GENERIC REMOTE COMMUNICATION SYSTEMS FOR THE FACTORIES OF THE FUTURE

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ABSTRACT

This paper reports on the benefits of the remote communication systems and presents two prototype systems for communication with microprocessor based machines and devices including household appliances. The wireless prototype version can also be used in remote and wireless programming of any device with a microprocessor or microcontroller.

It is a known fact that the researchers often become too embraced with technical breakthroughs and forget about communicating with the audience for whom the findings of their research is intended. To this end, initial emphasis is on the benefits of the systems, but later in the paper the technical merits of the research work are explained.

The prime aim of the project has been to develop the know-how for remote programming, control and up-dating of programs in microcontroller based devices using wired and wireless techniques.

An earlier wireless communication system using laser encapsulation techniques developed for a factory of the future site [1] was revisited with a view to incorporate the latest technologies where appropriate. The earlier system adopting Code Division Multi Access with a Pseudo Random Noise Spectrum (CDMA-PRNS) incorporating wideband Spread Spectrum (SS) using Hierarchical Genetic Algorithm (HGA) was found to provide a basis for establishing a working Wireless Local Area Network (WLAN) for many applications including in the manufacturing, where noise has been a problem for their use.

Keywords: *Remote programming, Wireless Communication, Factories of the future*

INTRODUCTION

One of the projects initiated by the Factory of the Future Program was the development of novel wireless communication systems. The project was funded by the EU, UK Research Councils and supported by IBM, Cincinnati, Renishaw and many other companies. The project partnership composed of some 50 major organisations. The outcome of the work on a prototype wireless system was reported in a keynote paper by Ziarati and Higginson [1]. The work on wireless communications continued with new partners including BT Fulcrum, Huddersfield University and Bristol University (UK). The latter work considered the work by Hawbaker and Rappaport [2] and Rappaport [3]. Later work by Wijayasuriya & McGeehan [4, 5] and the

outcome of the research by Kit-Sang et al [6] were reviewed. The current research work by the group has reviewed the recommendations of researchers developing the Bluetooth standard [7] and 802.11 [8]. Recent techniques in coding signals and neural network techniques [9-15] have also been reviewed for possible adaptation.

THE PROBLEM

The major problem confronting many manufacturers today is that present day markets demand a variety of diverse products often at short notice. Demand can often change at a short notice and required quantities could be overwhelming at times and small at others. The factories of the future should find new ways to satisfy the market requirements. As a consequence, delivery times can vary quickly and often just-in time requirements offers little time to spare. There is also pressure to reduce volume production times to an absolute minimum. Company survival is becoming more and more dependant upon being first to the market with a new product, which in turn means that there is pressure to reduce product development times. Moreover, the ability to be able to change a product specification, either a minor change or a major rewrite and quickly resume volume production can also influence a company's survival in the market place. Such a pattern of market demand is at odds with present day realities of volume production which tend to favour fixed production lines incorporating large complex and expensive machines with their attendant service supplies and control lines. Such production lines are usually laid out to facilitate the mass production of a single product and have large stocks of the product at various stages of construction and large stocks of components distributed along the line. Enormous amounts of capital are tied up in such lines and they are usually designed for the production of a fixed number of a single finished product per hour or day.

Furthermore, every CNC machine tool, robot and so forth is programmed locally through NC controllers or CAD/CAM links and not directly/remotely through the Internet. The systems presented in this paper demonstrate that any microcontroller device can be programmed and the program can be up-dated and changed at any time through the Internet. The

communication can be through wired means or wireless. The advantages of being able to program a washing machine at the point of manufacture with the capability of reprogramming it at home, remotely through the Internet, cannot be over-emphasized.

