Proposal for Innovative Manufacturing Research Centre (IMRC)

Exploring the Opportunities of Industrial Ethernet Fieldbus

Richard McLaughlin, WMG

Introduction

The widespread use of low level industrial computer networks (also known as Fieldbusses) to replace PLC – I/O wiring is now well established. Fieldbusses allow the use of intelligent sensors and actuators, each with a microcontroller and a network controller chip linked together via a computer network. Normally there is a central controller involved widely known as a Programmable Logic Controller (PLC).

In a traditional configuration, the PLC was linked to its devices (sensors and actuators) through I/O blocks on a central back-plane common to the PLC. This meant that there were many wires connecting the devices back to the PLC rack, which caused very labour-intensive installation and commissioning scenarios. Also, trouble-shooting was very inefficient, leading to unwanted and expensive downtime.

Over the past ten years, several fieldbus protocol standards were developed to eliminate these problems. This lead to:

- Installation times reduced by 75%
- Commissioning times reduced by 75%
- Downtime due to troubleshooting drastically reduced
- Enhance diagnostics for predictive failure analysis
- Status monitoring of process over the Internet via gateways.

The big issue with automation and manufacturing process industries now is the use of Ethernet in fieldbus applications. Sense of this is to realise a general, interfaceless communication through all levels of an enterprise – from the shop floor to the corporate network levels. This refers to all fields of plant automation, process automation, and building automation.

For years end users have been requesting an industrial version of Ethernet. The reasons are as follows:

1. Low Cost and Wide Acceptance - Ethernet is an established, worldwide standard with support from IEEE and the International Standards Organization. In addition to this support from standards organizations, Ethernet has been broadly used in both industrial and office environments. The high number of users has, in turn, ensured the downward price of Ethernet components. Plus, IS and IT departments worldwide have been using Ethernet for years. Such long-term exposure to the Ethernet technology has produced an expansive knowledge base and unparalleled resources.

2. Baud Rate - Recent developments in Ethernet technology include Fast Ethernet and Gigabit Ethernet. Fast Ethernet (100 Mbits/sec) provides a wire speed that is 10 times as fast as traditional Ethernet, which tends to benefit bandwidth-hungry applications, as well as the transfer of large data files over the network. Gigabit Ethernet is an emerging technology that is basically Ethernet operating at 1000 Mbits/sec.

3. Integration with Internet/Intranet - All installed Ethernet networks support one or more communications protocols that run on top of Ethernet and provide sophisticated data transfer and network management functionality. Of these, TCP/IP is receiving the most attention due to the global Internet (including the World Wide Web) and the corporate Intranets that are transforming how corporations distribute information today. Many believe that using Ethernet - especially with the dawning of e-commerce - at all levels in the factory will help integrate and optimise the flow of information from the shop floor to the Intra/Internet.

It was essential to create open protocol standards to ensure the use of products from many device vendors. DeviceNet and ControlNet are two well-known industrial networks based on the Control and Information Protocol (CIP). Both networks have been developed by Rockwell Automation, but are now owned and maintained by the two manufacturers organisations ODVA (Open DeviceNet Vendors Association, see http://www.odva.org) and ControlNet International (see http://www.controlnet.org/). ODVA and ControlNet International have recently introduced the newest member of this family – EtherNet/IP ("IP" stands for "Industrial Protocol").

Figure 1 shows that the concept of CIP is to utilise a common higher layer protocol over several data link network levels. On the device level (DeviceNet); Controller Area Network (CAN) is used. CAN is a well-established communication method utilised in production vehicles. Virtually every car manufacturer uses it. Because of its popularity, CAN is used in every industry that utilises control electronics. DeviceNet is the most popular open higher-level CAN-based protocol.

On the information level (EtherNet/IP), Ethernet is used along with TCP/UDP/IP embedded into the stack.

