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A Review of Prosthetic Hand Control Signal Source

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Abstract: Human limbs systemic function is complicated and the feedback is very abundant. How to make sure hands signal source becomes a very complicated conundrum with the push of development. After the theory of control is proposed, researchers spend much time on doing research. With the development of science technology, the requirement of prosthetic hands' multi-perceived information feedback is higher and higher in biomedical field and ammunition industry. Research on signal source about hand prostheses become a hotpot for long time. Nowadays, control signal sources are used to control prosthetic hand include mechanical movement, voice, reconstructed fingers, EMG, EEG, MEG and so on. This passage displayed a comparative analysis on the hand prostheses field in recent decade and introduced the theory of hand prostheses control. Whats more, researches on hand prostheses signal sources are surveyed. At last, hand prostheses control signals are under the comparison. Some further research and developing trend of prosthetic hand signal sources are indicated.

Keywords: control signal source, prosthetic hand, mechanical movements, voice, reconstructed fingers, EMG, EEG, MEG

1 Introduction

With the development of science technology, externally energized prosthesis is replaced ornamental hand prosthesis and rope traditional hand prosthesis. The current focus is development of prosthetic hand with multi-degree-of -freedom and intelligent sensing, the purpose is to improve flexibility of prosthetic hands, the inter-communication ability of environment information and autonomy of prosthetic hand. After entering the 21th century, the requirement of prosthetic hands' multi-perceived information feedback is higher and higher in biomedical field and ammunition industry. Meanwhile, in order to imitate the function of human's hands and improve bionic intelligence of prosthetic hand, Prosthetic hand signal source has become a hotpots research.

The purpose of prosthetic hand's research is to improve self-care for amputees, narrow the functional gap between the patient and healthy person, ensure amputees mental health and enhance social morality and the development of medical industry and warfare business. Meanwhile, the research of prosthetic hand with signal source is a multidisciplinary field: information fusion technology, electronic information, and so on, which promotes mutual penetration of each advanced technology. The function of human's limb system and its perceptional feedback are complex. How to make sure hand's signal source is a very complicated conundrum which follows the whole human history, while commercial electric prosthetic hands mainly use EMG control and applied in many fields. There still exist some questions. For instance, patients who use prosthetic hand with EMG control can fit tired easily, and with a very bad reproducibility on information model. The signal is terribly interfered by external electric field and. detected EMG can't totally report the sports command which sent out from sports area in brain. It is necessary to add signal source to prosthetic hand system for the hand imitation and the improvement of hand parentheses' bionic Intelligence to fulfill human's demand.

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Otto Bock, Motion Control, Liberating Technologies and Touch Bionic Inc. are representative companies in the world at present. According to the investigation of amputees, an ocean of amputees is unwilling to be equipped with prosthetic hand on sale and most of amputees with prosthetic hands are unsatisfied. The main reason is that the function of prosthetic hands is simple, its bionic performance is dreadful and there is a large gap between prosthetic hands and real hands. Amputees dream of having a sound body. And amputees with prosthetic hand wish to control the prostheses according to their own will and have function of perceptional feedback. At present and after a long time the man goal of prosthetic hand research is not only to make improvement in intelligence aspect, but also bring the probability of improvement or treatment to amputees and to improve its intelligence. Human hand is a bio-mechanical system with multilevel control, stimulation, and input and output channel of information reception, which can achieve various ingenious and complex actions via coordinated control of nervous system. Whereas conventional prostheses use vision as feedback to check the coherence with movements and signals, unlike human hand can work without nerve conduction. Consequently, to make prosthetic hand as same as human hand with a quick and concise react is becoming the front edge and hot spot of rehabilitate engineering.

Since Winner proposed a famous Cybernetics in 1948, researchers devoted themselves to study how to make biological signal controlled so that relations can be completed. Control signal sources included mechanical movements, voice, reconstructed fingers, EMG, EEG, MEG and so on. A comprehensive description of signal sources of prosthetic hand is provided below.