DİSADVANTAGES OF FİXED LİNE NETWORKS

Clearly, the maintenance of production flow requires a corresponding controlling data flow. Any relocation of machinery or controlling computers must mean an interruption of the production process either because local computers are deprived of data whilst the line is down or because the physical installation of network line causes disruption on the factory floor. Such changes to the network can take weeks to coordinate in addition to the time taken actually to do the work. In many factories, networks are often a tangled, confusing and virtually unmanageable maze of wiring. Although there are systematic premise wiring systems, these impose a measure of inflexibility into the production environment at the outset and faults on such lines are extremely costly and disruptive to rectify

Moreover, where factories are located in older buildings, wiring costs can rise enormously especially if, for example, asbestos insulation is encountered within the building structure. Where increasing flexibility within the production environment is seen as a necessary future objective, these problems can only become worse with LAN technology. For many production managers, software simulations of efficient production area lay-outs remain simulations. Maintaining control over production in the face of the thorny problems caused by altering LAN topology means that such simulations are unlikely to become reality. Given the expense and limitations of physical wiring, the idea of using radio or laser networking within a factory environment seems an obvious solution. Various alternatives are possible ranging between entirely wireless systems to combinations of wireless and LANs where parts of a factory lay-out are thought unlikely to change. What is suggested is that every piece of manufacturing equipment is in

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radio or laser contact with a central controlling server which coordinates all production within the factory using the Internet; in short, a WIN or "Wireless Internet Network'.

REMOTE CONTROL OF MİCROCONTROLLERS

As microcontrollers and digital circuits become smaller, cheaper and easier to use, their inclusion in various industrial machines, electrical devices and household appliances is becoming more prevalent and accepted. In line with such a trend, remote programming of these systems is becoming an urgent issue when considering novel wired and wireless communication systems and protocols. To this end, a development project supported by Motorola was instigated at Dogus University. Details of the project and experimental set up and results are presented in the next few sections. Based on the initial work it is now possible to program the flash memory of a microcontroller unit (MCU) remotely, through the Internet and the interface facilities designed, at Dogus. The systems provide new and interesting possibilities for controlling any devise with a MCU to be programmed from far distances with ease.

In real life software systems are not perfect and often changes become necessary several times over the systems' life cycle. The systems proposed not only facilitate updating of programs in the MPU memory, but also allow software developments to be carried out off- or on- line and for debugging to take place remotely if required. Such facilities in laymen terms can, for instance, change tasks of a machine tool or any MCU based system at will, directly and with a 100% reliability; more about reliability later.

WIRELESS INTERNET NETWORK (WIN) VS. WİRED LANS

The major advantage of a WIN is that any piece of production equipment can be moved anywhere within the production area with no more trouble than that associated with its actual physical movement. It would remain, at all times, locked in to the overall production network. Extra production equipment could be brought in and with the addition of a simple aerial and local small computer, be smoothly integrated into the existing production environment. Such a scheme could easily accommodate all kinds of additional inspection and testing equipment. Even the movement of a central testing server is reduced to the business of simply moving the server. Wireless links would make distributed testing more easily realisable, with consequent production savings. Engineering drawing data files or the latest specifications, production line status, etc. could be requested from anywhere on the factory floor, or indeed any where in world [16]. Such information can be upgraded with ease if it is all kept on one central server.

In short, WINs enable the production manager to rearrange his production lines to best advantage without any worry that he will lose overall control of the production process or that production will be disrupted because of the movement of an isolated piece of equipment. Some machinery is difficult to move anyway because it is dependent upon somewhat immobile services such as pneumatic systems or heavy electrical supplies but there are many other items used in the manufacturing environment, equally vital to production, (test heads, video cameras, card readers, local workstations, sensors and other control/monitoring devices) which could be used in a much more flexible way if they did not depend on ~ wire or optical fibre network. With a WIN network, potentially huge savings can be made because no costs are incurred when equipment is moved since there is no network line to re-route and re-connect hence managers could rearrange production lines with much more confidence. Further, by the use of alternative modulation schemes, additional independent networks could be implemented. Such systems could co-exist with existing installed radio or laser networks or LANs and be completely transparent to the user. There are some known disadvantages of WIN, such as multi-path fading, need of repetition of transmitted signals and complex-coding techniques. But with suitable chose of coding and wireless antenna configuration, the data rate of secure communication can reach up to 100 Mbps.

The broad aim of the project has been to free production managers from the constraints imposed by production technology, which is rooted to the floor and at the same time make the

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Internet the main means of all communications and data transfers including programming of MCU based devices. To provide manufacturers with an alternative to the dilemma forced upon them by fixed production line topologies, namely, whether to "sell and then make" or "make and then sell" with all the attendant problems of meeting market demand with the former philosophy or balancing capital investment against profits with the second. The proposed communication systems for transmitting design, test and manufacturing data within a manufacturing environment using Internet could formed the basis of the future communication methodology worldwide.

