Editorial

Hongnian Yu*

Faculty of Computing, Engineering and Technology,
Staffordshire University,
Stafford, ST16 9DG, UK
E-mail: h.yu@staffs.ac.uk
*Corresponding author

Hiroshi Inaba

The 21st Century COE Program,
Tokyo Denki University,
Hatoyama-machi, Hiki-gun,
Saitama 350-0394, Japan
E-mail: inaba-hiroshi@coral.broba.cc

David H. Owens

Department of Automatic Control and Systems Engineering,
University of Sheffield, Mappin Street,
Sheffield S1 3JD, UK
E-mail: D.H.Owens@Sheffield.ac.uk

Katsuhisa Furuta

The 21st Century COE Program,
Tokyo Denki University,
Hatoyama-machi, Hiki-gun,
Saitama 350-0394, Japan
E-mail: kfuruta@jcom.home.ne.jp

Biographical notes: Hongnian Yu is currently a Professor of Computer Science and Head of the MCDS Research Group at Staffordshire University. He has extensive research experience in modelling and control of robots and mechatronics devices and neural networks, mobile computing, modelling, scheduling, planning and simulations of large discrete event dynamic systems, RFID with applications to manufacturing systems, supply chains, transportation networks and computer networks. He has published over 140 research papers and held several grants from EPSRC, the Royal Society and other funding bodies. He is a member of the EPSRC Peer Review College and serves on various conferences and academic societies.

Hiroshi Inaba joined Tokyo Denki University (TDU) as a Professor in 1977. Since 1986, he has been with the Department of Information Sciences where he served as the Founding Chair. He served as Dean of the Graduate School of Science and Engineering (1993–1997) and Director of the Research Institute for Science and Technology (2000–2004). He was President of IEEE System, Man and Cybernetics Tokyo Section, Organising Committee member of many international conferences and Editor and Guest Editor of various international journals. He was Leader of the Control Group of the 21st Century Centre of Excellence (COE) Project on Human Adaptive Mechatronics (2004–2007) and currently Professor Emeritus of TDU.

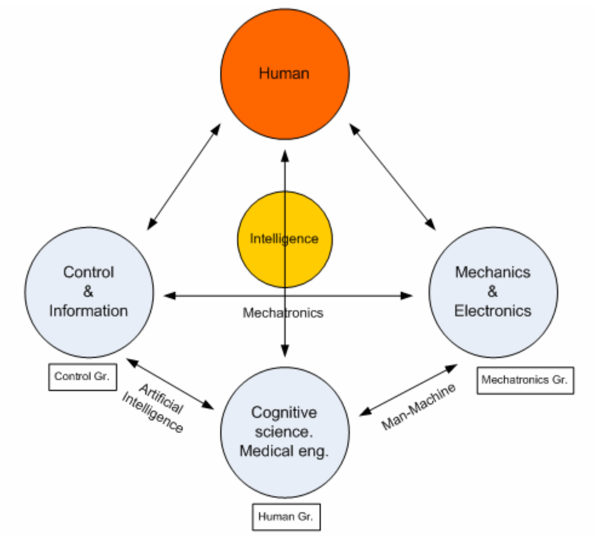
David H. Owens obtained his BSc and PhD from Imperial College and is a Fellow of the Royal Academy of Engineering. He has held academic positions at the Universities of Sheffield, Strathclyde and Exeter. He has been Head of the Department of Automatic Control and Systems Engineering since 1999 and Dean of the Faculty of Engineering (2002–2006) at the University of Sheffield. He was Chairman of the UK Automatic Control Council (1999–2002) and was Joint Editor-in-Chief of the IMA Journal of Mathematical Control and Information until 2007. His current research interests include algorithms for iterative and repetitive control.

Katsuhisa Furuta was with Tokyo Institute of Technology as a Professor of Control and Systems Engineering from 1967 until 2000 when he received Professor Emeritus. Since 2000, he has been with Tokyo Denki University where he served as a Director of the 21st Century Centre of Excellence (COE) Project on Human Adaptive Mechatronics. His research interests lie in the broad areas of system control, robotics and mechatronics. He has held numerous positions in academic societies and received many awards including Honorary Doctorate-Helsinki University of Technology (1998), IEEE CSS Distinguished Member (1998) and IEEE Third Millennium Medal (2000).