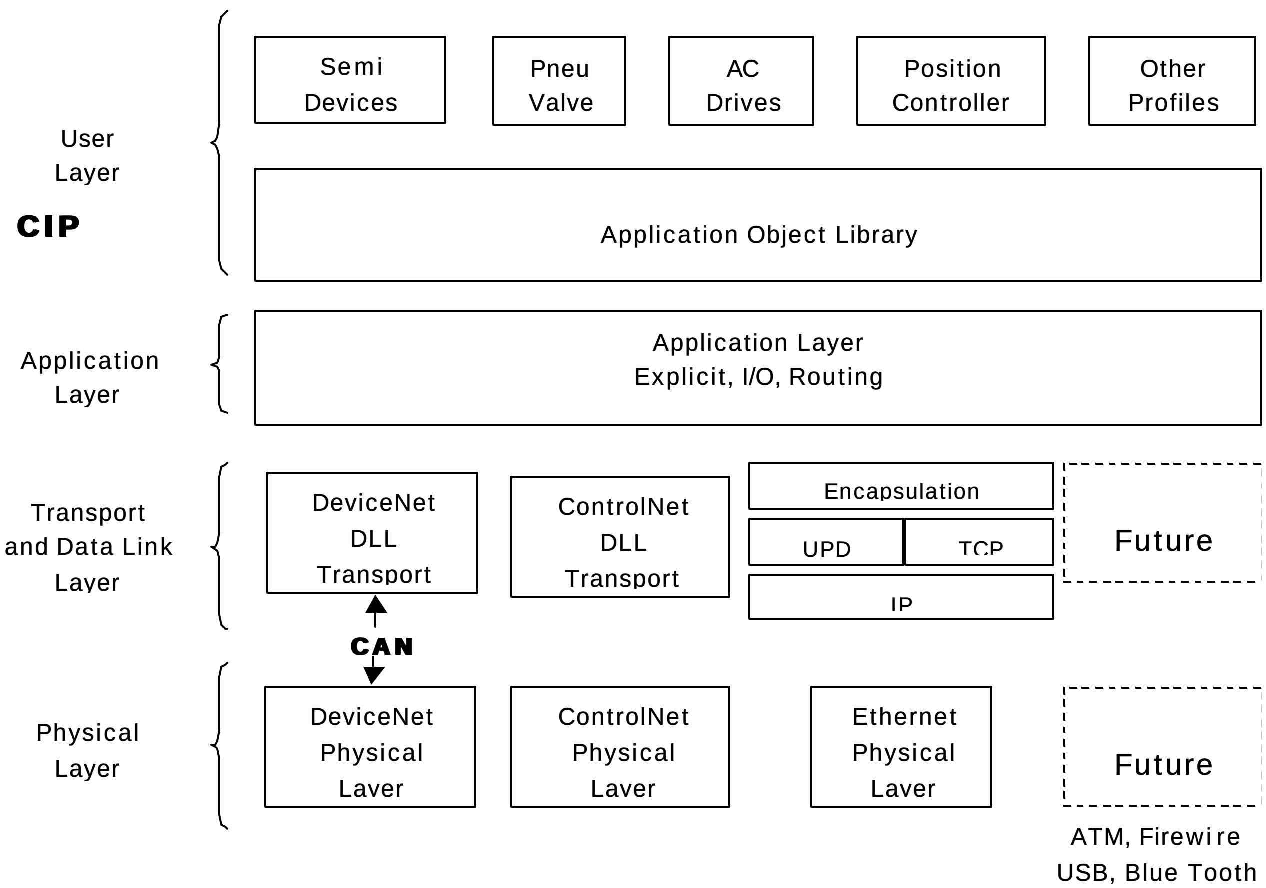

Figure 1. CIP and its Data Link/Physical Layers

Market Need

This project will address many issues essential to new developments in Ethernet fieldbusses by establishing the techniques and mechanisms needed to implement a fully consistent set of services and data objects on a TCP/UDP/IP based Ethernet network.

The pull for this technology is from the many automation and manufacturing industries that wish to simplify their control networks architecture. For example General Motors in the U.S. is currently running pilot programs to show how DeviceNet and EtherNet/IP can be used as a 2-level network solution for all automotive manufacturing needs. As with GM, it is the intention of many process industries to simplify the overall network architecture and greatly enhance the communication structure. This effects greater diagnostic capabilities while enhancing the e-business structure though communication across the existing corporate Ethernet.

Using an EtherNet/IP network and related hardware provides an opportunity to easily integrate the IT and factory floor networking architectures, providing substantial cost savings. This allows users to link customer and supplier data, reduce cycle time, increase manufacturing reliability and enhance customer satisfaction. EtherNet/IP broadens the range of factory automation devices. The new standard has already been adopted by more than 80 automation equipment vendors, including makers of PLCs, motion controllers, and operator interface stations.

This research will benefit most industries that already manufacture DeviceNet products, as well as the end users of these products, as many of these members are working toward Ethernet fieldbus implementations. These interested parties are members of the Open DeviceNet Vendor Association (ODVA), which has a very large consortium of members (more than 300) that are actively pursuing the implementation of industrial Ethernet in the form of EtherNet/IP. These member companies are of varying sizes, including many SMEs. Many of these companies will be active participants in this research programme (see Appendix A).

