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Mohammad Al Yami, Roger I Grosvenor, Paul Prickett

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2 **A microcontroller-based approach to monitoring pneumatic actuators.**
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4

5 M. Alyami, R. I. Grosvenor and P. W. Prickett
6

7 *Cardiff School of Engineering, Cardiff University*
8

9 *Queen's Buildings, Newport Road,*
10

11 *Cardiff CF24 3AA, Great Britain*
12
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14
15 **Abstract:**
16

17
18 This paper presents the development of a microcontroller-based process monitoring system that is
19 capable of being embedded within high speed automated assembly systems. A generic architecture
20 is presented to fully utilise the communication, data acquisition and signal processing attributes of a
21 current generation microcontroller. The efficacy of this approach is illustrated by the development
22 of an autonomous method in which the system acquires and analyses transient data related to the
23 operation of a linear actuator. The performance of this system clearly identifies the potential of
24 microcontroller based solutions as very powerful yet affordable real-time quality management tools.
25 The low costs associated with the implementation offer the prospect of affordable integrated quality
26 management to a wide range of industries.
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38 **Keywords:**
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40 Pneumatic actuator monitoring, pressure transient signal analysis, embedded microcontroller
41 architecture, Digital Signal Controller (dsPIC).
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1. Introduction

Recent advances in embedded microcontroller technology make it possible to consider that low cost solutions may be developed to monitor the operation of devices based upon the deployment of pneumatic actuators. This research has generated solutions that can support much needed quality management functions for applications, such as part transfer systems, where a number of pneumatic devices are operating continuously in confined spaces and hazardous conditions. This paper describes the current findings of this research activity and describes the approach taken to engineer such a system.

Pneumatic linear actuators or cylinders are used in many manufacturing operations, including the automotive, manufacturing and food packaging industries. The main purpose of deploying such systems is to perform position control and enable parts handling, especially in robotic manipulators, end effectors and grippers. Such devices and systems often exhibit highly nonlinear characteristics mainly due to the compressibility of air and the variability of motion associated with the “stiction” which arises in cylinders. This makes achieving accurate dynamic position and stroke control difficult. These devices therefore tend to be limited to pre-set end position tasks. In these circumstances problems may arise due to part misalignment, incorrect workpiece selection, variability in air supply pressure and the obstruction of motion due to foreign objects.

The parameters that may be of interest when approaching the monitoring of such systems include the number and type of sensors needed, the nature of the computational resources required and the operating variables to be considered. Some work has been conducted into aspects of monitoring and controlling these devices, including research considering how the compressibility of air introduces a dead time (or delay) in the system’s response that makes accurate control more challenging [Van Varseveld and Bone 1997 and Wang et.al 2004]. Air losses in cylinders and

1
2 transmission lines have been shown to add more barriers to successful control [Messina et.al 2005].
3
4 These factors can make it difficult to achieve accurate position control without the use of added
5
6 sensors. These sensors, and the controller needed to manage their operation, can be expensive.
7

8 The monitoring system outlined in this paper was developed based upon the data acquisition
9
10 and processing capabilities of the current generation of microcontrollers. It was intended that the
11
12 resulting system would be low cost, flexible and provide monitoring information for a range of
13
14 applications and configurations. Advancements in microcontroller technology mean that current
15
16 generation of devices can provide impressive levels of computational resources, as defined by
17
18 processing power and computational speed, on a single device. The cost of such devices and their
19
20 supporting circuitry typically vary between £50 and £300, depending upon the application being
21
22 considered. This means that the development of a low cost distributed process monitoring system
23
24 that offers real time diagnostic functionality can be considered. Previous experience indicates that
25
26 investment in such a monitoring system will only be successful if it is reliable and can provide an
27
28 acceptable cost-to-benefit ratio. In the case of the research described in this paper the attributes of
29
30 the developed system, which include a plug-and-play capability, mean that it can provide a possible
31
32 solution for a wide variety of monitoring applications.

33 Previous attempts have been reported based upon taking advantage of advances in low cost
34
35 computing resources to exploit the recent innovations in field bus systems, microprocessors and
36
37 computing technologies [Pu et al. 2000]. In this work the concept of intelligent component-based
38
39 servo pneumatic actuation systems was advanced by designing templates for smart sensors, smart
40
41 valves and smart actuators. It was proposed that limited intelligence can be embedded in such
42
43 devices in order to provide information rather than raw data. These devices can then be integrated to
44
45 form a smart pneumatic servo system capable of communication with the external world.

46 An analytical fault detection and diagnosis strategy for pneumatic systems was introduced
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48 [Li and Kao 2005] with the intention of preventing the failure of devices that can cause plant or
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1
2 process shutdowns resulting in the loss of production time and profits. The developed approach
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4 was signal-based, using parameters such as pressure and flow and employed an analysis
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6 methodology based upon wavelet decomposition. A pattern recognition technique was developed to
7
8 diagnose unknown leakages and experiments were successfully carried out to test and verify the
9
10 effectiveness of the proposed approach.

