DEVELOPMENT OF HUMAN-ROBOT COLLABORATIONWITH COLLECTIVEINTELLIGENCEFOR CYBER-PHYSICAL SYSTEM

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Abstract- With the advent of the intelligentization era, "Production on Demand" is the important manufacturing mode."Cyber-Physical System" is the key architecture for intelligent manufacturing systems. So it is more important to develop human-robot collaboration with collective intelligence for cyber-physical system.In the paper, a human-robot collaboration with collective intelligence for cyber-physical manufacturingsystem is proposed. It includes intelligent communication, intelligent coordination, intelligent cooperation and intelligent shared creation.Particle swarm optimization, artificial immune system algorithm and artificial fish swam algorithm will be used as artificial intelligence for cloud computing in the system.Finally, all the design flow and results of intelligent collaboration is presented. For human-robot collaboration, it increases overall competitive performance of products, reduces cost of products and consummation rates of human resources.

Keywords- Human-Robot Collaboration,Collective Intelligence, Cyber-Physical System, Intelligent System.

I. INTRODUCTION

With the advent of theintelligentization era,"Production on Demand" is the important manufacturing mode."Cyber-Physical System" is the key architecture for intelligent manufacturing systems. So it is more important to develop human-robot collaboration with collective intelligence for cyber-physical system. In 2011,Xu, Xun et al. [1]present a novel service-oriented remanufacturing platform which is introduced based on Cloud Manufacturing paradigm. And a LCD television model is taken to evaluate the proposed cloud remanufacturing service mechanism and information management methodologies during case studies.In 2011,Liu,Jian-Hong et al. [2]proposed an application cloud system, namely ACES (Application Cloud for Embedded Systems), which would be an effective approach to offloading the execution of applications from embedded system platforms to the cloud and helps transit to cloud computing. ACES allows existing applications, which are not developed for cloud computing, to be deployed on the server side in a cloud computing environment. And they can be executed, through operating a browser, from embedded system platforms on the client side. There is no need either to modify or port the existing applications in the deployment. In 2011, Hashemipour,M et al. [3] proposeda three tiered model for integrating the WSN (Wireless Sensors Network) into the function blocks for realization of the distributed intelligent manufacturing control system. The WSN is a technology that enhances flexible, distributed sensing, and collaborative information processing for the distributed intelligent manufacturing control paradigm. The integration of the emerging WSN technology into this framework in order to enhance the re-configurability and flexibility through the wireless sensing and distributed information processing provided by a network of wireless sensors. The IEC 61499 function blocks have become an industry standard which has been empowered with the Multi-Agent Systems in a framework for added intelligence in manufacturing automation.In 2013,Tiwari, P.K. et al. [4] demonstrated to realize a convergence of wireless sensor network with analytics software. The wireless sensors transmit data at regular intervals through the 2.4 GHz ISM band to a coordinatorwhichforwards the aggregated data to a messaging software. These messages can be further forwarded through a message broker to database servers and web servers via internet. By the time stamps, topics, and payloads of the messages which can be visualized using a GUI explorer of the messaging software and further forwarded through a message broker to database servers and web servers via internet, the analytics software could make use of the live data to provide decision support for engineers, automated control system, and actuators. In 2013,Morosabn A. D. et al. [5]present an intelligent system designed to increase the efficiency of production in a flexible manufacturing line.The intelligent systems represents a new paradigm in production, which is manufactured for quickly adjust of the production flow and functionality of the system in response to the new demands of the market production.In 2013,Ding, Hao et al. [6] proposed an approach for structuring the collaborative behavior using finite state automata (FSA). And the approach is extended to deal with multiple human-robot collaboration by applying the composition rules of FSA. Finally,the approach is demonstrated in an ABB Dual-Arm Concept Robot working with multiple human workers in an industrial assembly scenario. In 2014,Lenz, Claus et al. [7] proposed the concept of a collaborative human-robot