1 Concept of HAM and background

The concept of human adaptive mechatronics (HAM) was first proposed in the Center of Excellence (COE) Project of Tokyo Denki University (TDU) (Furuta, 2003; Harashima and Suzuki, 2006; 1st–5th COE Workshop on HAM, 2004–2007). The TDU COE project was awarded as a five-year program by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) of Japan, started in 2003 and ended in 2008. The research was performed by the human, control and mechatronics groups, as shown in Figure 1.

Figure 1 Human adaptive mechatronics proposed by TDU (see online version for colours)



Mechatronics may be roughly defined as a synergetic integration of diverse technologies such as mechanical, electrical, control and information engineering to achieve a high performance of machines. The main aim of the HAM concept proposed at TDU was to investigate and improve the relationship between the human and machine. More precisely, the main HAM objective is to introduce into a human-machine system a capability that the machine can measure or understand the level of skill of its operator (human) and to develop an integrated theory and technology which can adapt itself to the human according to the human's skill so as to maximise the total performance of the human-machine system whilst helping to improve the human's skill. Therefore, HAM is a new discipline that is a synergetic integration of not only mechanical, electrical and information technologies, but also of various human related sciences, including medical science, neuroscience, cognitive science, psychology and so on. It is important to notice that HAM studies a human need to be placed in a closed-loop system. This fact brings a very distinctive feature into activity as compared with ordinary engineering study.

From the systems and control engineering viewpoint, the fundamental problem of HAM is to construct and analyse a mathematical model for human-machine closed-loop systems, which introduces a mechanism that enables a machine to understand or identify a human's skill and to adapt itself to the human so that the performance of this human-machine closed-loop system is maximised as a total system with respect to a certain given performance index. Therefore, it is easily seen that there are at least two important features in HAM study, which need to be particularly emphasised or differentiated from ordinary engineering systems. These two features may be roughly summarised as follows:

1. To accomplish such adaptation of machine to human, it becomes inevitable for a machine to observe and extract sufficient information from the human to understand the human's skill. There would be many theories, tools and techniques developed for ordinary engineering systems which are applicable to measuring the human's skill by machine, but due to a possibility of the necessity of observing and extracting various brain activities and psychological information from the human, the HAM study seems to have quite different and difficult aspects in modelling and analysing such a human-machine system in comparison with the study of ordinary engineering systems.
2. Since a human is placed in a closed-loop system, the strong reliability and stability of the human-machine closed-loop system becomes an extremely important issue in HAM. Due to a possibility of including even psychological and emotional information in the human understanding, the resultant human-machine closed-loop system can be very complex and unusually non-linear, the stability and/or stabilisability of such a system may need to be thoroughly investigated. In fact, some of examples appearing in such systems are so complex that the existing stabilisation techniques cannot be directly applied due to, for instance, a chaotic behaviour in stability against a small parameter change, a high non-linearity causing unstabilisability and/or undetectability of linearised systems and so on. Therefore, a new theory and its implementation technology must be developed for such systems to ensure stability for all possible adaptations of the machine to the human.

Feature 1 above brings a new aspect into the traditional engineering field because accurate measurement of a human's skill may require understanding of various aspects of human behaviour, which has not been studied in depth in engineering. However, understanding a human seems to be one of the most important and difficult problems in HAM studies because it may require not only physical measurements but also psychological measurements from the human and further, in order to understand a human from such measurements, it is inevitable to know and analyse the relationship between the measurements and the skill. Feature 2 belongs to the traditional engineering field, but may involve technically very difficult but challenging problems.

