Institution: Newcastle University

Unit of Assessment: 13 Electrical and Electronic Engineering, Metallurgy & Materials

Title of case study: Development of an open network communication protocol standard

1. Summary of the impact

Research during the 1990's at Newcastle University resulted in the development of CANopen (Control Area Network open), a manufacturer independent communication protocol for connecting multiple devices used in industrial systems. It has resulted in opening up the market by providing the platform for a low-cost simplified method of connecting off-the-shelf devices to communicate effectively over a network, benefiting the global economy and inspiring innovation. The significance of the impact is evident by the wide incorporation of the technology in a diverse range of products ranging from health care, automotive, renewable energy, rail and aerospace industries. The reach of the impact is evident by its use in product development by national and international companies and is the de-facto European standard EN 50325-4 (CiA 301).

2. Underpinning research

Research in the School of Electrical & Electronic Engineering at Newcastle University was led by Dr Mohammad Farsi (Senior Lecturer: 1993-1997). Mr Karl Ratcliff (RA: 1993-1998) and Dr Roy Booth (RA: 1993 -1996) were responsible for the development of the CANopen layer 7 communication software. Mr Manuel Bernardo Barbosa (Research Student 1996-2000) was involved in documenting the CANopen implementation in industry and co-author of a book.

In 1986, Bosch introduced CAN (Controller Area Network) communication protocol for in-vehicle networking on passenger cars. In 1992, the CAN in Automation (CiA) association tried to simplify the protocol by defining an interfacing layer called a CAN Application Layer (CAL). However, CAL was very complex and did not allow engineers to use off-the-shelf devices for a wide range of applications in flexible manufacturing. Therefore, Bosch's long term vision to create a single open standard network based on CAN that could cover a whole factory floor, allowing vendor independent devices to be used.

In 1993, research led by Dr. Farsi in Newcastle University and collaborators in Germany under ESPRIT III project [**G1**] led to the development of the 'CANopen protocol' specification. The main objective of this project was to enable European industries to gain full access to the benefits of this open protocol and become competitive in flexible manufacturing and independent of technologies coming from the US and Japan. Bosch led and coordinated the project, installing and testing the developed prototype outputs to investigate whether they were implementable within a manufacturing environment. Newcastle University carried out a technology review in a manufacturing environment to ascertain the best methods to be used to form the open standard. Newcastle researchers Mr Karl Ratcliff and Dr Roy Booth then worked on the software development (i.e. Layer 7) of a simple to use method to interface the CAN to applications, which in turn led to the CANopen protocol. This Layer 7 software formed the interface that provided the effective communication link between different manufacturer's devices operating over a network.

An open system architecture was designed and implemented for a low cost flexible production unit for assembly, inspection and sequential tasks. This introduced the important device profiling concept, which provided a framework allowing manufacturers to independently develop their own hardware products certain in the knowledge that their equipment would be fully compatible with other manufacturers [**1**]. Further industrial system implementations illustrated a new concept in device communication within a manufacturing environment [**2**]. CANopen Configure Device and Test (CDT) software was developed to facilitate the configuring and testing of CANopen devices, allowing the use of CANopen compliant object dictionaries to communicate with a device [**3**].

To support the adoption of CAN and CANopen into European companies and enhance knowledge, Newcastle University presented details of the technologies at workshops, manufacturing exhibitions and conferences. The CAN concept, structure and operating principle, along with the software and hardware implementation methods were explained [**4**]. The methods of using CAN hardware in a CANopen context, in which CAN objects are transmitted depending on services and response times were published [**5**]. The main benefits to a company using the CANopen technology were pseudo real-time, robustness, inexpensive, simple to use with only 8 bytes of information and most importantly it's flexibility to industry.

The outcome of the ESPRIT III project - CANopen protocol specification was handed over to the CiA for future development and maintenance and by the end of 1995; the completely revised CANopen communications profile was released. The success of the CANopen protocol resulted in a further dissemination EEC CANopen project [**G2**] in 1996. The project established Newcastle University as the sole specialist centre in Britain for this technology and development of CANopen Conformance Testing. A document 'CANopen Implementation made simple' by Newcastle University was handed over to CiA in 1998 and distributed worldwide to companies interested in implementing CANopen. A book explaining the details of a CANopen implementation applicable to an industrial network was published in 2000 [**6**].