2 Prosthetic hand control

The research about structure of prosthetic hand[1]mainly involves two aspects: one is for multi-joints and multi-DOF; the other is for partial amputation. Based on its structure, prosthetic hand control with important practical value in clinic medicine, ergonomics, rehabilitation medicine[2], sports science and other fields, to some extent, decides the practicality of prosthetic hand.

The control[3] process of prosthetic hand is mainly through the observation of human eyes, then to the reaction of human body and finally to the movement of prosthetic hand, in which the core issue is the completion from human reaction to the movement of prosthetic hand. Lets take myoelectrical prosthetic hand[4] for example to make a brief introduction for prosthetic hand control. Surface electromyography (SEMG)[5] signals are the time and space synthesis result of complicated muscle electricity active on the top of the skin, mainly collected by surface electrodes [6] and its control theory is utilizing the weak myoelectric potential changes detected on the muscles of amputation stump of limb disabilities, which could reflects humans will, as the control signal for the movement of prosthetic hand, thus substituting the lost effector (hand) of human body. The whole control process is through the observation of human eyes, then the human body reacting to it, causing a change in myoelectric potential[7], and prosthetic hands make corresponding movements via the collected myoelectric signal. The collection and processing of signals the accuracy of the movement of prosthetic hands is decided by the collection and processing of signals in the whole process. As Fig 1 shown, Zhang Daohui chooses five different hand movements and accordingly presents four setting position of surface electrodes, then he draws a conclusion that different movements correspond to muscles with different functions.

Figure 1. In view of 5 hand movements of 4 surface electrode's placement

The processing of signals decides the accuracy of the completion of movements, aiming to extract the useful information from myoelectric signals and applied in prosthesis control more effectively. Traditional prosthetic hand with myoelectric control utilizes the power of myoelectric signal[8]as control parameters, but owing to power is merely one item of the signal parameters, many information are underutilized. Since Gaup proposed a method of AR parameters model to make functional separation of myoelectric signals in the system of prosthetic hand control, the study of prosthetic hand with myoelectric control enters a new period of development, in addition, there are some other typical ways like Sardiss analysis and classification of myoelectric model, Hogans optimal estimation method [9], Parkers model classification etc[10].

3 Control signal source

3.1 Taking mechanical movement of human body as signal source

This control method of upper limb prosthesis [11] mainly uses the remaining motor function of patients to control prosthetic hand by transmission devices [12] triggering of appropriate switches. It is a kind of mechanical prosthetic hand in early times, as Fig 2 shown. In the early studies like Gulaizefu, he used three-dimensional positioning measurement equipment to

detect patients specific movement, aiming to utilizing neural network[13]to determine the corresponding control instruction. Based on Simpsons theory that patients could control artificial limbs by measuring angle of uninjured joints, Aghili established relational mapping between closed-loop curve of the movement of shoulder joint and the corresponding movements, and use discriminant function to determine angular vector between elbow joint and wrist joint.

Figure 2. Mechanical Prosthetic hand

3.2 Use Voice as signal source

Acoustic control type of hand prosthesis[14]is used by paraplegia patients to restore movement function, which has incomparable superiority. Patient's Voice information is transformed into corresponding control command by DSP[15].

The schematic diagram are presented as follows:

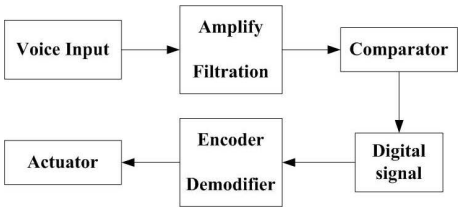

Figure 3. Voice Control schematic diagram

Patients' vocal cord vibration causes signals, and then they amplified and filtered in amplified circuit, signals changed into digital signal due to the comparator. At last, digital signals coded and decoded to make the actuator work.

At present, acoustic control technology[16]has been widely used in every field. Such as Moxing Company in England that produced a type of robot controlled by voice. Robots copied doctor's order, so that endoscope, this kind of elongated surgical instruments, was put in the patients through a small incision. All above provided stable and clear images for microsurgical operation. Walter R[17]designed a voice-activated wheelchair model. This kind of model can get the control accuracy of about 100%on the circumstance of environmental noise belonged low and medium level.