During the past five years, significant research on HAM has been conducted in the TDU COE Project and the EPSRC sponsored UK-Japan HAM collaborative research network started in 2004. In fact, the COE Project organised five COE Workshops on HAM in 2004–2007 (1st–5th COE Workshop on HAM, 2004-2007), a further international joint TDU COE-UK EPSRC Workshop on HAM in July 2005 (Inaba and Yu, 2005) and another joint international workshop on HAM and High Fidelity Tele-presence in October 2005. In addition, many special issues on HAM were edited in international journals (Yu and Inaba, 2006; Uchikawa, 2006; Miyashita, 2007; Furuta, 2007) and invited sessions on HAM have been organised in international conferences (Invited Session on HAM, 2004, 2005, 2007a, 2007b). Moreover, since March 2007 the UK-Japan HAM network has been set up and the network members have performed active research (www.epsrchamnetwork.org.uk). The TDU COE Project was terminated in March 2008 and according to the final report (The TDU COE-HAM Project, 2008), the members of the COE Project published 146 journal papers and 388 international conference papers. However, the HAM study has only just started and its fundamental problems are still far from being solved.

The present special issue had been originally planned to solicit its papers from those presented at the Invited Session on HAM of the IEEE International Conference on Networking, Sensing and Control (ICNSC), London, April 2007, but to speed up and promote HAM study worldwide, it was extended to solicit papers from the international community. There were about 20 paper submissions and 12 papers were selected for publication through rigorous review process. We would like to express our sincere appreciation to all authors and reviewers.

2 Brief summaries of the papers

The current special issue consists of 12 papers, which are, as a matter of convenience, classified into the three groups shown in Figure 1, where the control group roughly covers control and information areas, the human group covers cognitive science and medical engineering areas, and the mechatronics group includes robotics areas.

2.1 The control group (two papers in new control methods)

The first paper, 'Robust practical output tracking by output compensator for a class of uncertain inherently non-linear systems', is contributed by Keylan Alimhan and Hiroshi Inaba. The paper investigates a robust output tracking problem using a dynamic output feedback controller for a family of uncertain inherently non-linear systems in the p-normal form of a particularly complex nature such that their linearisation around the equilibrium state may be unstabilisable and/or undetectable. The paper expanded the previous results developed by the authors.

The second paper, 'Robust gradient iterative learning control: time and frequency domain conditions', is contributed by D.H. Owens and S. Daley. The paper studies gradient-based iterative learning control algorithms for discrete-time systems and analyses the behaviour and robustness of the system in the time and frequency domain.

2.2 The human group (four papers in cognitive sciences and medical engineering)

The third paper, 'Estimating multiple sources in somatosensory area to SEF of finger stimulus using SVD and time-frequency analysis', is contributed by Bong-Soo Kim and Yoshinori Uchikawa. The paper investigates human brain functions with MEG measurements and developing signal processing methods for measured data. The paper proposes a signal processing method for discriminating multiple sources in the human cortex. The proposed method, combining singular value decomposition (SVD) and time-frequency analysis, is applied to the measured somatosensory evoked field (SEF) data for discrimination of second somatosensory activity from primary somatosensory activity overlapping in time. The frequency of dominant power spectrum in each SEF data is investigated and the frequency of the fourth finger stimulation exists between the thumb (16–18Hz) and little finger (13–15Hz).

The fourth paper, 'Extraction of fine blood vessels from an ultrasound image by an adaptive local image processing', is contributed by Masayasu Ito and Yuzuru Saito. The paper studies useful image processing techniques for an ultrasound image using adaptive morphological operations. An adaptive local image processing approach is proposed and is applied to ultrasound images to extract blood vessels, where local images are successively specified and processed stepwise.

The fifth paper, 'Modelling soft tissue-mechatronic tool interactions during indentation', is contributed by T.M. Al-ja'afreh, Y.H. Zweiri, L.D. Seneviratne and K. Althoefer. The paper presents a new model to predict the 'force-displacement' characteristics between soft tissue and a circular indentor. The proposed model may be applicable in developing mechatronic systems required in many medical applications such as rehabilitation, clinical palpation and manipulation of organs since the proper characterising of soft tissue properties mainly depends on the accurate estimation of indentation forces. A six-degree of freedom robot manipulator with force and position sensors is used to validate the indentation model. Measured force versus tool displacement data for lamb liver and kidney, for a variety of tool diameters, are presented and compared with the forces predicted by the model, showing very good agreement (Root mean square error, RMSE <8%).