The most important outcome of the project was the acceptance of CANopen as an international standard (EN 50325-4 or CiA301) in 1999, which provided higher level protocols to CAN reference model standardized by International Standard Organization (ISO/OSI 11898), for industrial and embedded control networks.

3. References to the research

<u>Key Outputs</u>: (Note: Top 3 outputs are 1, 4, 6)

[1] Farsi, M. "Flexible robotics cells in factory automation: communication concept." In *Control Applications, Proceedings of the Third IEEE Conference on*, pp. 1763-1768. IEEE, 1994. *A flexible production unit with open system architecture. Introducing the device communication model adopted by the consortium with all devices described using device profiling.*

[2] Farsi, M. "Device Communication for Flexible Manufacturing:-A New Concept." In *Ninth International Conference on System Engineering, UK*, pp. 328-334. 1994.

[3] Farsi, M., and Ratcliff, K. "CANopen: configure and device testing." *Proceedings of IEEE International Workshop on Factory Communication Systems*, pp. 373-380. IEEE, 1997.

[4] Farsi, M., Ratcliff, K., Barbosa, M.B. "An overview of Controller Area Network." Computing & Control Engineering Journal, Volume 10, Number 3, June 1999. *The concept, structure and operating principle of CAN, with software and hardware methods explained. (**135 Citations)***

[5] Farsi, M., Ratcliff, K., Barbosa, M. B. "An introduction to CANopen." *Computing & Control Engineering Journal* 10, no. 4, pp. 161-168, 1999. *The concept of CANopen and implementation is explained including device profiling and types of communication.*

[6] Farsi M, Barbosa M,"CANopen Implementation, application to industrial network",RSP,2000. ISBN 0-86380-247-8. *Overview of CAN & CANopen, implementation and conformance testing.*

<u>Funding</u>

[G1] ESPRIT III, ASPIC: A European consortium led by Bosch, 7302, Design and Development of a communication protocol for production cell in automation industry,1992-1995, £286,000

[**G2**] ESPRIT Project, 22171, CANopen, August 1996 - July 1997, £25,000

4. Details of the impact

Research by Dr Farsi at Newcastle between 1993-97 led to the development of CANopen, a fieldbus communication protocol that provides a flexible and powerful open industrial communication solution for connecting multiple different manufacturer's devices. This protocol became the de-facto European standard EN50325-4 (CiA 301) for CAN (Controller Area Network) based automation solutions (**E8**), and opened up the market by providing industry with the option of not being reliant specifically to any one supplier. It is widely used by major companies within different industries, with current sales of CAN nodes in the automotive industry alone accounting for over 700 million units per year (**E9**).

Impact on practitioners and legislation:

The completed CANopen protocol specification was handed over to CAN in Automation (CiA). CiA is a non-profit international industry organisation whose aim is to promote CAN (Controller Area Network) and to provide a path for future developments of the protocol through technical, product and marketing information. It actively supports international standardisation of CAN-related standards (**E3**). CiA released the first stable CANopen specification (CiA 301 version 3.0) in 1995. Within the next few years CiA declared that *"it became the most important standardised embedded network in Europe*". Regular updates have since been released with CiA currently working on a new updated version to allow interface support for improved data transmission rates. (**E1, E2**)

Summarising the contribution made by Newcastle University on the initial CANopen specification the CiA Managing Director commented that (**E1**): *"The EN 50325-4 international standard (CiA 301 application layer and communication profile) would not have been introduced without the underlying scientific R&D work undertaken at Newcastle University by Dr Mohammed Farsi*."

Impact on commercial organisations:

CANopen defines a complete framework for low-cost flexible device independent systems. Aided by the introduction of the second generation of CANopen networks in 2007 and a new communication profile in 2011. These along with additional support for connecting different devices provide important reasons why industrial segments still widely use and provide CANopen support in their products today. The CiA Managing Director stressed the importance and significance of CANopen to industry by commenting (**E1):**

"*Over the time, CiA members have developed more than 60 devices, applications, and interface profiles. This has encouraged industries to buy low-cost, off-the-shelf devices and device vendors to provide end-to-end CANopen solutions. Some of the major companies supplying CANopen solutions around the world since 1999 include Siemens Medical Systems, GE Healthcare, Volkswagen, Toyota and Putzmeister. These companies cover a wide variety of industries such as automotive, medical devices, rail vehicles, laboratory equipment, building automation and control systems for renewable energy. Chipmakers such as Freescale, Fujitsu, Infineon, Microchip, NXP and Renesas support the CANopen protocol by means of third party products. The European Space Agency has implemented CANopen in hardware for space applications."*

