Institution: Coventry University

Unit of Assessment: 11

Title of case study: Digital Environment Home Energy Management System (DEHEMS)

1. Summary of the impact

This case study describes the national and international impact of research undertaken by Professor **Chao**, as part of an EU funded Framework 7 project, Digital Environment Home Energy Management Systems (DEHEMS). The project has improved existing household energy monitoring, tackling the issues of global warming and CO_2 emission reduction in the domestic sector. The research has directly contributed to the development of a product called EnergyHive, subsequently marketed by Small to Medium-sized Enterprise (SME) Hildebrand Ltd, who was the industrial partner in the DEHEMS consortium. The research has delivered the following:

- **Economic impact** - as a direct result of the research project, Hildebrand Ltd has diversified and entered into an entirely new market;
- **Impact on the environment** – home owners, local authorities and energy companies have installed EnergyHive meters which have shown significant energy and carbon dioxide reductions.

Beneficiaries of the research and the subsequent impact include: a commercial business, domestic energy consumers, UK and international energy companies and local authorities.

2. Underpinning research

Chao has been at Coventry University since 2000 and the research that forms the core of this case study was developed during his time here. **Chao**'s underpinning research focused originally on service and semantics modelling, distributed systems, cloud-based computing and systems integration [1].

Between June 2008 and July 2011, **Chao** was a work package leader within an international research consortium of 13 industry, local authority and university partners, from Belgium, Romania, Bulgaria, and UK, including SME Hildebrand Ltd. The research project, Digital Environment Home Energy Management Systems (DEHEMS) (http://www.dehems.eu), was an EU funded (3.5M Euros) Framework 7 project. The project's aim was to develop and test a domestic energy management system which would improve on the current generation of monitoring equipment and deliver carbon dioxide savings across Europe.

DEHEMS built on **Chao**'s existing research expertise in data modelling and integration. **Chao** led the work package developing an ontology of home appliances. The starting point in developing the ontology was to study general classifications of home electrical appliances provided by various vendors and manufacturers [2]. Although appliance vendors provide energy efficiency ratings of home appliances, they do not provide the detailed specification of the attributes that contribute towards their overall energy consumption. In the absence of these attributes and non-existence of a standard ontology and measurement of users' preferences [4], it is difficult for reasoning tools to provide a comprehensive comparison of home appliances based on their energy consumption performance. It is also difficult to provide a comparative analysis of energy consumption of these appliances and consumers' satisfaction [5]. Thus, the ontology is an important innovation for the development of systems to support energy reduction and it has the potential for wide application in home energy management.

Based on the ontology, which encodes knowledge of electrical appliances and their efficiency together with the association of appliances to households, **Chao** then developed an innovative recommender system based on group decision making method [7], which provided intelligent advice on efficient energy consumption to households. It is innovative as it works on ontology-based knowledge not previously encoded and also uses knowledge from external systems. The recommender system compares energy consumption of similar houses. The similarity criteria includes number of family members living in a house and type of houses as well as other fuzzy criteria. If a household has consumed more energy than the average of its similar type of houses and occupants, the system starts to look for possible causes. The recommender system also provides proactive energy consumption advice to households. For example, on starting the washing machine, the system checks weather forecast services provided by Google and generates

advice on drying clothes outside depending on the weather conditions.

The research developed a further innovation in the recommendation [3,6] as it linked to social networking sites, through APIs, allowing for community-based interactions. Energy savers are able to rate tips and compare progress and the system allows the households to record their feedback or experience. **Chao** also investigated the challenges of capturing and storing real-time energy data and developed an innovative method for addressing this challenge in the form of internet-based device addressing time-series data capture, and storage in multi-dimensional data cubes [2, 8] which has greatly influenced the subsequent EU FP7 CASSANDRA project.