Track Record

The group led by Richard Mclaughlin, has many years of expertise in this technology, including 10 years research in Controller Area Networks. This had led to significant innovations including:

- More than 30 papers published on CAN/DeviceNet performance and application issues for journals, referred conferences and trade press.
- Patent on CAN bus-load transducer technology.
- Diagnostic Software developments – commercialised through company spin-off (Warwick Control Technologies Ltd.).
- Provided essential training and consultancy to UK Automotive and Automation industries.

Research and development projects have included:

- future in-vehicle electronic control integration based on CAN technology (Rover).
- 35 research students (M.Sc., Ph.D., Eng. Doc., MEng), working on projects related to CAN/DeviceNet technologies.
- Established a Centre of Excellence to provide low cost training and consultancy on CAN technology for UK industries (ERDF). Research was carried out on the application of CAN in novel industrial implementations, e.g. Lift application, Entertainment controls, Manufacturing controls, etc.
- Application of CAN from in-vehicle controls to automation and manufacturing controls in the form of a DeviceNet assembly cell demonstrator (DTI).
- Conformance, interoperability test procedures, DeviceNet performance (ODVA).

This research has led to the creation by the University of Warwick of a start-up company, Warwick Control Technology, to exploit and commercialise developments in Automotive and Automation technologies created as a result of research at Warwick University which include:

- CAN diagnostic tools
- CAN-based Electronic Control Unit developments
- CAN bus-load transducer
- Hybrid Electric Vehicle developments
- CAN higher layer protocol developments, e.g. DeviceNet, CANOpen, J1939
- CAN/Ethernet Bridge

Knowledge transfer activities include:

- acting as the European testing and technical support centre for DeviceNet (ODVA).
- awareness seminars (delivered with DeviceNet UK) to UK end users in automation and manufacturing process industries.
- Promulgation of research outputs through academic, trade and professional publications, conferences, trade shows, road shows and company visits to the assembly cell at Warwick.

WMG's Automation Research Group headed by Dr. Ken Young is performing extensive research in best practice automation applications. Research outputs will be fed into the activities of the Automation Research Group.

Industrial Collaboration

The partners listed in Appendix A provide a representative mix of small and large vendors of control and device equipment. The project will have access to their extensive customer base of suppliers and OEMs from a wide rage of sectors. Target sectors will include:

- Automotive Manufacturers
- Food and Beverage process industries
- Assembly automation companies, e.g. computers, consumer goods, etc.
- Semiconductor industries.

Partners will contribute in the form of:

- Equipment and product to create an industrial Ethernet research lab/demonstrator.
- Manpower and expertise to support the set-up, operation and management of the industrial Ethernet research centre at Warwick.
- Direct cash contributions according to company size.

Overall Aims and Objectives

The aim of this project is to create new concepts of implementation (for vendors and end-users) of the CIP-based version in the form of EtherNet/IP.

Whilst, EtherNet/IP is already in limited use in the US, there are many technical issues that must be addressed to enable its successful implementation in UK manufacturing. Specific research challenges include:

- Mechanisms for implementing ADR (Automatic Device Replacement) on EtherNet/IP. This helps in interchangeability of devices and also reduces device configuration time and helps in time critical industries.
- Strategies for dealing with Multicast data on switches- switch is a multiport bridge and allows traffic between any two ports with an extremely low latency. Multicast is group destination and this feature can be used to filter all similar messages for example all DeviceNet traffic on a switch. This

will help in reducing bandwidth and time critical data transfer and also the ease of interconnecting different network protocols.

- Benefits of shared CIP (Control and Information Protocol) messages between EtherNet/IP and DeviceNet – DeviceNet and EtherNet/IP share the same application layer. So the implication is that it should be a very efficient process to map the two networks together. A study is to be made on the issues concerning the lower layers (Transport, Network, Data Link and Physical) of the two protocols and the most efficient means of bridging them together.
- XML (Extensible Mark-up Language) address mapping to allow access to CIP data via DirectX, SOAP (Simple Object Access Protocol)
- EDS (Electronic Data Sheet) migration to XML schema format – The Electronic Data Sheet (EDS) is what makes DeviceNet an easy to use open protocol. It allows configuration tools to recognise DeviceNet products from hundreds of vendors. The same ethos could be applied to EtherNet/IP very efficiently through the use of XML. This project is meant to study how the EtherNet/IP form of CIP could be even easier to configure using XML.
- Implications of Wireless networking on EtherNet/IP – There is much discussion about wireless LANs using Ethernet. This project could study the best means for interconnecting EtherNet/IP systems through a wireless medium. Also the future for other wireless CIP implementations could be investigated, e.g. GSM Networks, Bluethooth. etc.
- Study of Determinism of Ethernet/IP through the use of Ethernet hubs and switches – various methods of improving Ethernet's determinism are the hot topic for industrial applications of Ethernet. One promising method is to avoid collisions through the use of full-duplex technology and switched hubs. It would be in the interest of the future of EtherNet/IP to study the performance of Ethernet Hubs and switches.
- Establish best means of diagnostic data capturing for ease of use by shop-floor personnel.