workspace in production environments. Modalities including audio and visualizations are used for informing the human worker about next assembly steps and the current status of the system. To prevent errors and to increase ergonomic benefits, the robot supplies the human worker with needed parts in an adaptive manner. Further, the human worker can intuitively interact and adjust the robot using projected menus on the worktable and by force-guidance of the robot. In 2014, Madureira,A. et al. [8] present a negotiation mechanism for dynamic scheduling based on swarm intelligence. Swarm intelligence is the general term for several computational techniques which use ideas and get inspiration from the social behaviors of insects and other animals. Agents must compete to obtain a global schedule under the new negotiation mechanism. In brief, this work is concerned with negotiation, the process through which multiple self-interested agents can reach agreement over the exchange of operations on competitive resources. In 2015,Su,Jianhua et al. [9]present a strategy of human-robot collaboration in grinding system.The strategy of human-robot collaborationis firstly detected by tracking the operator motion and ensures an operator should not be collision with a robot arm in a collision-avoidance region. Whenever a possible collision with the robot and operator is predicted by using a path planning method of NURBS (Non-Uniform Rational B-Splines), the robot trajectory could be changed.Hence, a human-robot collaboration grinding system is built to enable a robot to perform safe grinding operations with the aid of humans. In 2015, Coupeté,Eva et al. [10] studied on a collaborative task between a robot and an operator. They present a framework and preliminary experimental results for technical gestures recognition using a RGB-D camera and reached a good recognition rate of 93% by using gesture from the same operator for the learning and the recognition.In 2015,Cherubini, Andreaet al. [11]present a multimodal sensor-based controller, enabling a robot to adapt to changes in the human collaborator behavior. Finally, the approach is validated in a mock-up industrial scenario, where pose, vision (from both traditional camera and Kinect), and force tasks must be realized either exclusively or simultaneously, for human–robot collaboration. In2015, Faber, Marco et al. [12]described the requirements for a workplace, where humans and robots jointly perform an assembly process without separation between their workspaces. And the requirements are identified in line with an ergonomic workplace for different aged working persons, whereas the robot assists the human with the assembly process. Consideringanalysisof technical, human-related, and normative requirements, an early implementation of the concept is presented based on a cognitively automated assembly system using a lightweight robot.In 2015,Flores,ReneLopezet al. [13]present an information-based software framework for collaboration in the problem resolution process. This information-based software framework proposes the implementation of techniques from the collective intelligence research field in combination with the systematic methods provided by TRIZ theory and improve the individual creativity provided by TRIZ method and tools, with the value created by the collective contributions.Cyber-Physical System (CPS) that integrates computational and physical capabilities has emerged as a promising topic. In2015, Liu, Lei et al. [14]developed a CPS model in light of fuzzy feedback linearization. The chaotic time prediction algorithm which takes both tracking control problem and synchronization control problem into accountis applied to solve the chaotic control problem in CPS.The experimental results suggest that the developed method is feasible and efficient in tracking control and synchronization of two chaotic CPS. To sum up, a human-robot collaboration with collective intelligence for cyber-physical manufacturing system is developedin the paper. It includes intelligent communication module, intelligent coordination module, intelligent cooperation module and intelligent shared creation module.

II. DESIGN OF INTELLIGENT COMMUNICATIONMODULE FOR COLLABORATION

For the purposes of communication module,the low cost,the high efficiency and the high correctness of information exchange and understandingare the goals. The computing model of intelligent communication is built up by using particle swarm optimization (PSO) method. The architecture of the intelligent communication module using PSO method is shown as figure 1. The names and the meanings of the parameters forthe intelligent communication module are listed in table 1.And the flowchart of the intelligent communication module using PSO methodis shown as figure 2.

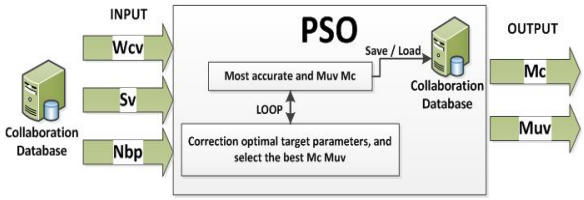


Fig.1.The architecture of the intelligent communicationmodule using PSO method

Table1:The parameters for the intelligent communication module

	Parameter Name	Parameter Explanation
Input	Wcv	Working competent value
	Sv	Synchronization values
	Nbp	New best processes
Output	Mc	Message correctness
	Muv	Message understood validity

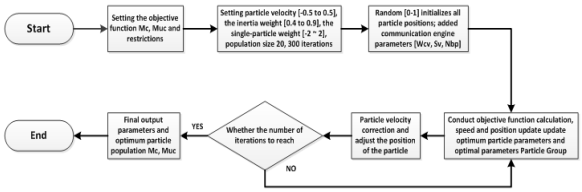


Fig.2.The flowchart of the intelligent communication module using PSO method

III. DESIGN OF INTELLIGENT COORDINATION MODULE FOR COLLABORATION

The low cost, the high efficiency and the high correctness of taskconsensusandcompromiseare the goals for the purposes of coordination module.The computing model of intelligent coordinationis built up by using artificial immune system (AIS) method. The architecture of the intelligent coordinationmodule using AIS method is shown as figure 3.