The sixth paper, 'Relationship between structure and information processing in *Physarum polycephalum*', is contributed by D.S. Hickey and L.A. Noriega. The paper provides a preliminary demonstration that information processing in *Physarum* can be modelled and understood in terms of standard artificial intelligence (such as search, path finding and ant colony optimisation) constructs and known physiological responses.

2.3 The mechatronics group (six papers in mechatronics and robotics) is further divided into two sub-groups

2.3.1 Sub-group 1 (two papers in modelling and control methodologies in mechatronics)

The seventh paper, 'On tracking control of a pendulum-driven cart-pole underactuated system', is contributed by Yang Liu, Hongnian Yu, Sam Wane and T.C. Yang. The paper investigates the trajectory tracking issue of underactuated dynamic systems using a special example – a pendulum-driven cart-pole system. The paper first reviews two previous proposed control algorithms for the investigated underactuated dynamic system: open-loop control (OLC) and closed-loop control (CLC). Based on OLC and CLC algorithms, the authors propose a new control algorithm called simple switch control (SSC) which aims to overcome the issues raised in real experiments. The robustness of the three algorithms is investigated and compared by applying a variable parameter to the system.

The eighth paper, 'Attitude control system design and application on a helicopter experimental system', is contributed by Mingcong Deng and Akira Inoue. The paper studies the attitude control issues of a helicopter system and proposes a new design scheme of combined attitude control for a helicopter experimental system with weight variation. The laboratory experimental studies have demonstrated the performance of the proposed approach.

2.3.2 Sub-group 2 (four papers in control and actuators of robotics)

The ninth paper, 'Soft' actuation for dextrous hands – a 23 DOF anthropomorphic hand powered by pneumatic muscle actuators (pMA)', is contributed by P.Y. Chua, Z. Amran and Darwin G. Caldwell. The paper studies the design, construction and testing of a 23 DOF robotic dextrous end-effector powered by powerful, yet compliant and accurate braided pneumatic muscle actuators (pMAs). The control and drive systems are also investigated. The paper demonstrates a hand performing a number of complex manipulative tasks involving dexterity and power such as that the hand can perform high speed tele-operated catching operations.

The tenth paper, 'A biomechatronic trans-tibial prosthesis powered by pleated pneumatic artificial muscles for the study of human walking biomechanics', is contributed by Rino Versluys, Anja Desomer, Gerlinde Lenaerts, Bram Vanderborght, Louis Peeraer and Dirk Lefeber. The paper investigates the design of a pneumatically powered transtibial prosthetic device. A prototype is built for providing a preliminary test bed for control algorithm development and testing with able-bodied subjects in laboratory conditions. The characteristics and working principle of a pleated pneumatic artificial muscle (PPAM) are described. The design specifications and the mechanical model of the prosthesis are discussed. The mechanical design and the control structure are outlined. Furthermore, some initial walking trials with an able-bodied subject wearing the prosthesis prototype are presented and discussed.

The eleventh paper, 'Vision based Cartesian space motion control for flexible robotic manipulators', is contributed by Zhaohui Jiang. This paper investigates the issue of Cartesian space trajectory tracking control of robot arms with link flexibility and proposes a control method using vision feedback based on dynamics of the robot and Lyapunov stability theory. A CCD camera and video tracker are used as a vision system for the measurement of end-effector position and link flexural behaviour in the control process. Using this vision system, the end-effector position is measured directly, whereas the link defections are measured indirectly based on kinematics and inverse kinematics of the flexible robot. End-effector trajectory tracking control experiments are carried out using a two-link flexible robot system as the test bed.

The twelfth paper, 'Online mapping with a mobile robot in dynamic and unknown environments', is contributed by H.M. Wang, Z-G. Hou, Long Cheng and M. Tan. This paper addresses the issue of mapping dynamics and unknown environments for a mobile robot and presents an approach for simultaneous localisation and mapping (SLAM) in the dynamic environment with detection of moving objects. The proposed approach can improve the Gaussian mixture model (GMM) for mapping the dynamic environments and jointing GMM learning with SLAM.

3 Further research

Future research in HAM (The TDU COE-HAM Project, 2008) can, in many ways, be simply viewed to be under and at the interface of the three headings of:

1 intelligent control

2 mechatronics

3 human sciences.