The Objectives of the project are:

- Identify key research targets with Industrial Collaborators, as well as end-users.
- Set-up an EtherNet/IP demonstrator/test bed for research and dissemination.
- Investigate real-time performance of Ethernet switches and hubs.
- Create diagnostic methodologies for EtherNet/IP for ease of use by installers and maintenance personnel.
- Establish methods of integrating shop-floor networks with corporation level networks utilising state-of-the-art Internet technologies, e.g. XML, SOAP, DirectX, etc.
- Establish methods of integrating DeviceNet fieldbus with Ethernet fieldbus across a common higher layer protocol known as CIP (Control and Information Protocol).
- Create mechanisms for implementing Automatic Device Replacement to reduce maintenance time.
- Assess cost vs. benefits of EtherNet/IP implementations.
- Set-up a technical resource centre for industry in the form of a web site and an information hotline with the demonstrator open to the public.

Programme of Work

The research will be undertaken over a two year timescale that is commensurate with the rapid technological developments in this field. The programme is divided into ten areas (please see attached Gantt chart in Appendix B)

Task 1 : Consult with the Industrial Partners

The first task in the programme will be to identify and prioritise the topics for research based on Partner companies' and potential end-users' inputs.

1.1Short list most promising technology options.

1.2 Select most appropriate case types.

Participants: Warwick and Industrial Partners
Deliverables: Short list of technology and applications

Task 2 : Set-up of Warwick Industrial Ethernet Research Centre web site and information centre
Set up web site to ensure continuous information dissemination for product vendors and end-users. Form links to participating partners. Post case studies as they are acquired. Information centre to be made available to all interested parties
2.1 Set up web site.
2.2 Form hyper-links to partners.
2.3 Gather Case Studies.
2.4 Email-shot to potential interests advertising the web site and information centre.
Participants: Warwick and Industrial Partners
Deliverables: Web site and information hotline.

Task 3 : Creation of EtherNet/IP Demonstrator
Product is to be gathered from industrial partners to set up the test bed for the basis of much of the research work to be performed. The test bed will be open for public viewing to help disseminate information to all interested industries.
3.1 Obtain EtherNet/IP products.
3.2 Build-up the EtherNet/IP test bed at the Warwick International Manufacturing Centre.
3.3 Create scenarios for performance testing.
3.4 Inform the public that the demonstrator is open to public viewing by appointment.
Participants: Warwick and Industrial Partners
Deliverables: EtherNet/IP Demonstrator and test bed

Task 4 : Investigate real-time performance of Ethernet switches and hubs.
There are many issues surrounding the real time performance of Ethernet switches and hubs. Research is needed to establish that the currently available switches and hubs are of a real-time performance standard, and to identify requirements for next generation products.
4.1 Identify Ethernet switches and hubs from industrial partners.
4.2 Form test plan for performance testing of switches and hubs on the EtherNet/IP Demonstrator/test bed.
4.3 Perform testing of the various products made available by the industrial partners.
4.3 Disseminate information concerning minimum acceptable latencies for real-time control.
Participants: Warwick and Industrial Partners
Deliverables: Performance reports on the real-time capabilities of the Ethernet switches and hubs.

Task 5 : Methods of integrating shop-floor networks with corporation level networks utilising state-of-the-art Internet technologies, e.g. XML, SOAP, DirectX, etc.
This will utilise XML (Extensible Mark-up Language) address mapping to allow access to CIP data via DirectX, SOAP (Simple Object Access Protocol)
5.1 Establish technologies that can be migrated from internet technologies to EtherNet/IP
5.2 Develop software routines to link the industrial EtherNet/IP seamlessly to the corporate network level.
Participants: Warwick and Industrial Partners
Deliverables: Software routines for networks integration of EtherNet/IP onto the corporate Internet.