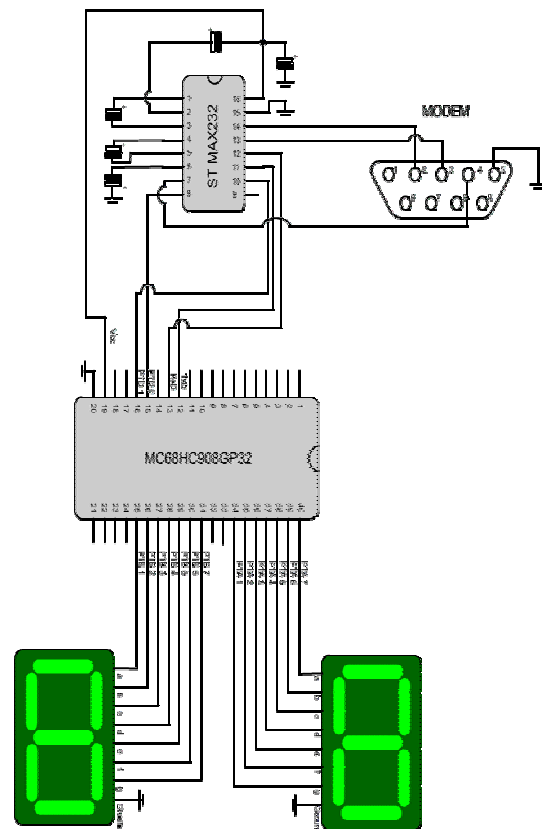## INITIAL TECHNICAL CONSIDERATION

In the initial work two different methods were used for remote programming of MCUs. The common objective as far as both methods are concerned is the remote programming or re-programming of a MCU. However, the difference between two approaches is the media used. The first approach uses public telephone lines as a means of communication with a server through a modem, and the second method, uses a wireless connection technology (radio frequency, RF or laser).

There are some components which are used in both approaches such as a level-shifter as an interface mechanism between the MCU and the other peripherals like computers, modems or other components that have the ability to communicate serially. This interface adjusts the voltage levels and hence allows devices, with different voltage levels/requirements, to talk to each other. Another common device used in both approaches is the end-effectors which are used to monitor the current status of processes taking place during the programming of MCU.

In the experiments carried, a MAX232 was used as a level-shifter and two Hitachi 44780 LCD controllers VP (8-bit bus) were used as end-effectors. In all experiments the MCU used was a Motorola 68HC908 GP32, configured for serial communication with the MAX232 and the end-effectors as elucidated in figure 1. The MAX232 provided the interface unit for interaction with the computer/server connected through the

Internet to the computer/server programming/reprogramming the MCU.

However what are different, in the approaches used, are the communication protocols for talking to the MCU. Since the main difference between two methods is the connection media, the protocols and devices used are different. The wired approach needs a modem to work, hence appropriate protocol needs to be set up on the MCU. The protocol used, in the wired case, is based on a generic and common communication media (modem communication). On the other hand, the wireless method, be it RF or Laser, requires a great deal of thought. For experimental work RF techniques are considered sufficient, however, existence of noise in factory floor has resulted in signal distortion/interference problems. For this reason, the protocol proposed by (21) has so far proven to be a good method of bypassing the effects of unwanted noise signals in the environment e. g. on the shop-floor.

Figure1. The MCU connection arrangements with the level-shifter and the end-effectors

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To overcome noise problems it has been necessary to decide upon a suitable operating frequency and investigate the characteristics and problems associated with radio or laser wave propagation in a factory. Multiple reflections (electrical noise) make this a difficult environment in which to propagate radio or laser waves. It was also necessary to assess the extent to which radiation "leaks out" of the production area and any implications this may have for data integrity and security.

Decision had to be made about aerial design and characteristics. A method of data analysis had to be found and a way in which data is passed around the factory and how a specification could be devised for the operating requirements of the communication system created needed to be established. Designing a transceiver using appropriate modulation/spread spectrum techniques posed its own challenges. Furthermore, deciding upon and implementing an appropriate communication protocol created additional challenges. The prototype systems have yet to be installed inside an actual factory in order to assess the robustness of the system.