Acoustic control technology[18]on the application of hand prosthesis has stepped into an experimental stage and begun to market. Sivaram produced a kind of hand prosthesis system relied on simple language, this system get a good control and can finish more instruments when instruction words are increasing. What's more, Wang Congzheng[19]put out a portable DSP system which provided enough control instructions to control electric prosthesis accurately.

3.3 Use "Reconstructed finger" as signal source

Electric hand prosthesis use EMG to control[20]its accuracy which is hard to improve. In order to break through the barrier, Professor Hu and academician Chen Zhongwei change the original model and start with another alternative source, applying microsurgical technique to recovering fields[21]. A reconstructed finger which is put upon the residual limb was used to deliver human brain message precisely as a signal source. The method is that, after patients are given a general anesthetic, the second digit with vascular pedicle is transplanted on right forearm stump by microsurgical operation. After reengineering "finger" surviving, recover training is started again. Physics method (temperature, pressure, displacement) can change the control information into operation, thus, to realize the precisely control on hand prosthesis[22].

Reconstructed finger used as signal source, a new conception combined medicine with engineering is opened up. There is a vital guide meaning upon theory and practice. Patients' using tracking indicates that hand prosthesis not only can deliver the brain's movement information correctly, but also rebuild the weight capacity. Hand prosthesis with three multiple degrees of freedom with six movement with a quiet high accuracy almost 100%.

3.4 Use EMG signal as signal source

The myoelectrically controlled hand is a new type of dynamic prosthetic hand by using EMG [23]as the control signal, and its a typical Human-machine system. The schematic diagram is presented as follows:

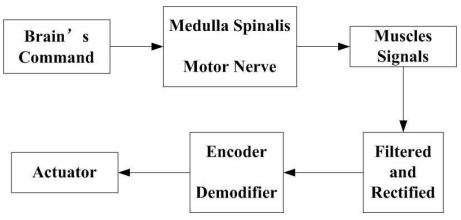

Figure 4. SEMG Control schematic diagram

The sports command was produced in Patients brain, and then they go through the medulla spinals and motor nerve to the muscle. Signals that are collected by electromyographic electrode filtered and rectified. At last, signals coded and decoded to make the actuator work[24].

Researches about EMG signal[25]have been started at in 17century. The fact that muscular contraction is related to electrical changes was proved by Galvani in 1791. Human muscular contraction[26]can produce electrical signal was firstly discovered by Dubios Reymond in 1849. Noble prize owner Gasser and Newcomer use cathode ray oscilloscope show the electrical changes[27]produced by muscle movement. After 1960s, analytic technique of EMG signal has developed rapidly and was widely used in areas like sport medicine, rehabilitation therapy[28]and clinical diagnosis[29]. EMG signal has become a research hotpot.

To help people who has disability in arms live a normal life, we hope to operate them with impersonate artificial limbs, the most natural way is to use signals from their remaining arm to regular certain facility and complete trivial movements. In 1986, P. Paker and R. Scott from a Canada collage named New Brunswick use surface EMG signal[30]to control electric artificial limb, this research is groundbreaking. With the slapping development of electronic technique and information technology, and the progress made in neuromuscular physiology research, we can conduct careful research about the relation between surface EMG signal and neuromuscular function, which can provide a found technique basement to researches focus on provide patients who have different degree of damage with different artificial limbs[31]. In 1945, Reihold Reier from Germany published his research result about use EMG to control artificial limb, and manufacture the first EMG control prosthetic hand in the world in 1948. The Soviet Union prosthetic center developed the world first functional EMG control prosthetic hand in 1957. In 1960, Kborinsk put EMG prosthetic hand into clinical usage for the first time. In 2004, LOWA State University from the US developed a kind of prosthetic hand formed by spring, compression link, rope and conduit. In 2007, David Gow[32]from UK designed a kind of bionic hand i-Limb which is used in clinical rehabilitation, As Fig 3 shown. Harbin Institute of Technology institute of intelligent robotics has started the research on artificial limbs since 2001, up to now they have already developed the 4th generation HIT artificial limb which has 13 joints and equipped with 3 electric motors. Korea Kyungpook National University designed KNU machine hand[33] with self-locking and self-adoption functions. Self-locking device is designed to block outside interference, this can guarantee that finger will be pulled back by load when powered down. Finger joint was equipped with elastic element, making machine hand[34]can drive five fingers and has a strong self-adoption capacity to the shape of grasping object when there are only 2 electric motors drives it, moreover, small objects can also be grasped.