Task 6: Bridging DeviceNet and EtherNet/IP
DeviceNet and EtherNet/IP share the same application layer. The implication is that it should be a very efficient process to map the two networks together. A study is to be made on the issues concerning the lower layers (Transport, Network, Data Link and Physical) of the two protocols and the most efficient means of bridging them together.
6.1 Establish hardware platform for bridging DeviceNet and EtherNet.
6.2 Develop software routines for efficient real-time bridging in an embedded system.
6.3 Implement the firmware in the embedded system.
Participants: Warwick/Warwick Control Technologies/HM Computing
Deliverables: DeviceNet - EtherNet/IP Bridge.

Task 7: EDS (Electronic Data Sheet) migration to XML schema format

The Electronic Data Sheet (EDS) is what makes DeviceNet an easy to use open protocol. It allows configuration tools to recognise DeviceNet products from hundreds of vendors. The same ethos could be applied to EtherNet/IP very efficiently through the use of XML. This project will study how the EtherNet/IP form of CIP could be even easier to configure using XML.

7.1 Study EDS format of a selection of DeviceNet products.

7.2 Establish a method of migrating the EDS format to XML.

7.3 Develop the XML format to allow use by industrial partners configuration tools.

Participants: Warwick/Rockwell Automation/Omron/Woodhead

Deliverables: Software routines for migrating EDS to XML.

Task 8: Best means of diagnostic data capturing

Create diagnostic methodologies for EtherNet/IP for ease of use by installers and maintenance personnel. There are many techniques for collecting diagnostic information from a data bus, but it is essential to develop diagnostic routines that are easy to use for shop floor personnel.

8.1 Investigate existing platforms for data collection.

8.2 Establish the format for ease of use.

8.3 Develop a diagnostic tool for EtherNet/IP that is simple to use and easily readable.

Participants: Warwick/Warwick Control Technologies

Deliverables: Software routines for collection of CIP data.

Task 9: Assess cost vs. benefits of EtherNet/IP implementations.

Many in the Automation and Manufacturing industries are developing and implementing Ethernet fieldbus applications. While there are many established benefits of this, and there are many more to be researched in this programme. The project will assess the likely cost benefits of each new technology, both to help prioritise research opportunities, and to aid exploitation of outputs.

9.1 Collect.

9.2 Assess.

9.3 Report.

Participants: Warwick

Deliverables: Report detailing the cost vs. benefits issues of EtherNet/IP implementations.

Task 10: Disseminate EtherNet/IP research information.

One of the most important areas of research is the dissemination of the research results. This task will be ongoing throughout the project. There are various avenues of dissemination, as follows:

10.1 Write papers

10.2 Present papers at conferences

10.3 Host training sessions.

10.4 Host visits.

10.5 Take technical enquiries

Participants: Warwick

Deliverables: 4 Academic Journal paper, and Conference and Trade Press papers.

Project Management

Richard Mclaughlin will manage the project. He has considerable experience of managing multi-partner research programmes. A steering committee, consisting of senior representatives from partner companies, will meet at 4 month intervals to ensure that the direction of the project remains aligned with the partners and EPSRC IMRC priorities. Many of the partner companies are involved with the ODVA Technical Review Board, which sets policy for technical issues in DeviceNet and EtherNet/IP. These members will feed information to the project manager to ensure that the research is relevant to the needs of the industry. Day-to-day management will use a combination of weekly technical meetings and monthly progress meetings, to ensure smooth progress of the research. The project manager will ensure that all documentation, including annual progress reports and collaborator involvement details, are supplied to the EPSRC IMRC in a timely manner.

Dissemination & Exploitation

Dissemination and technology transfer within collaborating organisations will be accomplished through regular progress reviews, production of technical reports and seminars. It is envisaged that partner companies, and a broader network of companies, will be able to incorporate learning from the project in their next generation of devices. Dissemination to the EPSRC will be achieved by means of the regular progress reports and technical reports associated with specific milestones. Wider dissemination and thus exploitation of the results of the programme will be achieved through traditional channels of 4 refereed publications, industry trade journals, conferences and industrial seminars together with the WWW pages of the academic and industrial partners. New knowledge generated will be incorporated within the extensive CPD Masters training programme at Warwick and associated short courses.

A Warwick Industrial Ethernet Research Centre will be set up to disseminate information about industrial Ethernet to UK (and European) automation and manufacturing process industries. Dissemination will be in the form of:

- Demonstrator/test bed open to public display.
- Set-up of Warwick Industrial Ethernet Research Centre web site and information centre.
- Papers for conferences and journals.
- Unpublished thesis from full-time M.Sc. students involved in EtherNet/IP projects will be available for review.
- Seminars at Warwick on EtherNet/IP.

