Novel Bees Algorithm Research at the Manufacturing Engineering Centre

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Abstract
The Manufacturing Engineering Centre (MEC) is an international R&D Centre of Excellence for Advanced Manufacturing and Information Technology at Cardiff School of Engineering, Cardiff University. The MEC was founded in 1996 by Professor Duc Truong Pham, OBE, FREng, FSME, BE, PhD, DEng, CEng, FIET, FIMechE. The MEC mission is to conduct world-class research and development in all major areas of Advanced Manufacturing and use the output to promote the introduction of new manufacturing technology and practice to industry. Researchers at the MEC conduct basic, strategic and applied research as well as technology transfer with partners from 22 countries in Europe, Asia and the Americas. The MEC research spans a broad spectrum of subjects, from Robotics and Microsystems, Sensor Systems, High-speed Automation and Intelligent Control, Rapid Manufacturing, MicroManufacturing, NanoTechnology, Quality Engineering, Multi-Media, Virtual Reality to Enterprise Information Management. The MEC offers postgraduate programmes in the areas of Manufacturing Engineering, Industrial Engineering and Systems Engineering leading to MPhil and PhD degrees [1]. Within the Systems Engineering the innovative Bees Algorithm, a novel swarm-based optimisation technique, has been developed and researched into for different applications. This paper presents the range of PhD research studies conducted on the Bees Algorithm and, related to this, in the area of Machine Learning.

Key words: Manufacturing Engineering Centre, Bees Algorithm, Swarm-based Optimisation Technique, Machine Learning, RULES family

1. Introduction

The Manufacturing Engineering Centre (MEC) is an international R&D Centre of Excellence for Advanced Manufacturing and Information Technology at Cardiff School of Engineering, Cardiff University. The MEC was founded in 1996 by Professor Duc Pham, OBE, FREng, FSME, BE, PhD, DEng, CEng, FIET, FIMechE.

The MEC conducts basic, strategic and applied research as well as technology transfer on the themes of Micro/Nano Manufacturing and Innovative Manufacturing with partners from 22 countries in Europe, Asia and the Americas. The MEC has formed research partnerships with more than 30 companies, ranging from small local firms to multi-national corporations, and more than 50 academic institutions around the world. Through this partnership programme, the MEC has created or safeguarded hundreds of jobs and have contributed significantly to the regional economy [1].

The MEC's research work has received the overwhelming endorsement of sponsors and supporters in the private and public sectors. Over 100 industrial partners including multinationals like Hewlett-Packard, IBS, Mitutoyo, Parametric Technology, SAP, Silicon Graphics, Siemens and Tecnomatix support research projects at the Centre. The MEC also has collaborative projects with more than 22 countries in Europe, Asia and the Americas. As a result, the Centre is one of the largest and most successful operations in any UK university. Within the past ten years, the Centre has secured over £50 million in grants and contracts. Three of the contracts won recently by the MEC are a £3.25 million contract with the Engineering and Physical Science Research Council (EPSRC) on Sustainable Manufacturing research (in collaboration with Cardiff Business School) and two EC 6th Framework Networks of Excellence contracts totalling 15 million Euros in value. The two Networks of Excellence, namely innovative Production Machines (I*PROMS) and Multi-Material Micro Manufacture (4M), led by the MEC involve some 50 centres of excellence in the field of advanced manufacturing across the EU [2].

In 1999 the MEC was awarded the DTI Secretary of State's First Prize in recognition of its success in building research partnerships with industry. In 2000 the Centre was also awarded the Queen's Anniversary Prize for using its expertise in manufacturing engineering to build an exceptional programme of support for firms, providing first class research and practical technology transfer and showing how a University can meet the diverse needs of SMEs and larger industrial concerns. The MEC is the only advanced manufacturing research centre in the UK to have earned both accolades [2].

This paper presents the research activities at the MEC in general, and highlights the Bees Algorithm, a novel swarm-based optimisation technique and Machine Learning and some PhD research topics conducted in these areas.

The paper is organised as follows. In Section 2 the research activities at the MEC are given. The special features of the MEC are highlighted in section 3. The research areas investigated at the MEC are outlined in section 4. Section 5 describes the novel Bees Algorithm and Machine Learning research at the MEC, and some of the PhD and MPhil research topics studied in this area. Finally, the conclusions are given in section 6.