3. References to the research

1. Huang, C-L., Lo, C-C., **Chao, K-M.,** and Younas, M. (2006). Reaching consensus: A moderated fuzzy web services discovery method. *Information and Software Technology, 48* (6), 410-423. (Impact Factor: 1.692; Citations: 18)
2. Shah, N., Tsai, C-F., Marinov, M., Cooper, J., Vitliemov, P., and **Chao, K-M**. (2009). Ontological on-line analytical processing for integrating energy sensor data. *IETE Technical Review 26* (5), pp. 375-387. (Impact Factor: 0.724; Citations: 5)
3. **Chao, K-M**., Shah, N., Farmer, R., and Matei, A. (2012). Energy management system for domestic electrical appliances. *International Journal of Applied Logistics 3*(4): 48-60
4. Lin, W-L., Lo, C-C., **Chao, K-M.** Younas, M. (2008). Consumer-centric QoS-aware selection of web services. *Journal of Computer and System Sciences* 74(2): 211-231 (Impact = 5-Year Impact Factor: 1.106; Citations: 18)
5. Lin, W-L., Lo, C-C., **Chao, K-M.,** and Godwin, N. (2011). Multi-group QoS consensus for web services. *Journal of Computer and System Sciences,* 77(2): 223-243. (Impact Factor: 1.106; Citations: 5)
6. Wang, P., **Chao, K-M**., Lo, C-C., and Farmer, R. (2011). An evidence-based scheme for web service selection. *Information Technology and Management, 12*(2): 161-172. (Impact Factor: 3.025; Citations: 12)
7. Wang, P., **Chao, K-M.**, and Lo, C-C. (2010). On optimal decision for QoS-aware composite service selection. *Expert Systems with Applications, 37* (1), 440-449 (5-Year Impact Factor: 2.339; Citations: 20)
8. Dong, B., Zheng, Q., Tian, R., **Chao, K-M**., Ma, R., & **Anane, R**. (2012). An optimized approach for storing and accessing small files on cloud storage. *Journal of Network and Computer Applications,* 35(6): 1847-1862 (5-Year Impact Factor: 1.251)

Key Funding:

- **Chao** and 12 other partners across Europe 3.5M Euros, Digital Environment Home Energy Management Systems (DEHEMS) EU Framework 7, 2008- 2011, **Chao**'s element of the funding 0.26M Euros
- **Chao** and 8 other partners across Europe, A multivariate platform for assessing the impact of strategic decisions in electrical power systems (CASSANDRA) 3.4M Euros EU Framework 7, 2012- 2014, **Chao**'s element of the funding 0.30M Euros

4. Details of the impact

The outcome of **Chao**'s research within the DEHEMS work package fed directly into the development of the next generation energy monitoring product and 'Software as a Service' (SaaS) called EnergyHive. This was subsequently commercialised by Hildebrand Ltd, the industrial partner within the DEHEMS consortium. **Chao**'s research led to innovations in the EnergyHive product, including: the use of data capture and storage techniques for time series analytical processing; the ontology which encodes knowledge of electrical appliances and their efficiency together with the association of appliances to households; the recommender system which provides advice; and the techniques for social interaction to encourage community efforts. The research resulted in diversification into new markets for Hildebrand Ltd, and the development of the EnergyHive

product and service, delivering environmental impact by reducing consumers' energy bills and carbon footprint.

Impact on the environment

As part of the DEHEMS project Hildebrand Ltd produced the prototype monitoring devices that developed into the EnergyHive product and service. The semantic system developed by **Chao** is at the heart of the energy saving functionality of EnergyHive. During the DEHEMS project the prototype system was developed in three cycles and incorporated users' feedback into the improved system design from each prototype test cycle. The prototype product, produced by Hildebrand Ltd, was deployed in 250 households in the UK cities of Manchester, Birmingham and Bristol and the Bulgarian cities of Plovdiv and Ivanovo. The results from this work indicated that individual homes reduced their energy consumption as a result of the usage feedback about their energy consumption. The analysis of energy consumption data collected before and after deployment of the prototype system showed an average weekly reduction in energy consumption of 7.89%. A survey of the residents that took part in the project showed that, as a result of DEHEMS, households had increased their awareness of how their own energy usage impacts the environment, as well as the cost of energy consumption.

Chao also developed the recommendation system and ontology, which automatically and in a timely manner makes appropriate recommendations for the users to reduce both energy usage and CO_2 emission. Following the completion of the DEHEMS project, the EnergyHive product (shown in Figure 1a, b and c) was developed, enabling users to make informed decisions to reduce their energy consumption, thus having a positive impact on the environment. Camden Council have installed energy heating and hot water meters in 1000 homes (using EnergyHive 'Software as a Service' SaaS) and are currently installing it in a further 800 homes during 2013. The semantic work of **Chao** is used to display intelligent feedback on energy usage on tablet devices. Daniel White, Camden Council, commented that the EnergyHive product was the most advanced of its type and Camden Council estimates that over the lifetime of their heat metering programme they will save 8,000 tonnes of CO_2 within 2500 homes [b].