11
12 Another example of a fault detection and diagnostic system was developed for applications
13
14 such as the mechanical systems operating pneumatic train doors commonly found in rapid transit
15
16 systems [Lehrasab et al. 2002]. These doors are often controlled by solenoid valves and faulty
17
18 operation can be a significant source of delay in railway services. The research demonstrated how
19
20 the health of the system can be determined using feature extraction methodologies. This included
21
22 throw and activation time characteristics, spectral features of the door displacement profile as well
23
24 as abstract features such as velocity profiles and pressure drop during the throw. Once a fault was
25
26 indicated neural network models were utilised for diagnosis. The authors suggested the
27
28 implementation of this approach in a distributed architecture and proposed that diagnostic results be
29
30 integrated into the maintenance information system in order for a proactive maintenance regime to
31
32 be produced.

33
34 Neural network enabled fault detection and identification was the basis of a system
35
36 developed to manage actuator faults in a process control valve [Karpenko et al. 2003]. A software
37
38 package supplied by the valve manufacturer was used to communicate with onboard sensors and
39
40 obtain its' position response under various operating conditions. Fault signatures associated with
41
42 incorrect supply pressure, actuator vent blockage and diaphragm leakage were considered.
43
44 Experimental data was collected and neural networks trained, and tested. The authors claimed to be
45
46 successful in the detection and identification of various magnitudes of the faults of interest.

47
48 The research outlined above supports the potential for developing low cost monitoring
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50 approaches that can be applied to pneumatically operated parts handling operations. However, most
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1
2 of the reported research solutions are not suited to such applications, either due to cost
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4 considerations or due to the time needed for diagnosis. This paper describes the development of a
5
6 distributed process monitoring system which may be deployed to oversee operations based upon
7
8 pneumatic actuators and illustrates its efficacy with an example application.
9

10 11 **2. Monitoring System Architecture**

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14
15 The term “distributed system” is used here in to describe a system in which interconnected
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17 hardware or software components communicate and coordinate their actions. The main benefits of
18
19 such systems include their robustness and reliability; since processing power is distributed the
20
21 failure of a single element does not disable the entire system. Data can be maintained at different
22
23 locations to further improve system reliability. Other attributes include functionality and scalability.
24
25 Since the system may incorporate various types of devices each element may be selected to
26
27 optimise the function it is expected to perform. Additional task specific elements may be added as
28
29 required. These attributes mean that the devices deployed in a distributed system can operate
30
31 concurrently to undertake monitoring actions independently. Such actions must however be
32
33 coordinated within suitably structured system architecture.
34

35 The Intelligent Process Monitoring and Management (IPMM) research group at Cardiff
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37 School of Engineering has previously exploited the capabilities of the 8-bit microcontrollers in a
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39 range of monitoring applications; including the monitoring of machine tools [Amer et.al. 2006] and
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41 process plant [Ahsan et.al. 2006]. The advantages of such devices may be considered in terms of
42
43 their low cost and ease of use. The limitations of such devices, most specifically measured in terms
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45 of their processing capabilities, may have previously restricted their application. However the
46
47 current generation of microcontroller devices, such as those used in this research, has overcome
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49 such limitations. In particular the availability of the new more powerful microcontrollers and
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1
2 similar devices seems to offer an almost limitless potential in the engineering of product quality and
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4 process management and monitoring systems [Siddiqui et.al. 2007].
5

6 To support effective monitoring real-time information about the enactment of the process
7
8 and the condition of selected machine components is needed. A fundamental aspect of the
9
10 deployment of a monitoring system is data acquisition, which is normally enabled through the
11
12 installation of various sensors and transducers. An industrial application may require a large number
13
14 of such sensors. If this data is collected at a central location, communication infrastructure will have
15
16 to be provided from every sensing element. This approach can lead to a complex communication
17
18 network and result in a system that is hard to install and difficult to maintain.

19 Advances in wireless technologies have supported developments in this area, but the cost
20
21 and data transmission limitations associated with such systems remains an important issue to
22
23 consider. The handling of the data acquired from sensors in such applications tends to be very
24
25 challenging. Data files can become very large and the communications infrastructure has to cope
26
27 with the often continuous nature of much of the data. For example, the monitoring of a six station
28
29 press line with a four stage part transfer system per station operating on a three second cycle, could
30
31 result in some two million separate actuator motions per week. The effectiveness of the monitoring
32
33 system may thus be compromised by the quantity of data to be acquired, processed and
34
35 communicated. A modular, microcontroller-based, data acquisition and analysis system was
36
37 therefore developed to provide a more applicable solution. The key aim in this system is the
38
39 intelligent acquisition and analysis of data and the determination of any associated fault diagnosis at
40
41 source, thus massively reducing data communication and storage requirements.