2. Research activities at the MEC

The award-winning Manufacturing Engineering Centre (MEC) which forms part of Cardiff University, which dates back to 1883 and is one of Britain's major civic universities. The MEC is a designated Centre of Excellence in Manufacturing Engineering under two different programmes, the Centre of Excellence for Industrial Collaboration Programme managed by the WDA and the Regional Centres for Manufacturing Excellence Programme funded by the DTI and the Welsh Assembly Government. The 90-strong ISO 9001:2000 accredited Centre has an international reputation for its leading-edge research in advanced manufacturing and information technology spanning a broad spectrum of subjects. The centre has a highly respected tradition of research and the excellent resources we provide for our research students. These include high quality research facilities and an extensive in-house training programme of supporting studies. In addition, the Centre’s research community is cosmopolitan yet close-knit, an atmosphere fostered by both staff and student efforts, providing a supportive research environment. As a research student, you will find a friendly and committed body of staff who have extensive experience in supervising people from many different academic and ethnic backgrounds [2].

2.1 Basic and Strategic Research

Our basic research programme covers fundamental subjects such as machine learning, artificial intelligence, non-linear control and mechanical behaviour of microsystems. Our strategic research programme focuses on achieving greater efficiency, better quality, less waste and higher competitiveness by judiciously integrating advanced IT tools and techniques. The areas selected for collaboration with industrial partners are key Foresight areas and present multi-billion pound opportunities for industry. These include the use of time compression technologies such as rapid prototyping and concurrent engineering to speed up the development and manufacture of new products thus increasing UK industry's competitiveness in the global market [1].

2.2 Applied Research and Technology Transfer

Our projects are aimed at solving specific problems for companies, many of which are local SMEs. Our activities at this end of the spectrum support the Regional Technology Plan for Wales which promotes the use of advanced and innovative IT-based systems and techniques to help SMEs achieve competitive advantage [1].

On the whole, the MEC advanced and innovative manufacturing research spans a broad spectrum of subjects, from Machine Learning, Soft Computing, Artificial Intelligence, Robotics and Microsystems, Sensor Systems, High-speed Automation and Intelligent Control, Rapid Manufacturing, MicroManufacturing, NanoTechnology, Quality Engineering, Multi-Media, Virtual Reality and Enterprise Information Management. They focus on fundamental research contributing to the discovery of new scientific knowledge and better understanding of advanced manufacturing processes, operations and systems leading to postgraduate degrees. In order to facilitate the wide range of research activities the MEC is equipped with state-of-the-art equipment.

3. Research facilities at the MEC

Apart from possessing a critical mass in terms of manpower and finances, the MEC has unrivalled world-class facilities. The MEC’s research income currently exceeds £50 million from the public and private sectors and supports innovative research in traditional and emerging subject areas.

The MEC’s track record in industrial research has encouraged major companies to endow it with substantial facilities and equipment. This, coupled with its success in attracting funding, has established the MEC as one of the best equipped, most advanced research and development centres for manufacturing and IT in Europe, that incorporates [2]:

- Modern laboratories equipped with multi-million pound rapid prototyping and tooling, and advanced manufacturing machinery.
- State-of-the-art software and systems for computeraided design, computer-aided engineering and computeraided manufacture.
- Micro-machining, micro-tooling and micro-manufacturing facilities including Micropattern fabrication and casting, Micromilling, Micro EDM, Laser Ablation, Hot Embossing, Micro Injection Moulding, and Quality Control.
- Nano Facilities which includes Pico Second Laser Ablation machine, Dual Beam Focused Ion Beam machine, Nano Imprint Lithography machine, and Atomic Force Microscope.
- Robotic and computer-integrated machine tools and manufacturing systems.

- Virtual prototyping and IT systems.
- The Mitutoyo Metrology Centre.

4. Research areas at the MEC

The MEC offers postgraduate research programmes in the areas of Manufacturing Engineering, Industrial Engineering and Systems Engineering leading to MPhil and PhD degrees.

4.1 Manufacturing Engineering

This research began at the Centre ten years ago and has experienced a rapid expansion, with substantial funding from the EPSRC, the EC, the Welsh Assembly Government and industry. Currently, 25 research staff, PhD students and visiting researchers are engaged in this area of research. State-of-the-art facilities totalling more than £6 million in value have been installed at the Centre to support its work [2].