Figure 1a - EnergyHive hub ©Hildebrand Ltd

Figure 1b - Energy Elite electricity clamp and transmitter ©Hildebrand Ltd

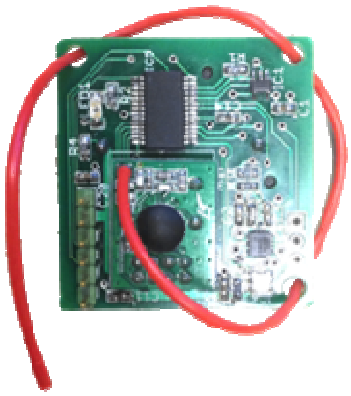

Figure 1c - EnergyHive multi-sensor ©Hildebrand Ltd

One of the main aims of the DEHEMS project was to increase both the awareness and understanding of the public in relation to their individual energy consumption and enable them to make informed decisions about their future energy usage. General energy usage has been reduced by those who viewed their energy usage through the EnergyHive product [c]. In a survey (n=183) of initial motivations for saving energy, more than half of the respondents indicated their motivation for saving energy was financial. As a result of the DEHEMS project, the number of respondents solely interested in financial savings was reduced by 50%. The number of users motivated by the environmental impact of their actions increased to 77% [d]. This evidences the changes in attitude and behaviour as a result of the research project and the developed EnergyHive product. The DEHEMS research impact has been featured in "Big Ideas for the Future" report published in 2011 by UK Research Councils [e].

Economic impact

The research has also had significant economic impact for the consortium's industrial partner, Hildebrand Ltd [a]. As a result of the research by **Chao** and membership of the DEHEMS consortium Hildebrand Ltd, previously a small R&D company providing cloud computing products, has diversified into an entirely new market through the development of the EnergyHive product to monitor energy use and provide advice on how to reduce energy consumption. The simple interface shown in Figure 2 has been designed to make the EnergyHive product easy to use and to understand by consumers, but flexible enough to monitor the whole house with up to five heat, motion and other sensors.

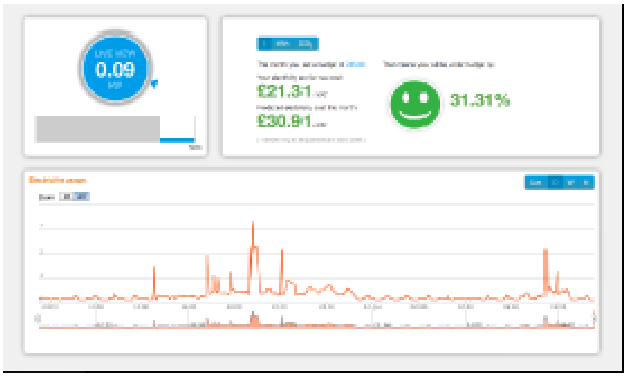

Figure 2 – Screenshot of EnergyHive's web interface ©Hildebrand Ltd

Sales of EnergyHive have been to individual consumers, energy companies for their customers and local authorities for their tenants. For example, NPower have purchased 10,000 EnergyHive licences which they have rolled out to their customers. In addition to sales within the UK, the product has been taken up internationally. The housing authorities in Australia are projecting to reduce energy consumption for their tenants by 20% by using the product. Since 2011, EnergyHive products have generated income to Hildebrand Ltd of £7,509,5000. This is made up of 2000 units of EnergyHive Home to individuals, 6500 EnergyHive 'Software as a Service' (SaaS) licences and one EnergyHive Enterprise licence.

In addition, to the development of EnergyHive, **Chao**'s research also transferred to Hildebrand the necessary knowledge to enable them to work with IBM to develop and market the Hildebrand database acceleration product with ontology, which improves efficient time-series analytical processing for big data.

Conclusion

This case study demonstrates that **Chao**'s research had **economic impact** and as a direct result Hildebrand Ltd has diversified and entered into entirely new profitable markets. In addition, the research has an **impact on the environment** by creating the core technology for EnergyHive meters which enable home owners, local authorities and energy companies' significant energy and carbon dioxide reductions by smart monitoring and advising on energy use.

5. Sources to corroborate the impact

a. Chief Executive Officer, Hildebrand Ltd, (information collected by RAND in an interview – see report PR-546-CU) and additional testimonial.
b. Mr Daniel White, Senior Energy and Sustainability Officer, Camden Council, RAND report PR-546-CU
c. DEHEMS Final Report http://tinyurl.com/ojz38m6
d. DEHEMS D7.7: Project Cycle Analysis Report for Cycle 3 http://tinyurl.com/qjpleut
e. http://www.rcuk.ac.uk/documents/publications/BigIdeasfortheFuturereport.pdf