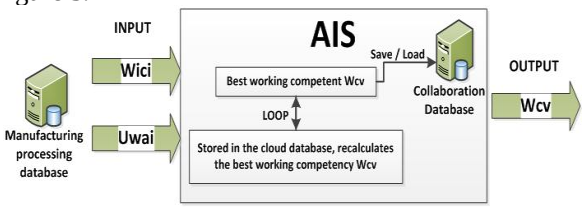


Fig.3.The architecture of the intelligent coordination module using AIS method

The names and the meanings of the parameters forthe intelligent coordinationmodule are listed in table 2.And the flowchart of the intelligent coordination module using AIS methodis shown as figure 4.

Table2:The parameters for the intelligent coordination module

	Parameter Name	Parameter Explanation
Input	Uwai	Unit (worker or robot) work ability index
	Wici	Work Item Capability Index
Output	Wcv	Working competent value

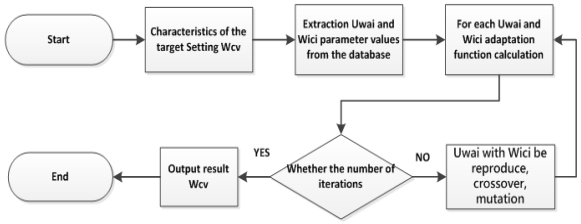


Fig.4.The flowchart ofthe intelligent coordination module using AIS method

IV. DESIGN OF INTELLIGENT COOPERATION MODULE FOR COLLABORATION

For the purposes of cooperation module,the low cost, the high efficiency and the high correctness of integration of objectives and capabilityare the goals. The computing model of intelligent cooperation is built up by AIS method. The architecture of the intelligent cooperation module using AIS method is shown as figure 5. The names and the meanings of the parameters for the intelligent cooperationmodule are listed in table 3.And the flowchart of the intelligent cooperation module using AIS method is shown as figure 6.

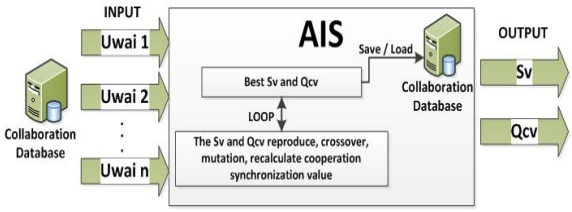


Fig.5.The architecture of the intelligent cooperation module using AIS method

Table3: The parameters for the intelligent cooperation module

	Parameter Name	Parameter Explanation
Input	Uwai	Unit (worker or robot) work ability index
Output	Sv	Synchronization values
	Qcv	Quality consensus value

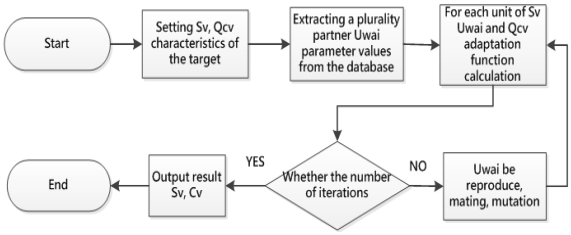


Fig.6.The flowchart of the intelligent cooperation module using AIS method

V. DESIGN OF INTELLIGENT SHARED CREATION FOR COLLABORATION

The high efficiency,the low costand the high correctness of values and innovation are the goals for the purposes of shared creation module. The computing model of intelligent cooperation is built up by artificial fish swam algorithm (AFS) method. The architecture of the intelligent shared creation module using AFS method is shown as figure 7. The names and the meanings of the parameters for the intelligent shared creation module are listed in table 4.And the flowchart of the intelligent shared creation module using AFS method is shown as figure 8.