Our research addresses the compression of product development timescales using rapid prototyping technology. Both virtual and physical prototyping are employed. The physical prototyping research has a strong practical bias and underpins the Centre's technology transfer activities in this area. Research topics have included: control of virtual humans on a prototype production line; simulation of robotic and human prehension; orientation of parts in stereolithography (SLA); product design for SLA; characteristics of selective laser sintering (SLS); prediction of SLS build time, and rapid tooling techniques. This work involves partners from non-engineering disciplines, as well as a large number of industrial collaborators. The latter have included technology suppliers (for example Silicon Graphics, Parametric Technology, Tecnomatix, 3D Systems, DTM, Stratagem and DMG), large users (such as Land Rover and BOC) and numerous SMEs (such as Iota Sigma, Atlantic Plastics, GX and Methods Centreline) [2].

Within Manufacturing Engineering we offer a full range of expertise, but the following areas are of particular strength [2]:

- Rapid manufacturing, Rapid prototyping and Rapid tooling
- Reverse engineering
- Micro manufacturing
- Nanotechnology

4.2 Industrial Engineering

Research in the area of Industrial Engineering is also long established at the Centre, originating from an interest in design, in addition to the intelligent manufacturing research described above. This work has received substantial support from the EPSRC, the EC, the Higher Education Funding Council for Wales, the Welsh Assembly Government and industry. Currently, 25 research staff, PhD students and visiting researchers are involved in this area of research [2].

The focus of the work is the effective use and management of information to reduce the time-to-market for new products, thereby improving industrial competitiveness. The research has addressed the problem of assisting the designer through the provision of advanced manufacturing related information and, secondly, of supporting the manufacturing engineer with information derived from the design stage. The

Centre's work has also covered the extraction or 'mining' of useful information from large manufacturing databases, the organisation of virtual teams of designers located at different sites and the management of engineering changes in such a concurrent environment. Recently, the Centre has been devoting a large amount of effort to Internet-based multimedia systems for supporting users of complex products. For example, work has been undertaken on methods of developing electronic product manuals concurrently with the design of the product [2].

Notable collaborators in this area are Daimler-Chrysler, SAP, Siemens, Welsh Water and Allied Steel and Wire. As two of the Centre's 'generic research partners', Siemens and SAP have established substantial facilities at the Centre to support its work. Among the multinational partners recently attracted to the Centre are Aerospatiale, Nokia and Schneider who have joined new initiatives to obtain EC Framework 6 funding for further research on intelligent product support [2].

To date, results have included: a new approach to concurrent engineering that facilitates simultaneous product and process design; methods for structuring and re-using manufacturing information; new machine learning and data mining algorithms and a new methodology for creating and maintaining product support systems using integrated product data and knowledge-based and hypermedia techniques [2].

Within Industrial Engineering we offer a full range of expertise, but the following areas are of particular strength [2]:

- Concurrent engineering
- Workflow management
- Innovative design
- Data mining and machine learning
- Fit manufacturing and Sustainable manufacturing

4.3 Systems Engineering

Systems Engineering is another broad area of research within the MEC. In this area, our sponsors include the EPSRC, the DTI, the EC and industry. Our partners operate in a number of industrial sectors in the UK and Europe, including computer manufacture, telecommunication technology, pharmaceuticals, transport and energy, and petroleum production. Currently, 25 research staff, PhD students and visiting researchers are working in this area of research. Much of our work has been adopted profitably by industry, as well as widely reported in leading journal articles and books [2].

Within Systems Engineering we offer a full range of expertise, but the following areas are of particular strength [2]:

- Intelligent process modelling and control systems
- Intelligent information systems
- Mobile robots and mechatronics
- Data mining, neural networks and machine learning
- Intelligent manufacturing
- Intelligent systems techniques
- Genetic algorithm, ant algorithm and bees algorithm
- Fuzzy Logic

The novel Bees Algorithm covered by research areas under Systems Engineering is described in detail in the following section.

5. The novel Bees Algorithm and Machine Learning research at the MEC

Many complex multi-variable optimisation problems cannot be solved exactly within polynomially bounded computation times. This generates much interest in search algorithms that find near-optimal solutions in reasonable running times. The swarm-based algorithm described in this paper is a search algorithm capable of locating good solutions efficiently. The algorithm is inspired by the food foraging behaviour of honey bees and could be regarded as belonging to the category of "intelligent" optimisation tools [3-6].