Justification of Resources – 2 years

Staff: A full-time Research Fellow (Eva D'souza) will undertake the research. Her work will be supported by M.Sc. student projects and potentially PhD studies in underpinning aspects. **£63k**

Technical Support staff in the form of a technician at one-quarter time, and an electrician at one-quarter time **£12k**

Equipment: This will be provided through donations and loan of equipment from partner companies, valued at £100k. Other equipment required is computers, bench power supplies, tools, etc. **£10k**

Consumables: plus costs associated with dissemination events **£10k**

Travel and Subsistance: To partner companies, to other companies to disseminate research outputs, to academic colleagues, e.g. University of Michigan, Manchester Metropolitan University, and to present findings at key academic and industry conferences, e.g. Trade conferences and IEE Symposiums. **£10k**

Indirect Costs: 46% of staff salaries **£32k**

The total funding sought from Warwick IMRC is: **£137k**

Cash Contributions from Partners: *(Rockwell)* **£20k**

In-kind contributions from Partners: *(Rockwell, Tellema, Warwick Control, HM Computing, Contemporary Controls, Cutler-Hammer, Dearborn Electronics, Woodhead, Hirschman, Harting, plus more later)* ***£100k+***

References – papers published over the past 5 years

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"DeviceNet System Planning", K. Young, R.T.McLaughlin, R.S.H. Piggin, Drives & Controls Conference, Telford 13th March 1997

"DeviceNet Conformance Testing Procedures and Experiences", Richard McLaughlin, K.H.Tang, Dr. James Moyne, Jigney Shah, Proceedings 4th International CAN Conference, Sponsored by CAN in Automation, Berlin, Oct 1997.

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"Fieldbus Selection", K. Young, R.T. McLaughlin, R.S.H. Piggin, Fieldcoms USA, Chicago, 19th March 1998

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"Diagnostic Implementation Utilising DeviceNet", K. Young, R.T. McLaughlin, R.S.H. Piggin, (1998) Fieldcoms USA, Chicago, 19th March 1998

"DeviceNet Interoperating Test Procedure", Richard McLaughlin Kiah Hion Tang, Proceedings 5th International CAN Conference, Sponsored by CAN in Automation, San Jose, Oct 1998.

"Safety Related Fieldbus", R S.H. Piggin, K. Young, R.T. McLaughlin, R.T., Drives & Controls Conference, Telf ord, 18th March 1999

"Fieldbus selection – Open Vs Proprietary Systems", R S.H. Piggin, K. Young, R.T. McLaughlin, R.T., Drives & Controls Conference, Telford, 18th March 1999

"Tool integration utilising fieldbus technology", R.S.H. Piggin, K. Young, R.T. McLaughlin, Assembly Automation, Volume 19 Number 4 (1999), MCB Press

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"DeviceNet Physical Layer Design and Conformance Testing", Richard McLaughlin, Kiah Hion Tang, Drives and Controls Conference Paper, March 2000.

"A Study of DeviceNet Technology for the Low Quantity Vehicle Industry", Richard McLaughlin, Kiah Hion Tang, Chris Quigley, Proceedings SAE 2001 World Congress (SAE 2110-01-0064), Detroit, Michigan, March 2001. Also incorporated in In-Vehicle Network 2001 (SAE SP-1594).

"The Application of Low Cost CAN Bus Load Transducer Technology", Richard McLaughlin, Kiah Hion Tang, Chris Quigley, Andrew Roxburgh, Proceedings SAE 2001 World Congress (SAE 2110-

01-0070), Detroit, Michigan, March 2001. Also incorporated in In-Vehicle Network 2001 (SAE SP-1594).

"An investigation of into Future of Automotive In-Vehicle Control Networking Technology", Richard McLaughlin, Chris Quigley, Andrew Roxburgh, Proceedings SAE 2001 World Congress (SAE 2110-01-0071), Detroit, Michigan, March 2001. Also incorporated in In-Vehicle Network 2001 (SAE SP-1594).

"A Low Cost CAN Bus Load Transducer and its Application", Richard McLaughlin, Kiah Hion Tang, Chris Quigley, Andrew Roxburgh, Proceedings 7th International CAN Conference, Sponsored by CAN in Automation, Amsterdam, Oct. 2000.