The real situation is, however, more complex extending to education and exploitation. As a consequence, there is a need to examine other issues including:

1. Greater integration and involvement of other disciplines in the endeavour. For example, the involvement of researchers from psychology (more precisely, researchers with interests in the psychology of humans interacting with machines) is essential for proper modelling and understanding of the 'human in the loop systems' within HAM.
2. More fundamental assessments and developments of the tools required for modelling, analysis and control are needed, for example, the development of appropriate tools for non-linear analysis of systems based on ordinary differential, discrete, partial differential and hybrid models of HAM systems incorporating aspects of
   - a adaptation
   - b cognition
   - c learning (including learning from failure).
3. A greater understanding of the differences between the benefits of human-aided machine operation and machine-aided human performance and the implications of these concepts for HAM systems and algorithm design.
4. The development of improved hardware support systems including sensors and actuators to cope with the wide-ranging needs of human-machine systems.
5. The creation of a widely recognised design framework for HAM systems.
6. A focus on the educational needs of staff and students to ensure the sustainability of a healthy and productive future for HAM in Japan, the UK and, more generally, worldwide. This discussion should cover both undergraduate and postgraduate courses and will need to address the challenge of ensuring an effective multi-disciplinary education from a single subject background. This will include traditional approaches but will also require the integration of theory and application through extensive individual and team-based project work.
7. Creating wider awareness of HAM capabilities both through the development of a system that has a global impact academically and through a commercial product, preferably in an area that improves quality of life, for example, easily used assistive technologies supporting complex tasks or the requirements of an aging population.

In this way, HAM can seek to establish itself as a new and widely recognised mainstream discipline and a preferred discipline of study for many engineering, computing and technology students.

References

(2004) 'Invited session on human adaptive mechatronics', *Proceeding of IEEE International Conference on Mechatronics Technology (ICMT)*, Hanoi, Vietnam, November–December.

(2004–2007) *Proceedings of the 1st–5th COE Workshop on Human Adaptive Mechatronics (HAM*), Tokyo Denki University, Hatoyama-machi, Hiki-gun, Saitama 350–0394, Japan.

(2005) 'Invited session on human adaptive mechatronics', *Proceeding of IEEE International Conference on Mechatronics Technology (ICMT)*, Kuala Lumpur, Malaysia, December.

(2007a) 'Invited session on human adaptive mechatronics', *Proceeding of IEEE International Conference on Mechatronics Technology (ICMT)*, Ulsan, Korea.

(2007b) 'Invited session on human adaptive mechatronics', *Proceeding of IEEE International Conference on Networking, Sensing and Control (ICNSC)*, London, April.

(2008) *The TDU COE-HAM Project final report (in Japanese)*, Tokyo Denki University, Japan, April.

Furuta K. (Ed.) (2007) 'Special issue on human adaptive mechatronics', in *International Journal of Assistive Robotics and Mechatronics*, Vol. 8, No. 4.

Furuta, K. (2003) 'Control of Pendulum: from super mechano-system to human adaptive mechatronics', *Proceedings of the 42nd IEEE Conference on Decision and Control*, Maui, Hawaii, USA, pp.1498–1507.

Harashima, F. and Suzuki, S. (2006) 'Human adaptive mechatronics – interaction and intelligence', *Proceedings of the 9th IEEE International Workshop on Advanced Motion Control*, pp.1–8.

Inaba H. and Yu H. (Eds.) (2005) *Proceedings of The TDU COE-UK EPSRC Workshop on Human Adaptive Mechatronics*, Tokyo Denki University (TDU), Hatoyama-machi, Hiki-gun, Saitama 350–0394, Japan, 25 July.

Miyashita, O. (Ed.) (2007) 'Special issue on human adaptive mechatronics', *International Journal of Assistive Robotics and Mechatronics*, Vol. 7, No. 1.

Uchikawa, Y. (Ed.) (2006) 'Special issue on human adaptive mechatronics', in *International Journal of Assistive Robotics and Mechatronics*, Vol. 7, No. 1.

Yu, H. and Inaba, H. (Eds.) (2006) 'Special issue on the research conducted in robotics and intelligent machines', in *International Journal of Automation and Computing*, Vol. 3.