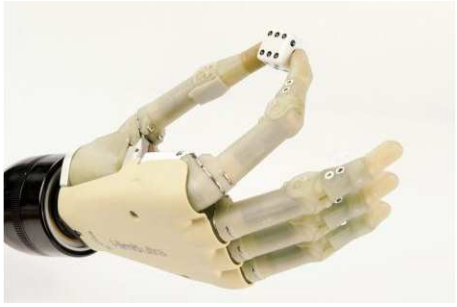

Figure 5.hand i-Limb

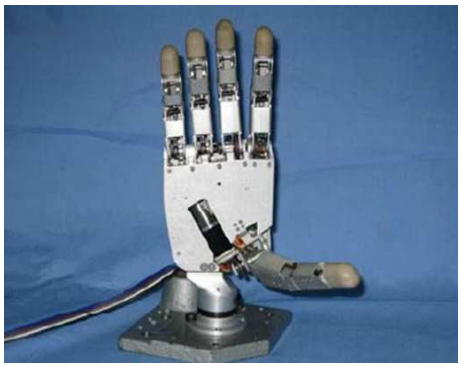

Figure 6.hand HIT

In recent years, with people's deepening cognition to nonlinear characteristics of neuromuscular system, experts start using nonlinear mathematical methods to analyze EMG signals. It mainly consists of iEMG and RMS in time domain analysis respect. Calculation method of iEMG is:

$$iEMG = \int_{t}^{t+T} |EMG(t)|dt \tag{1}$$

Calculation method of RMS is:

$$RMS = \left(1/T \int_{t}^{t+T} EMG^2(t)\,dt\right)^{1/2} \tag{2}$$

Mean Power Frequency (MPF) and Median Frequency (MF) are used for quantitative characterization of sEMGs frequency spectrum or power spectrum in frequency domain analysis respect. The calculation methods are presented as follows:

$$MPF = \int_0^{\infty} fp(f)\,df \Big/ \int_0^{\infty} P(f)\,df \tag{3}$$

$$\int_0^{MF} P(f)\,df = \int_{MF}^{\infty} P(f)\,df = \frac{1}{2}\int_0^{\infty} P(f)\,df \tag{4}$$

Because FFT spectrum curve of sEMG is not typical normal distribution, spectrum characteristic of sEMG

characterized by MF is better than MPF from statistics perspective. But the sensitivity of MPF is better than MFs in specific work.

3.5 Use EEG as signal source

EEG[35]movement literally is a noise produced by nerves and synapsis when CNS is working. In 1875, English physiologist Richard Carton got a small current from rabbit's and monkey's brain. Researches about brain show that EEG movements connected with movements information. Prosthetic hand can be controlled if EEG[36] or its branches transmitted into a new output channel and exchange the information with outside. For the present researches, the EEGs amplify and collection is still defined as a difficulty.

A circuit table about brain's signals' collection listed, the schematic diagram is presented as follows:

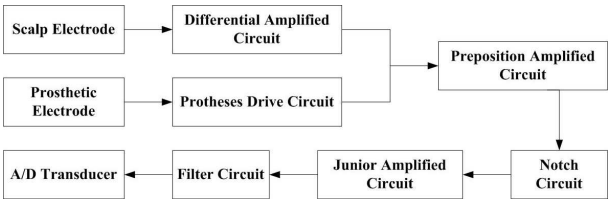

Figure 7. EEG Control schematic diagram

The circuit's preposition amplified circuit which is used high precision, brain signal that is trapped and filtered in amplified circuit, and eventually mixed into system.