"The Feasibility Study of DeviceNet over Extended CAN", Richard McLaughlin, Kiah Hion Tang, Proceedings 7th International CAN Conference, Sponsored by CAN in Automation, Amsterdam, Oct. 2000.

"CAN Bus Analysis of DeviceNet I/O Connection Services", Richard McLaughlin, Eva D'souza, Kiah Hion Tang, Proceedings 8th International CAN Conference, Sponsored by CAN in Automation, Las Vegas, Feb. 2002.

Appendix A – Potential Industrial Partners for IMRC
Exploring the Opportunities of Industrial Ethernet Fieldbus

ABB Industrial Systems Ltd
9 The Towers
Wilmslow Road
Didsbury, Manchester
M20 8RB
Nick Brown
Phone: 0161 445 5555
Fax: 0161 445 6066

Applicom
Control Technology International Ltd
Regal Chambers
49/51 Bancroft
Hitchin, Herts
SG5 1LL
Tel: 01462 457 700
Fax: 01462 453 377
info@cti.u-net.com

Baldor UK Ltd
6 Bristol Distribution Park
Hawkley Drive
Bristol
BS32 0BF
Mark Crocker

Beckhoff
Hayes Control Systems
The Boathouse, Station Road
Henley-on-Thames
Oxon RG9 1AZ
Great Britain
Stephen Hayes
Phone: 01491 410 539
Fax: 01491 577 267
sales@hayescontrols.co.uk
www.hayescontrols.co.uk

Beta Lasermike Limited
Stirling Road
Cressex Business Park
High Wycombe Bucks HP12 3RT
England
Amolak Bahra
Phone: (44) 1494 89 4400
Fax: (44) 1494 84 4401

British Federal Limited
Castle Mill Works
Birmingham New Road
Dudley West Midlands DY1 4DA
Kevin Cambridge
Phone: 01384 455400
Fax: 01384 455554

BOC Edwards Ltd
Marshall Road
Eastbourne East Sussex BN22 9BA
Brian Roberts
Phone:(44) 1323 501147
Fax: (44) 1323 509824

Contemporary Controls Ltd
Barclays Venture Centre
University of Warwick Science Park
Sir William Lyons Road
Coventry
CV4 7EZ
Phone: 024 7641 3786
Fax: +44 (0)24 7641 3923
http://www.ccontrols.co.uk/

Control Techniques PLC
Unit 79
Mochdre Industrial Estate
Newtown Powys SY16 4LE
Kevin Manton
Phone: (44) 1686 612300
Fax: (44) 1686 612800

Cutler-Hammer
Mill Street
Ottery St. Mary
Devon
EX11 1AG
Terry Price
Tel: + 44 (0)1404 812131
Fax: + 44 (0)1404 815471
PRICETJ@ch.etn.com

Crouzet Limited
Intec 3
Wade Road
Basingstoke
RG24 8NE
Brian Hornsby
Phone: 01256 318900
Fax: 01256 318901

Danfoss Limited
Perivale Industrial Park
Horsenden Lane South

Greenford, Middlesex
UB6 7QE
Andrew Cooper
Phone: 0181 991 7030
Fax: 0181 991 7149

Dearborn Electronics (U.K.) Ltd.
The Technology Centre, Glaisher Drive
Wolverhampton Science Park
Wolverhampton
WV10 9RU
Jim Samuel
Phone: 01902 824051
Fax: 01902 824053

Eurotherm Drives Ltd Head Office (Drives)
New Courtwick Lane, Littlehampton, West Sussex, BN17 7RZ Tel:
Phone: +44 (1903) 737000
Fax: +44 (1903) 737100
EMail: info@drives.eurotherm.co.uk
URL: http://www.eurotherm.co.uk/drives/

Festo Limited
Automation House
Harvest Crescent
Ancells Business Park
Fleet, Hampshire
GU13 8XP
Nigel Lowe
Phone: 01252 775000
Fax: 01252 775001
nigel_lowe@festo.com

Harting Ltd.
Caswell Road
Brackmills Ind. Est.
Northhampton
NN4 7PW
Graham Traill
Phone: 01604 766686
Fax: 01604 706777
Graham.traill@harting.com
www.harting.com

Hilscher and HMS
Miles Industrial Electronics Ltd.
The Stable Yard
Holdenby House Holderby
Northampton, NN6 8DJ
Mike Hiller
01604-771122
01604-771181
sales@milesie.co.uk
http://www.milesie.co.uk