5.1 Bees in nature

A colony of honey bees can extend itself over long distances (more than 10 km) and in multiple directions simultaneously to exploit a large number of food sources. A colony prospers by deploying its foragers to good fields. In principle, flower patches with plentiful amounts of nectar or pollen that can be collected with less effort should be visited by more bees, whereas patches with less nectar or pollen should receive fewer bees [3-6].

The foraging process begins in a colony by scout bees being sent to search for promising flower patches. Scout bees move randomly from one patch to another. During the harvesting season, a colony continues its exploration, keeping a percentage of the population as scout bees [3-6].

When they return to the hive, those scout bees that found a patch which is rated above a certain quality threshold (measured as a combination of some constituents, such as sugar content) deposit their nectar or pollen and go to the "dance floor" to perform a dance known as the "waggle dance" [3-6].

This mysterious dance is essential for colony communication, and contains three pieces of information regarding a flower patch: the direction in which it will be found, its distance from the hive and its quality rating (or fitness). This information helps the colony to send its bees to flower patches precisely, without using guides or maps. Each individual's knowledge of the outside environment is gleaned solely from the waggle dance. This dance enables the colony to evaluate the relative merit of different patches according to both the quality of the food they provide and the amount of energy needed to harvest it. After waggle dancing on the dance floor, the dancer (i.e. the scout bee) goes back to the flower patch with follower bees that were waiting inside the hive. More follower bees are sent to more promising patches. This allows the colony to gather food quickly and efficiently [3-6].

While harvesting from a patch, the bees monitor its food level. This is necessary to decide upon the next waggle dance when they return to the hive [10]. If the patch is still good enough as a food source, then it will be advertised in the waggle dance and more bees will be recruited to that source [3-6].

5.2 Proposed Bees Algorithm

In any optimisation algorithm the following two actions, namely, exploration and exploitation will be in operation. The exploration activity will ensure that new areas of interest are constantly discovered by the algorithm while the exploitation task will focus on the promising areas found so far and strive to investigate them further until the best solutions are found. Therefore, the exploration is similar to random search conducted by the scout bees while the exploitation is compared to local search carried out by the recruited bees.

The Bees Algorithm (BA) is an intelligent optimisation tool imitating the food foraging behaviour of honey bees found in nature. In the natural environment bees are able to discover food sources using two kinds of search methods, namely, a global random search and a local search. The former consists of sending the bees at random around the hive. Once these bees, which are called the scout bees, discover potential food sources they return to their hive and start recruiting more bees to exploit those food sources which were discovered during their random search attempt. The bees waiting in the hive receive their instructions from the returning scout bees in the form of a “waggle dance” which gives them the following useful information [4]: the location of the nearest food source, the quality of that food source, and the amount of energy needed to harvest the food. Logically, the better the food source and the closer to the hive the more numerous the recruited bees will be. The search performed by the recruited bees is similar to a local search. While some bees are recruited to conduct local search a percentage of the bee population would continue the global random search to look for other promising food sources. This ensures that the search continues cycle after cycle in an iterative manner until all the good food sources including the best food source in the vicinity of the hive are found. This is similar to an intelligent optimisation process and could be formulated into an algorithmic form as in the basic Bees Algorithm [3-6].

Figure 1 shows the pseudo code for the algorithm in its simplest form.
The algorithm requires a number of parameters to be set, namely: number of scout bees (n), number of sites selected out of n visited sites (m), number of elite sites out of m selected sites (e), number of bees recruited for the best e sites (nep), number of bees recruited for the other (m-e) selected sites (nsp), initial size of patches (ngh) which includes site and its neighbourhood and stopping criterion. The algorithm starts with the n scout bees being placed randomly in the search space. The fitnesses of the sites visited by the scout bees are evaluated in step 2. The valuation of fitness would depend on the optimisation problem, but in general ‘fitness’ is taken as the value of the objective function being optimised [3-6].

In step 4, bees that have the highest fitnesses are designated as “selected bees” and sites visited by them are chosen for neighbourhood search. Then, in steps 5 and 6, the algorithm conducts searches in the neighbourhood of the selected sites, assigning more bees to search near to the best e sites. The bees can be chosen directly according to the fitnesses associated with the sites they are visiting. Alternatively, the fitness values are used to determine the probability of the bees being selected. Searches in the neighbourhood of the best e sites which represent more promising solutions are made more detailed by recruiting more bees to follow selected bees than the other selected bees. Together with scouting, this differential recruitment is a key operation of the Bees Algorithm [3-6].