Therefore, many scholars had made a huge quality of research. Pfurtscheller[37] designed BCIs[38]. Finger's movements are recognized by the user's imagination movement. Whats more, the device can distinguish the imaginative movement from left and right hand. Roberts put out a quicker and more accurate real-time BICs joggle system based on single channel to weak EEG signals[39]. As a result, Roberts detected out data are classified which get from a 8-order AR model[40]and Bias logic separator to control the mouse up and down movements with the performance of 82%[41]. Zhulinlian, researchers from Dalian University of Technology, applied the theory of somatosensory stimulation causes wave P300. He designed a hand prosthesis which would do six movements only by three-degrees-of freedom. ChenMing, Gaoshanghai from Tsinghua University designed cursor control system in view of SSVEP. 4 blocks in screen represent 4 positions. They are flickering in their own rate range 6Hz to 9Hz, which applied FFT to deal with SSVEP to judge coiner's eyes, fixed on blocks and control cursor's moves. Hereafter, ChenMing, Muller designed another BCI based on SSVEP to control hand prosthesis. BCI equipped with much visual stimulation and each stimulation is corresponded an operation. There will be caused SSVEP with different rates when users watched different stimulations. Four movements can be controlled in this way. In June, 2006, Institute of Neural Engineering of Medical College, Tsinghua University displayed advanced BCIs. With imagine to "kick" the football means dog robot can kick the soccer all controlled by two students wear a special cap.

The method for the present researches mainly based the wavelet transformation on the brain signals extraction and analysis. $f(t)'$ swavelet transformation defined as:

$$\int_0^{MF} P(f)\,df = \int_{MF}^{\infty} P(f)\,df = \frac{1}{2}\int_0^{\infty} P(f)\,df \qquad (5)$$

For the problem about EEG's extraction[42]and its analysis, a portable EEG acquisition system based on DSP is designed by Wang Peng[43], Noninvasive EEG signal is responded to pretreatment by the ways of bipolar lead, after multistage amplified and filtering to make signal digitalized, again by digital filter, power frequency interference and physiological artifact are filtered by using the least mean square algorithm and independent component analysis. Zhang Xiaodong proposed a new brain-computer interface way based on expression drive. Neuron clustering model is used to analysis and model the facial EEG, and get a spontaneous expression related with brain areas and its frequency distribution. Duan Suolin put forward a kind of specific frequency bands of wavelet packet based on wavelet packet variance. A way to extract EEG makes wavelet package entropy patterned with common space. Shi Weijun designed and implemented automatic detection of EEG noise method. Zhang Shaobai proposed an EEG adaptive sparse decomposition model which is extracted its own features.

3.6 Use MEG as signal source

The current between muscles and nerves can form external magnetic fields, such as MCG and MEG. The very first reliable experimental measurement of biological magnetic was completed in1963, Baule and Mcfee used two side by side coils (gradient meter) recorded MCG[44]for the first time. Several years later, S.Williamson and his colleague proved that MEG can be measured by second gradient meter when background noise is relatively strong (like in urban area) and without shielding.

4 Prospection of the research

The research of use artificial limb to control signal sources is a work of great challenge and can bring great beneficial result to the society. Present there are various methods to control signal source. In the following passage, we will

make brief introductions of the features of different control methods of signal sources, and make comparison. Through we can make a prospection of this research area.

1) Artificial limb that use mechanical motions as control method of signal source is economic and has a simple structure, thus makes is popular among some patient. However, it can only accomplish extremely simple control missions and lake of flexibility.

2) The design basement of vocal control artificial limb is simple language order control system, with the development of computer technology the system can be programmed to complete more functions. Whats more it is easily controlled and of high precision. As for shortcomings, other voices made by patient in their life may give order to the movement of the artificial limbs. How to improve the background noise proof ability is the problem that requires immediate solutions.

3) Reconstructed finger open up a new way to combine medical science with engineering science, it is of great guide meaning no matter theoretically and practically. This kind of artificial limb can not only deliver brains movement messages correctly, also it rebuilt the gravity sensing ability which is of high control precision. But, to install these artificial limb patients will have to suffer the pain of operation, and to carry this operation will need microsurgical technique which limit its spreading. It will take a long time to recover after operation.