Hirschmann Electronics Ltd.
St. Martins Way
St. Martins Business Centre
GB-Bedford MK42 0LF
Paul Taylor
Phone: +44-1234-34 59 99
Fax: +44-1234-35 22 22
ptaylor@hirschmann.co.uk
www.hirschmann.co.uk

HM Computing Ltd
Harmac House
Enigma Park
Malvern, Worcestershire
WR14 1GP
Mike Harrison
Tel. 01684 581850
Fax. 01684 581851
sales@hmcomputing.net
http://www.hmcomputing.net/

IMI Norgren Limited
P.O. Box 22
Eastern Avenue
Lichfield
Staffordshire WS13 6SB
Michael White
Phone: (44) 1543 414 333
Fax: (44) 1543 257 180

IXXAT
Nohau UK Limited
The Station Mill,
Alresford, Hampshire,
SO24 9JQ
Cliff Malcolm
Phone (+44) 01962 733140
Fax (+44) 01962 735408
cliffm@nohau.co.uk
www.nohau.co.uk

Lantronix
Beech Cottage
20 Goodliffe Gardens
Tilehurst, Reading
Berkshire RG31 6FZ
United Kingdom
Tel: +44 (0)118 945 1555
Fax: +44 (0)118 945 1633
micks@lantronix.com

Murreletronik Ltd
Albion Street
Pendlebury Ind Estate

Swinton, Manchester
M27 4FG
Paul Chapple
Phone: 0161 728 3133
Fax: 0161 728 3130

National Instruments
21 Kingfisher Court
Hambridge Road
Newbury, Berkshire
www.ni.com/uk

Omron Electronics Ltd
1 Apsley Way
Staples Corner
London
NW2 7HF
Michael Juniper
Tel: 020 8450 4646
Fax: 020 8450 8087
www.omron.co.uk

Numatics Limited
Cherrycourt Way
Leighton Buzzard, Bedfordshire
LU7 8UH
Martin Bonfield
Phone: 01525 370735
Fax: 01525 382567
martinbonfield@numatics.co.uk

Rockwell Automation UK HQ
Pitfield, Kiln Farm
Milton Keynes
MK11 3DR
Tel: 01908 838800
Fax: 01908 261917

Schneider Ltd
University of Warwick Science Park
Sir William Lyons Road
Coventry
CV4 7EZ
Dan Cronin
Tel: 02476 416255
Fax: 02476 417517

SMC Pneumatics (UK) Ltd
Vincent Avenue
Crownhill
Milton Keynes
MK8 0AN
Brian Pollard
Peter Norris
Ray Bardsley
Tel: 01908 563888
Fax: 01908 561185
bpollard@smcpneumatics.co.uk
rbardsle@smcpneumatics.co.uk
www.smcpneumatics.co.uk

Tellima Technology Ltd.
Denby Dale Industrial Park, Wakefield Rd,
Denby Dale. Huddersfield.
HD8 8QH
Tel : +44 (0)1484 866806
Fax :+44 (0)1484 866816
sales@tellima.co.uk
http://www.tellima.co.uk/

Turck Banner Ltd.
Stephenson Road
Leigh-on-Sea, Essex
SS9 5LS
Chris Clarke/Mike Rowlands
Phone: 01702 421124
Fax: 01702 510453
mike@mteturck.co.uk
www.mteturck.co.uk

WAGO Limited
Triton Park
Swift Valley Ind Est
Rugby, Warwickshire
CV21 1SG
Gordon Smith
Derek Lane
Tel: 01788 568008
Fax: 01788 568050
www.wago.com

Warwick Control Technologies Ltd.
University Of Warwick Science Park
Sir William Lyons Road
Coventry
CV4 7EZ
Chris Quigley
Phone: 024 76323 312
Fax: 024 76417 875
chris@warwickcontrol.com
www.warwickcontrol.com

Westermo Data Communications Ltd
Unit 14, Talisman Business Centre
Duncan Road, Park Gate
SOUTHAMPTON

SO30 7GA
Phone: +44 (0) 1489 580585
Fax: +44 (0) 1489 580586

Wind River Systems U.K. Ltd
Unit 5 & 6 First Floor
Ashted Lock Way
Aston Science Park
Birmingham
B7 4AZ
Tel: 0121 359 0999
Fax: 0121 380 4444
mailto:inquiries-uk@windriver.com

Woodhead Connectivity Limited
Factory No.9
Rassau Industrial Estate
Ebbw Vale, Gwent, Wales
NP3 5SD
Mark Birchmore
Phone: 01495-350436
Fax: 01495-350877
markb@wdhd.co.uk
www.wdhd.co.uk