However, in step 6, for each patch only the bee with the highest fitness will be selected to form the next bee population. In nature, there is no such restriction. This constraint is introduced here to reduce the number of points to be explored. In step 7, the remaining bees in the population are assigned randomly around the search space scouting for new potential solutions. These steps are repeated until a stopping criterion is met. At the end of each iteration, the colony will have two parts to its new population – representatives from each selected patch and other scout bees assigned to conduct random searches [3-6].

1. Initialise population with random solutions.
2. Evaluate fitness of the population.
3. While (stopping criterion not met) //Forming new population.
4. Select sites for neighbourhood search.
5. Recruit bees for selected sites (more bees for the best e sites) and evaluate fitnesses.
6. Select the fittest bee from each patch.
7. Assign remaining bees to search randomly and evaluate their fitnesses.
8. End While.

Figure 1. Bees Algorithm - Pseudo code

5.2 PhD and MPhil research studies on the Bees Algorithm

The initial research embarked on the basic Bees Algorithm which has been developed by researchers at the MEC in 2005. Since then the Bees Algorithm has been researched by many students and it has enabled them to earn their PhD and MPhil degrees. Some of the thesis topics in Bees Algorithm submitted for PhD and MPhil degrees are given below:

- The Bees Algorithm: a novel optimisation tool / by Afshin Ghanbarzadeh. Thesis (Ph.D.) - Cardiff University, 2007.
- An improved version of the Bees Algorithm based on an adaptive learning search framework / by Mohamed A. Negm. Thesis (M.Phil.) - Cardiff University, 2009.
- Nature-inspired optimisation: improvements to the particle swarm optimisation algorithm and the bees algorithm / by Michael O. Sholedolu. Thesis (Ph.D.) - Cardiff University, 2009.
- Data clustering using the Bees Algorithm and the Kd-tree structure / by Hasan Al-Jabbouli. Thesis (Ph.D.) - Cardiff University, 2009.
- Enhanced Bees Algorithm with fuzzy logic and Kalman filtering / by Ahmed Haj Darwish. Thesis (Ph.D.) - Cardiff University, 2009.
- The bees algorithm: theory, improvements and applications / by Ebubekir Koç. Thesis (Ph.D.) - Cardiff University, 2010.
- Multi-objective optimisation using the Bees Algorithm / by Ji Young Lee. Thesis (Ph.D.) - Cardiff University, 2010.

The Bees Algorithm research deals with the enhancement of the algorithm and its applications to complex problems. The application of novel Bees Algorithm to real engineering problems has also generated interesting results which have been published in numerous conference proceedings and international journals. Some of these publications can be classified as shown in Table 1.

5.3 Novel Machine Learning Algorithm

One of the long-term objectives of Artificial Intelligence (AI) research is the creation of machine intelligence. If a machine has intelligence, it does not only behave as though it has knowledge equipped by its creator, but it also learns new knowledge from the environment by itself to improve its own performance. Knowledge thus learned by a machine can even improve on human intelligence. Such self-learning is essential for intelligent objects to exist in a changing world. Therefore, Machine Learning (ML) is the key to artificial intelligence [7-10].

Classification	**Title**
Continuous – Function Optimisation	The Bees Algorithm – A Novel Tool for Complex Optimisation Problems
Discrete – JShopS	Using the Bees Algorithm to schedule jobs for a machine
Shape Grammars	Generating Branded Product Concepts: Comparing the Bees Algorithm and an Evolutionary Algorithm
Multi-objective Function Optimisation	Multi-objective Environmental/Economic Power Dispatch using the Bees Algorithm with Pareto optimality
Meta-heuristics – NN	Learning the Inverse Kinematics of a Robot Manipulator using the Bees Algorithm
Meta-heuristics – FCM	Application of the Bees Algorithm to Fuzzy Clustering
Meta-heuristics – SVM	Using the bees algorithm to optimise a support vector machine for wood defect classification
Hybrid – Fuzzy Bees	Using the Bees Algorithm to schedule jobs for a machine
Hybrid – PSO Bees	Using a Hybrid PSO-Bees Algorithm to train Neural Networks for Wood Defect Classification

Table 1: Classification of Bees Algorithm applications

Classification is a common task in data mining and machine learning. With the assistance of human teachers, a learning system can induce classifiers from the training data. Learned classifiers can be used to sort new objects into specified classes [7-10].