4) Myoelectric hand has been a great success in practical application because electromyography signal can correctly response to limb moves. Whereas, if the patient has a short meromelia or muscular atrophy, he cannot provide enough control messages, whats more muscle fatigue, change of position of electrode and the training of electromyography signal can influence the accuracy of electromyography signal. Apart from all above, the electromyography signal degree of freedom is an important point.

5) Use EEG movement recorded by scalp as signal source, free of the control of nerve-muscle, thus even the most damaged patient can use it. Electrical stimulation will not influence the record of EEG. However, EEG process is very complicated, present research related to it is very limited. To build a system that completely controlled by EEG will need a breakthrough in brain science research, and that is a long though journey to go.

6) Develop limbs controlled by MEG. The first problem need to be solved is to deal with the man-machine joggle so that a reasonable relationship is established between EEG and hands' control instruction. The research remains in some important brain areas of surgical operation and insufficient assessment about brain function. Its application is still explored.

EMG applied most in prosthetic hand' control nowadays. EMG is more flexibly than mechanical movement signal source; it also can complete a more complicated one. Compared with other kinds of methods, use EMG and voice as signal source need not burden any operation risks. Brain waves and MEG involve nervous system and nervous signal is regarded as an ideal one because they are not interfering each other and clear enough. Otherwise, Researches proves that nerves system is plastic and has a good ability of adaption to outside. The most important is that nerves system gets recover ability on its structure and function. Superiority is outstanding among all the features of nerve information. Research about nerves information as signal source is a hard difficulties to overcome and which will become a hotspot.

5 Conclusion

The theory of hand prosthesis and its signal sources are introduced and the research development about signal sources is surveyed in this paper. These control signal sources include mechanical movements, tendon, reforge fingers, nerves message, and so on. Artificial limb that use mechanical motions as signal source is mainly use patient's residual sports function to touch off corresponding switches by gears. Vocal control artificial limb is to transmit patient's voice information to corresponding control demand by DSP. Reconstructed fingers as signal source, which is to rebuild another finger which can deliver mind's sports information upon the disabled. Myoelectric hand's signal source comes from the action potential stump muscle. Artificial limb that use EEG, MEG as signal source is basically regarded nerve information as control information. Currently, a huge number of hand prosthesis applied myoelectric signal as control signal source, and the research of hand prosthesis which use nerve information as control signal source is a new trend. Not only the research and efforts of this field has great theoretical value, but also has great market value.

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References

[1] Z.X. Pang, L.N. Gong, D.W. Jiang et al., Journal of Changchun University of Technology(Natural Science Edition) **34**, 264-267(2013).

[2] Y. Sun, Z.Z. Luo, W. Wei, Space Medicine & Medical Engineering **24**,128-133(2011).

[3] G.F. Li, J.Y. Kong, G.Z. Jiang , L.X. Xie, Z.G. Jiang and G. Zhao, INFORMATION-An International Interdisciplinary Journal **15**, 4487-4494(2012).