The project team was aware of the new developments elsewhere, this together with the work carried out here have added to the body of knowledge of the problems, both human and technical, of wired and wireless communication,

within a factory environment. An independent criterion on which communication standards can be based has also emerged. Such, standards will almost certainly become a necessary requirement for CAD and CAM equipment suppliers if WIN becomes an accepted means of transferring data inside factories. One important consideration has been the 'Jamming Margin'. While there are many applications using DSSS (Direct Sequencing Spread Spectrum) form of modulations, including the Global Position Systems (GPS) which is largest application of DSSS, the data rates (200 bps, nominal) are far too slow when a multimegabit data transfer is needed, as may be the case with CAD/CAM data transfer requirements. Clearly the FHSS with the superior Jamming Margin and high data transfer capability has the competitive edge. However, the 'time utilisation' of DSSS makes it the right candidate for certain applications where high data transfer rates are not the deciding factor. The emergence of data compression techniques has widened the scope for application of DSSS in specific applications.

EXPERİMENTAL PROGRAMME

Figure 2 shows various components of the wireless systems used in the remote programming of the MCU.
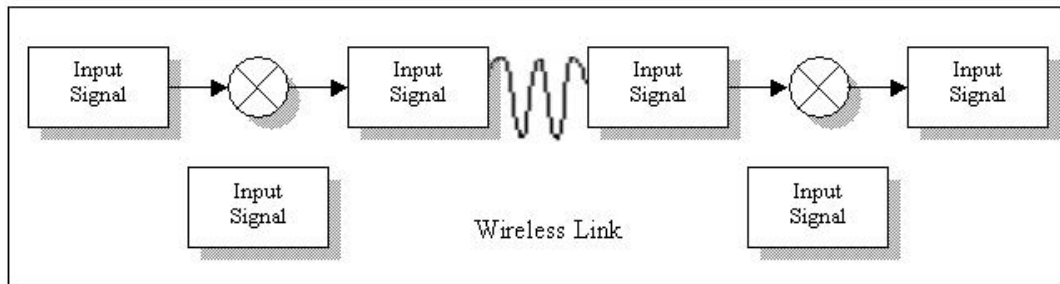

Figure 2. The pictorial presentation of the wireless transmitter and receiver
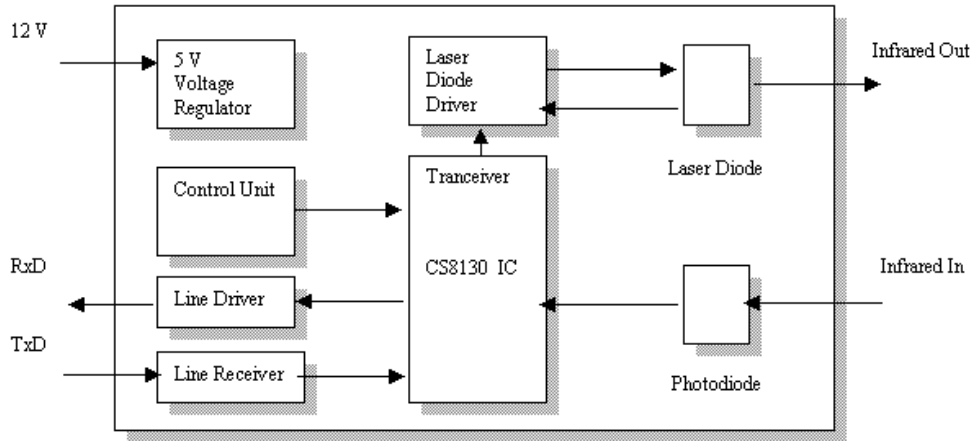
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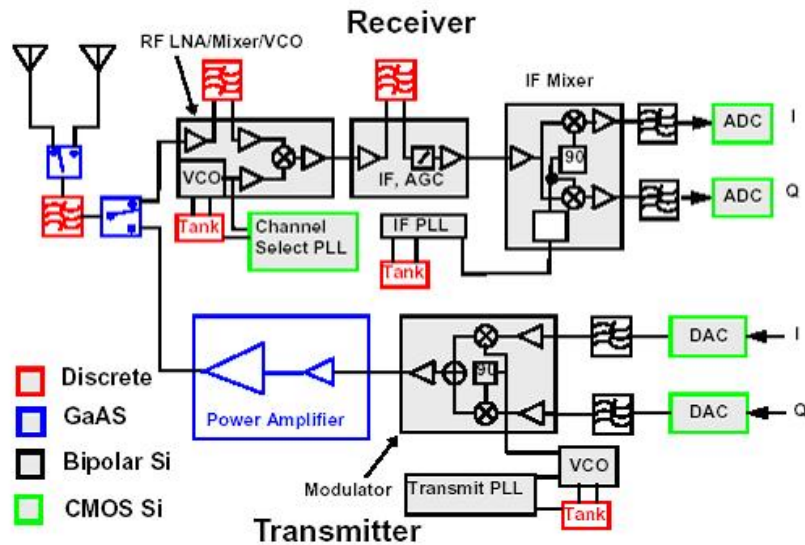**Figure 3.** Wireless communication system for remote programming of MCUs