Rule induction is a common method of generating classifiers. Classifiers in rule induction are in the form of “If conditions Then actions” rules. Knowledge represented as rules is easy for users to understand and verify. In addition, the rules generated through the learning process can be utilised directly in knowledge-based systems [7-10].

The separate-conquer-without-reduction approach was first established at Cardiff University with the RULES family of algorithms [7-10]. The general induction procedure for a training set is a recursive process as follows:

- Form a rule to classify a number of uncovered (unmarked) objects which has the highest evaluation measure on the entire training set.
- Mark objects covered by the formed rule.
- Repeat the above two steps until all objects of the training set are marked.

The novel Inductive Learning Algorithms called the RULES family which have been developed at the MEC in 1993 have been researched into since then.

5.4 PhD research studies on Machine Learning Algorithm

The machine learning research started with the introduction of the RULES family algorithm which has been developed by researchers at the MEC in 1993. Since then the RULES family algorithm has been studied by many students and it has provided an opportunity for them to gain their PhD degrees. Some of the thesis topics in the RULES family Algorithm submitted for PhD degrees are given below:

- New algorithms for machine learning / by Mehmet Sabih Aksoy. Thesis (Ph.D) – Cardiff University, 1993.

- Enhanced computer algorithms for machine learning / by Ziad Salem. Thesis (Ph.D.) – Cardiff University, 2002.
- New techniques for handling continuous values in inductive learning / by Samuel Bigot. Thesis (Ph.D.) – Cardiff University, 2002.
- Design and analysis of scalable rule induction systems / by Ashraf A. Afify. Thesis (Ph.D.) – Cardiff University, 2004.
- Flexible information management strategies in machine learning and data mining / by Duc-Cuong Nguyen. Thesis (Ph.D.) – Cardiff University, 2004.
- New rule induction algorithms with improved noise tolerance and scalability / by Khurram Shehzad. Thesis (Ph.D.) - Cardiff University, 2010.
- New covering, pruning and incremental post pruning methods for RULES family / by Dinh Trung Pham (Ph.D.) – Cardiff University, in progress.

6. Conclusion

The Manufacturing Engineering Centre at Cardiff University has been presented. The research activities, the research facilities, and the research areas at the MEC have been highlighted. The novel Bees Algorithm and the Machine Learning Algorithm, in particular, the RULES family developed at the MEC have been described. The research studies on the Bees Algorithm and the Machine Learning Algorithm, namely, the RULES family leading to PhD and MPhil degrees have been outlined. The MEC offers unique PhD and MPhil research opportunities to students globally including East Asia, in the areas of Manufacturing, Industrial and Systems Engineering.

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References

[1] www.mec.engineering.cf.ac.uk

[2] Cardiff University Postgraduate Prospectus 2011.

[3] Pham D.T., Ghanbarzadeh A., Koc E., Otri S., Rahim S., and Zaidi M. The Bees Algorithm – A Novel Tool for Complex Optimisation Problems. Proceedings of IPROMS 2006 Conference, 2006, 454-461.

[4] Packianather M.S., Landy M., and Pham D.T. Enhancing the speed of the Bees Algorithm using Pheromone-based Recruitment. INDIN 2009, 2009, 789-794.

[5] Pham D.T., Soroka A.J., Ghanbarzadeh A., Koc E., Otri S., and Packianather M. Optimising neural networks for identification of wood defects using the Bees Algorithm. INDIN2006, 2006, 1346-1351.

[6] Pham D.T., and Castellani M. The Bees Algorithm: modelling foraging behaviour to solve continuous optimization problems. Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science, 223 (12), 2009, 2919-2938.

[7] Pham D.T., and Aksoy M.S. RULES: a simple rule extraction system. Expert Systems with Applications, Vol. 8, no. 1, 1995, 59-65.

[8] Pham D.T., and Aksoy, M.S. A New Algorithm for Inductive Learning. Journal of Systems Engineering, Vol. 5, no. 2, 1995, 115–112.

[9] Nguyen C.D. Flexible information management strategies in machine learning and data mining, PhD Thesis, Cardiff University, 2004.

[10] Pham D.T., Dimov S. S., Nguyen C.D. An incremental K-means algorithm, Proc. Instn Mech Engrs, 218 (C), 2004, 783-795.