In the early 1990s, Siemens Medical Solutions were faced with an ever-growing demand for more functionality combined with market pressure to reduce the cost of medical equipment. Siemens engineers looked at the automotive industry for guidance and decided that CAN would form the communication backbone of the next generation of products (**E4**). Siemens incorporate embedded CANopen networks to various sub-systems in several of its diagnostic medical devices. In 2009, the Catholic Medical Center in Seoul, Korea ordered 70 systems of medical equipment incorporating embedded CANopen networks for eight hospitals. Worth around 28 million Euros, the order is one of the biggest of its kind in the medical industry worldwide (**E5**).

In 2008**,** European scientists working for CERN started high-energy physics experiments hoping to discover among other things the Higgs particles. The scientists designed and developed several detectors for the Large Hadron Collider (LHC), which took a decade to construct at a cost of approximately $4.75 billion. The Detector Control System (DCS) is partly based on CANopen network systems. The DCS had the task to permit coherent and safe operation of other large detectors (some accounting for 60 million electronic channels) and to serve as a consistent interface to all sub-detectors and technical infrastructure of the experiment. Many other European high-energy research institutes have also used CANopen-based systems for more than 10 years in a broad range of applications (**E7**).

Sevcon Ltd. operate in the global market for electrically powered vehicles with annual sales of over $35m, and have adopted CANopen for the forklift truck sector and standardised on it over 10 years ago. Sevcon Vice President (Engineering) states the reasoning: "*It provides support for connecting different devices from a range of manufacturers which is one of the important reasons why it is widely used and why Sevcon provides CANopen support in our products today. CANopen is standard on all our AC motor controller range and has been designed into all the new motor control products we have developed over the last ten years*" (**E6**).

Impact on economic prosperity:

CiA has around 580 companies who are members of this international users and manufacturers group (**E1**). To try and quantify the market value of CANopen, the Managing Director of CiA provides an estimation of the manufacturers' (producing CAN interfaces) sales figures by calculation and estimation (**E9**):

We know the annual number of cars produced (60 million cars per year), multiply them by the average number of CAN nodes in a car (high-end cars have 80 ECUs (Engine Control Units), mid-range cars about 40 ECUs and low-end cars just a few). The total average number is about 12 ECUs per car, thus, resulting in about 720 million CAN nodes per year. The automotive market is approximately 80% of the total CAN market. Depending on the forecast for future car production volumes, CiA estimates that in 2015 the use of CAN nodes will reach 1 billion/year.

The estimated number of sold CAN transceivers, stated by NXP (market leader in the semi-conductor industry), provides a figure of approximately 800 million CAN interfaces for 2013. Although the provision of CAN interfaces on the marketplace is huge, there is no exact figure on how many use the CANopen technology. It is known that 80% of the wind power systems use CANopen for controlling the pitch control system movement. Worldwide there are over two hundred thousand wind turbines operating, with a total capacity of 282,482 MW at the end of 2012 (**E10**). *If we multiply each by seven (three encoders, three drives, and one controller) then we have a total in excess of 1.4 million CANopen interfaces in use.*

From these examples alone, it is clear that the overall financial effects from the CANopen technology form a worldwide billion dollar industry.

5. Sources to corroborate the impact

[E1] Corroborating statement: Managing Director, CAN in Automation (CiA)

[E2] CANopen history by CiA, 'From theory to practice' stating Newcastle University's research work on CANopen. http://www.can-cia.org/index.php?id=522#c2106

[E3] CiA history and information. http://www.can-cia.org/index.php?id=aboutcia

[E4] CANopen in X-ray machines, http://www.can-cia.org/index.php?id=364

[E5] CANopen networks in medical devices, http://www.can-cia.org/index.php?id=991

[E6] Corroborating statement: Vice President – Engineering, Sevcon Ltd.

[E7] CANopen: CERN on Large Hadron Collider (LDC), http://www.can-cia.org/index.php?id=958

[E8] CANopen European standard EN 50325-4

[E9] Financial sales estimation of CAN by Holger Zeltwanger, Managing Director, (CiA)

[E10] Number of worldwide wind power systems, http://en.wikipedia.org/wiki/Wind_power