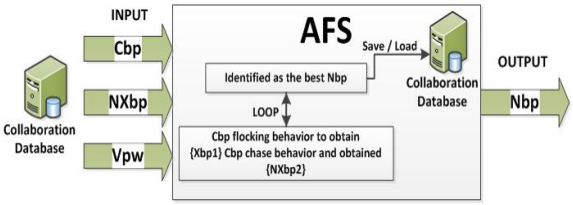


Fig.7.The architecture of the intelligent shared creation module using AFS method

Table4:The parameters for the intelligent shared creation module

	Parameter Name	Parameter Explanation
Input	Cbp	Current best processes
	NXbp	Next best processes
	Vpw	Volume of project work
Output	Nbp	New best processes

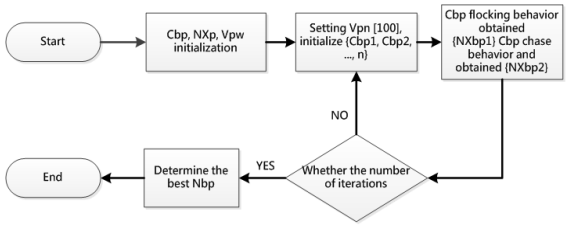


Fig.8.The flowchart of the intelligent shared creation module using AFS method

VI. RESULTS AND DISCUSSION

Ubiquitous human machine interface for the intelligent communication module using PSO method is shown as figure 9. For example, we can find the computing correctness of the intelligent communication module are (1)the correctness of thecoordination message:1.0043 ; (2)the correctness of the cooperation message: 1.0591 ; the correctness of the shared creation message: 1.0147. The effective range of the correctness in the collaboration database is [1 – 1.05]. If the correctness is in the range, "YES" is showed. Otherwise, "No" will be showed.Theexperimental results are shown as figure 9.

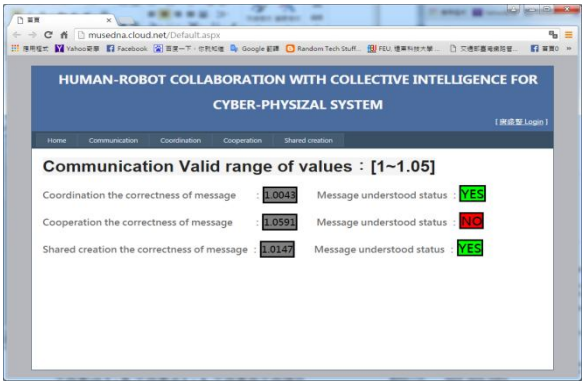


Fig.9.Ubiquitous human machine interface for the intelligent communication module using PSO method

Ubiquitous human machine interface for the intelligentcoordination module using AIS method is shown as figure 10. For example, we can find the computing correctnessof task consensus andcompromiseof the intelligent coordinationmodule are (1)the values of thetask consensus between worker 1 and worker 2: +0.1 and +0.3 ; The effective range of the consensus in the collaboration database is [-0.5 – +0.5].(2)the values of thecompromise: 5.6 and 5.8 ; The effective range of the compromise in the collaboration database is [5.5 – 6.0]. The experimental results are shown as figure 10.

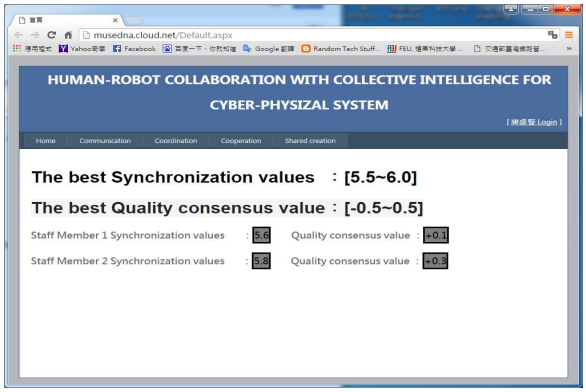


Fig.10.Ubiquitous human machine interface for the intelligent coordination module using AIS method

Ubiquitous human machine interface for the intelligentcooperation module using AIS method is shown as figure 11. For example, we can find the computing of objectives and capabilityof the intelligent cooperationmodule are (1)the values of thecapabilityfor workers(human worker or robot worker): Worker A is +0.2and Worker B is -0.3 ; The effective value of the capability in the collaboration database is over 6.If the capability is over 6, "YES" is showed. Otherwise, "No" will be showed. The experimental results are shown as figure 11.