Figure 4. The transmitter and receiver circuit

The earlier work [1] concerned the general area of wireless communication. These had been centered on Infra Red (IR) systems and frequencies around the upper end of the UHF band. Infra Red systems suffer from the disadvantage that IR radiation is blocked by opaque obstacles and has variable reflection properties from different surfaces making it difficult to suffuse an area with radiation. Peak reliable data throughput for these systems is limited to around 1 Mbps which is an order of magnitude inferior to data rates available on Cupper wired LANs and two orders of magnitude worse than optical fiber LANs. UHF frequencies are already crowded and there is limited bandwidth available at these frequencies.

Moreover, these frequencies may be difficult to confine within the production area. Thus preliminary work had to determine required data rates and operating frequencies. The use of WLAN is wide-spread in offices and factories where physical wiring poses a problem. With the emergence of Bluetooth and 802.11 and other related standards together with decreasing prices of wireless technologies, majority of the problems associates with wireless communication in organisations are expected to be resolved.

The work here offers practical, high qualified WIN having minimised multi-path fading and bit error using optimum source coding, space time

coding and antenna array configurations. Turbo coding, Turbo Trellis Coded Modulation (TTCM) and other update techniques such as Turbo-Trellis Coded Continuous Phase Modulation (T-TCCPM) will be applied to solve severe fading problems of wireless communication. Some of these new techniques are well defined by the research team at Dogus [9-17]. It is pertinent to note that in new green sites the design and layout of the base stations can be strategically decided [18 and 19], however, in brown sites the decision to locate the base stations for optimum performance would depend on the layout of the existing machines particularly those requiring higher voltage/current or hydraulic and pneumatic services [8]. The minimization of the path losses of the signal transmitters and receivers and the optimisation of the number of base stations would reduce the actual cost of the network and would ensure that minimum power is available for the tasks in hand. Prediction of path losses therefore needs to be accurate. These losses have been studied by [20] and it is possible to estimate minimum power requirements to over come co-channel interferences and when the frequency can be re-used. A good method of calculating the required base power for given threshold values and where of transmitter and receiver units can be located is described by [19]. The initial work carried out in the UK has now been passed for further development to Doğuş University to address several problems. Some simulation and test equipment will be required at Doğus to reduce the need for travelling between the collaborating organisations. The work on the data rates, modulation scheme, operating frequencies and other specifications, has now been finalised. Transceiver design, aerial design and communication protocol have been tested. Several trials were conducted and performance of the prototype is being evaluated. The components of the serial interface circuit are as shown below:
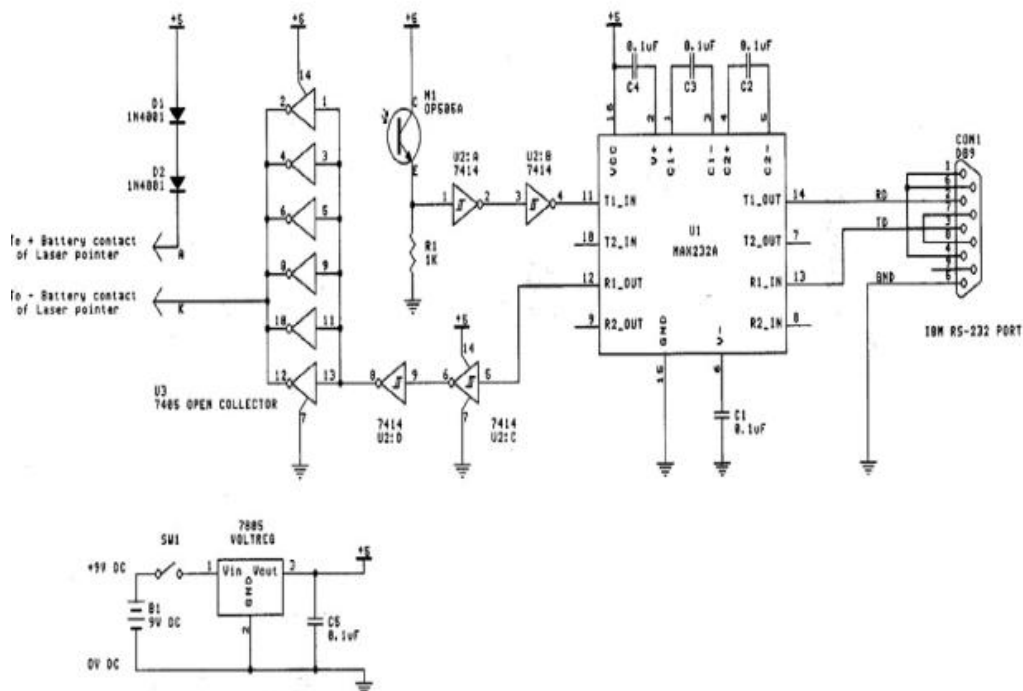

