperature sensing system with AT89C51 as core processor

# 11.5 Development on Brain-controlled Technology-1




Precision detection

EEG

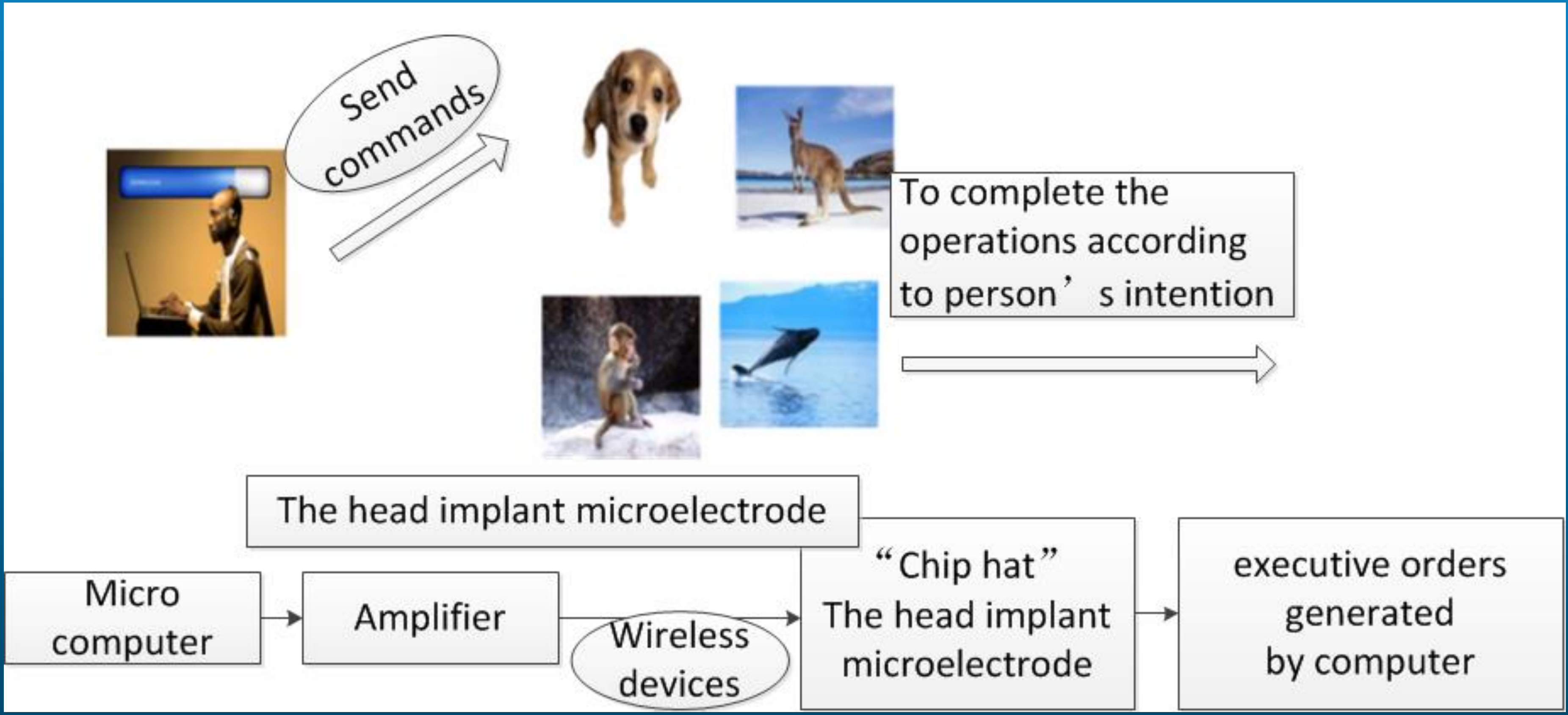
Filtration & Amplification

Signal processing

Control command

**" Brain to control"** is based on extracting EEG signal which generated by Cortical of human or animals .It has built a bridge between human or animal's imagery and peripheral equipment

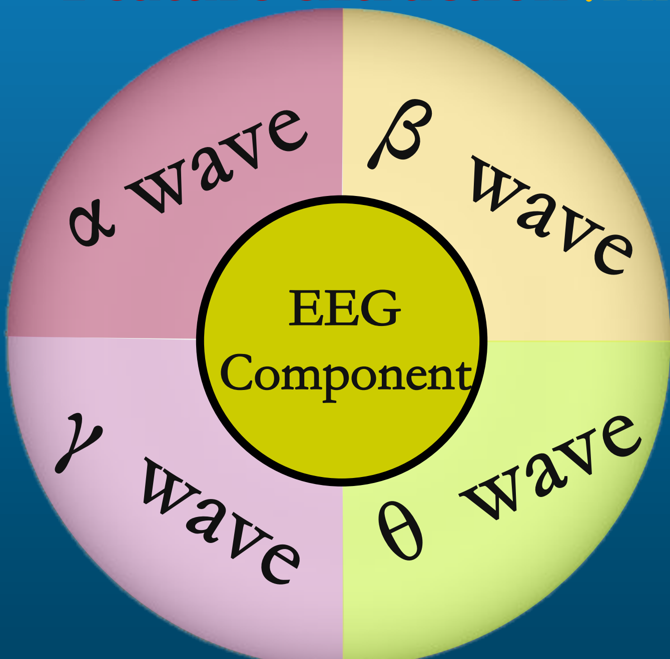
# 11.5 Development on Brain-controlled Technology-2

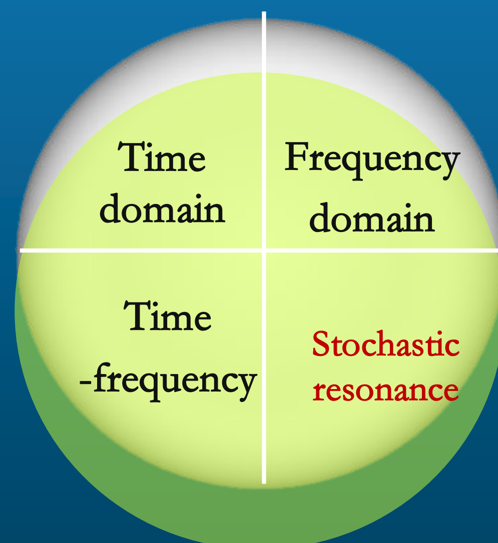



**"Control the brain"** has chosen animal as a subject, it uses invasive BCI technology, namely, implanted microelectrodes in the animals Cortex. Using a special stimulation instead of receptor's brain activity.

# 11.5 Development on Brain-controlled Technology-3

- **Precision measurement**： Wire Wireless
- **Design of BCI paradigm**: SSVEP; Motion imagination; Motion recognition; facial expression
- **Feature extraction** :Time domain ;Frequency domain ; Time-Frequency




- **Pattern recognition:**BP neural network ; Artifical neural network ;Fuzzy neural network
- **Driven & control strategy; Design of prosthesisi structure**

That is all for today.

Thank you very much for your attention!


ann d. martin
(C)1994