[4] C.Z. Yi, Journal of Yichun University **37**, 46-48(2015).
[5] J.C Chen, X.D. Zhang, R. Li et al, Journal of Xi'an Jiaotong University **49**, 26-33(2015).
[6] W.J. Mei, C.J. Yang, Electronic Components & Materials **34**, 36-39(2015).
[7] Jiang N, Rehbaum H, Vujaklija I., Neural Systems and Rehabilitation Engineering, IEEE Transactions on **22**, 501-510(2014).
[8] Q.Z. Zhang, X.G. Xi, Z.Z. Luo et al., Journal of Basic Science and Engineering **21**, 1999-1209(2013).
[9] Angela P Giddings, Ronald L Rardin, Reha Uzsoy. Journal of Heuristics **20**, 329-358(2014).
[10] L. Wang, Z. Zhang, P. Sun, International Journal of Robotic & Automation **31**, 225-232(2016).
[11] L.Q. Zhang, Y.F. Su, W.Z. Yang et al, International Journal of Biomedical Engineering **36**, 311-316(2013).
[12] Ergun Hakan, Rawn Barry, Belmans Ronnie, IEEE Transactions on Power Systems **29**, 2469-2477(2014).
[13] Patricia Melin, Olivia Mendoza, Oscar Castillo, Computer Applications in Engineering Education **21**, 164-184(2013).
[14] C.Y. Liang, J.T. Luo, L.X. Zhou, Audio Engineering **37**, 70-74(2013).
[15] W. Chen, L.M. Tang, W. Wang et al, Journal of Guangxi Normal University (Natural Science Edition) **33**, 45-53(2015).
[16] R. Nie, Information Technology **38**, 175-177(2014).
[17] Walter R, Frontera, Julien Ochala. Skeletal Muscle, Calcified Tissue International **96**, 183-195(2015).
[18] Nathalia Peixoto, Hossein Ghaffari Nik, Hamid Charkhkar, Computer Methods and Programs in Biomedicine **112**, 156-165(2013).
[19] C.Z. Wang, S. Hu, C.M. Gao et al,Metallurgical Equipment **41**, 58-60,64(2015)
[20] L. Jiang, Q. Huang, D.P. Yang et al,Chinese High Technology Letters **23**,1268-1274(2013).
[21] Keyi Wang, Lixun Zhang, Hao Men, International Journal of Robotics & Automation **28**,35-38(2013).
[22] Y.J. Tian, X.D. Zhang, L.M. Zhang, Machinery & Electronics **10**, 12-16(2015).
[23] L.W Wang, Q. Cai, Y. Xiao et al,Electronic Measurement Technology **34**, 53-55,92(2011).
[24] J.J. Zhang, Bulletin of Science and Technology **31**, 19-21(2015).
[25] Y.F. Fang, H.H. Liu, G.F. Li et al., International Journal of Humanoid Robotics **12**, 1-13 (2015).
[26] D.S. Chen, G.F. Li, Y.Sun et al ,Sensors **17**, 1-17(2017).
[27] Q. Chen, Journal of Beijing Sport University **31**, 226-229 (2008).
[28] Z.Q. Ni, T.M. Wang, D. Liu ,Journal of Mechanical Engineering **51**, 45-52(2015).
[29] J.Y. Wu, B. Yi, Control & Automation **26**, 101-103(2010).
[30] A.B. Xiong, Q.C. Ding, X.G. Zhao et al,Journal of Mechanical Engineering **52**, 6-13(2016).
[31] David Caplan, David Gow, Brain and Language **120**, 174-186(2012).
[32] X.H. Zheng, X.H. Liu, L. Zhang et al, Manufacturing Automation **35**, 147-149(2013).
[33] W.G. Wu, Y. Zhao, Machinery Design & Manufacture **4**, 188-190(2010).
[34] W. Miao, G.F. Li, Y. Sun et al, International Journal of Wireless and Mobile Computing **11**, 348-356(2016).
[35] X.D. Zhang, J. Guo, R. Li et al., Journal of Xi'an Jiaotong University **50**, 1-8(2016).
[36] B.G. Xu, A.G. Song, S.M. Fei, Acta Electronica Sinica **39**, 1025-1030(2011).
[37] Pfurtscheller, Journal of Xi'an Jiaotong University **50**, 1-8(2016).
[38] J. Zheng., Science Technology and Engineering **11**, 8149-8154(2011).
[39] X.F. Tang, J.Z. Zhou, Computer Engineering **41**, 290-294(2015).
[40] W.J. Shi, B. Wang, X.Y. Qing et al, Journal of East China University of Science and Technology (Natural Science Edition), **41**, 659-665(2015).
[41] S.B. Zhang, Y. Wang, Y.Y. Liu, Acta Electronica Sinica **43**, 700-707(2015).
[42] S.L. Duan, Y.K. Shang, L.Z. Pan, Computer Measurement & Control **24**, 283-287(2016).
[43] P. Wang, S.S. Li, M.L. Shao, Journal of Harbin University of Science and Technology **21**, 77-82(2016).
[44] L. Gao, L.Y. Huang, C.L. Ding, Journal of Xidian University (Natural Science) **34**, 939-943(2007).

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