Figure 5. Serial interface circuit for the experimental laser wireless system

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CONCLUSIONS

The potential for the two communication approaches in factories of the future are considered immense. The two systems developed as part of the project also have substantial application in existing factories. The cost of the developing the two systems was no more than 30 dollars excluding the MCU. Applying remote techniques for programming and reprogramming of machines and devices with MCU decreases the dependencies of each device on others and make the task of developing and debugging much cheaper and more direct and hence more reliable. The use of RZ protocol (21) would make the system 100% reliable and safe as the RZ's poka yoke protocol requires 100% compatibility between data transmitted and data used. The protocol, when applied in a manufacturing environment, requires a test program to be installed in the microcontroller of each machine tool, robot and material handler, etc. Then by transmitting the same program through the wireless network 100% compliance is checked before the actual data for the manufacture or movement of a component is transmitted. The data transfer is carried out during actual manufacturing periods on the shop-floor. The data is once again transmitted to check 100% compliance with the earlier transmitted data before the component is machined and/or moved. The data is transferred in a tabulated format containing X, Y and Z co-ordinate values. To this end, irrespective of the nature and level of noise in the surrounding environment, no corrupted data is allowed to be retained or used in any of the processes.

The experience gained here is intended to be incorporated in future work as outlined in an invited paper [21]. The concept of 802.11 and Bluetooth has played a major role particularly after the final prototyping phase. However, more specific experiments are needed to ascertain their specific application areas. The latter two approaches were found to be adequate for most applications but not where there are large and wide-ranging noise signals.

The prototype systems were unable, under experimental conditions, to cope with multi-faceted noise signals in factories (Laboratory conditions only) where large robots are used for welding and where high voltage and current machine tools are switching on and off on continuously. Autocorrelation – TTL 16 bit multiplexer, 74150 using 10 MHz (4:1 count down) 14 pin Dip Clock to drive the 74HC163 programmable counter were used. The problem, as reported earlier in the paper, was alleviated by adopting the RZ protocol developed earlier as part of the research work at Dogus. Further work is needed to ensure that the WIN system developed have to pass a range of test before it can be concluded that it can be applied in severely harsh manufacturing shop floors. As with most other high technology manufacturers, the present facility at Dogus comprises a mix of highly automated machine tools and robots for generic testing, but the machines are semi industrial units and hence do not emit wide-ranging noise signals as is the case, for example, in an auto manufacturing shop-floors.

Generic design techniques were made available in this paper since the scope of the work is of potential interest to almost all major manufacturing companies. Ideas developed and tested in this project have led to further projects which would further develop and refine the prototype systems. The work concluded so far has provided the collaborating organisations with technologies which they intend to use with a view to extend the range of products currently available (21).

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