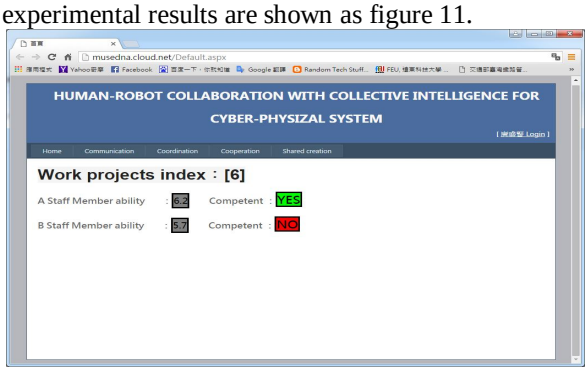


Fig.11.Ubiquitous human machine interface for the intelligent cooperation module using AIS method

Ubiquitous human machine interface for the intelligentshared creation module using AFS method is shown as figure 12. The new workflow will be generatedfrom the intelligentshared creation module using AFS computing. As figure 13 shown,the work status of human-robot collaboration with collective intelligence for cyber-physical systemwill be showed on App of mobile devices.

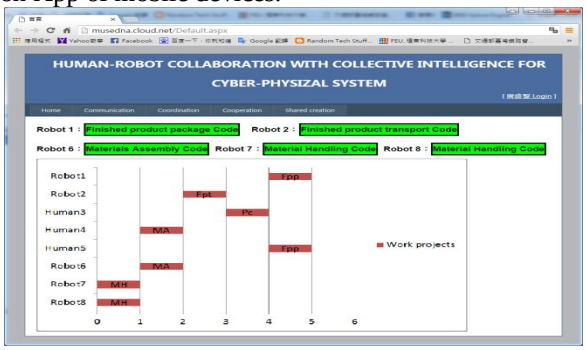


Fig.12.Ubiquitous human machine interface for the intelligent shared creation module using AFS method

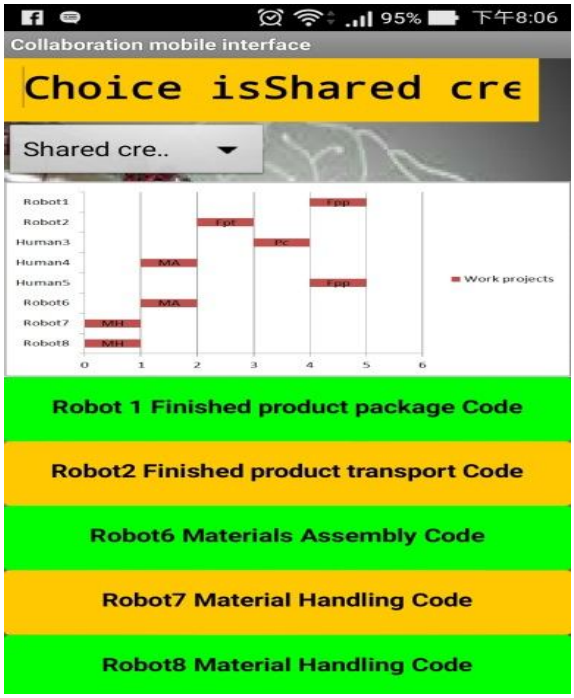


Fig.13.The work status on App of mobile devices for cyber-physical system

CONCLUSIONS

The goal of the paper is to develop a human-robot collaboration with collective intelligence for cyber-physical manufacturing system. It includes intelligent communication, intelligent coordination, intelligent cooperation and intelligent shared creation.For the purposes of intelligent collaboration, the low cost, the high efficiency and the high correctness of the information exchange and understanding, task consensus andcompromise, integration of objectives and capability, values and innovationare the goals. Particle swarm optimization, artificial immune system algorithm and artificial fish swam algorithmwill be used as artificial intelligence for cloud computing in the system. Finally, all the design flow and results of intelligent collaboration is presented. For human-robot collaboration, it increases overall competitive performance of products, reduces cost of products and consummation rates of human resources.

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