42 Another important objective of this research was to develop and deploy data processing
43
44 techniques capable of monitoring the operation of a particular machine function or activity, whilst
45
46 keeping the number of added electronic components and sensors to a minimum. The hardware
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48 architecture developed in previous IPMM research is shown in Figure 1. It was decided to deploy
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1
2 the 16-bit dsPIC microcontrollers in the further development of this system. Their built-in digital
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4 signal processor and computational speed make them superior to the previous generations of
5
6 microcontrollers, thereby promising considerable additional benefits to fault diagnosis.
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8

9
10 Figure 1. IPMM Microcontroller based monitoring system architecture.
11

12 13 **2.1 The Front End Node (FEN)**

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15 The key feature required in this approach was processing speed. The device selected for
16
17 both the front-end node of the distributed process monitoring system had five (16-bit) timers; two of
18
19 which can be paired to form a 32-bit timer if and when required. An input capture module, well-
20
21 suited for applications where the period or frequency measurement is required, is also available on
22
23 this chip. The microcontroller offers several I/O ports supporting multiple serial and parallel
24
25 communication protocols. In this research communication between the nodes was supported by the
26
27 adoption of a Controller Area Network (CAN) infrastructure which is employed in many areas of
28
29 industrial automation.

30
31 The CPU of this device has a 16-bit (data) modified Harvard architecture. It provides 144Kbytes
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33 of program memory, 4Kbytes of data EEPROM memory. It's possible to execute all instructions in
34
35 a single cycle. The architecture supports program loop constructs through the use of DO and
36
37 REPEAT instructions, yielding no program overhead. The CPU supports various flexible
38
39 addressing modes to meet compiler needs; for most instructions the devices have the capability to
40
41 perform a data (or a program) memory read, a data memory write and a working register (data) read
42
43 in a single instruction cycle. The essential feature of the acquisition process supporting this
44
45 development is that analogue signals have to be converted into a more convenient format so that
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47 they can be analysed in a meaningful and efficient manner as near to their source as is practical.
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49 This is achieved by means of the on board 12-bit (16 channel) analogue-to-digital converter.
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2 In the developed approach any desired parameter can be connected to a suitably configured
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4 FEN. When processed the acquired digital data can be very quickly analysed using the same
5
6 microcontroller to identify “pre-defined” known fault symptoms. If required the processed
7
8 information can then be sent through the CAN bus to collaborating FENs. Signal acquisition and
9
10 processing are thus performed in this layer of the monitoring system. It is important to state that
11
12 data generated from each monitoring action will be analysed for possible faults and, if none are
13
14 identified, the data is summarized and sent to a buffer. This retains data that can be interrogated
15
16 should a fault condition occur, but, as more data is generated the previously analysed data which
17
18 relates to normally enacted operations can be discarded.

19 **2.2 Data Acquisition**

20
21 The first step in the operation of the FENs is to acquire the required signals from different
22
23 sensors and transducers. Various sensors are usually installed in the process or machine to perform
24
25 such a task. In most cases the output measurement of a sensor requires signal conditioning to
26
27 conform to the requirements of the data acquisition hardware. In the context of this research for
28
29 example a typical pressure transducer output would be a 4-20 mA current signal. This signal had to
30
31 be converted to voltage in the range 0 to 5 VDC as required by the dsPIC. The resulting signal then
32
33 needs to be converted into digital format for processing using the ADC module embedded in the
34
35 dsPIC. This employs the concept of successive approximation, which is the fastest and most
36
37 commonly used technique in analogue to digital conversion.

38
39 When using ADC some parameters have to be considered in order for a process monitoring
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41 and control system to be most effective and robust. Those of major importance include resolution;
42
43 the available ADC converter has a 12-bit resolution, which provides 4096 levels of representation
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45 of the analogue signal. Another consideration is the sampling rate, which should be at least twice
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47 the maximum frequency content of the signal to avoid aliasing [Smith, 1999]. For practical reasons,
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49 analogue signals are actually sampled at an even higher rate to account for the differences in
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1
2 performance between real-world ADC and the ideal one [Huddleston, 2007]. In this application the
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4 pressure signal was sampled at 2 KHz, which is five times the highest frequency content as
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6 empirically determined. Similar levels of capability were possible in the linearity, repeatability and
7
8 range of the input signals.

9
10 The second types of signals that are of interest to monitoring systems are digital signals.
11
12 These can be acquired to provide information about discrete events in the process or machine such
13
14 as the on/off state of a valve or a limit switch. Once these were interfaced with the microcontroller's
15
16 timer modules it was possible to measure the time between discrete events.

17 **2.3 The Connectivity node**

18
19 The Connectivity node, which forms the second level in the distributed monitoring system
20
21 architecture shown in Figure 1, has two functions. Firstly it is required to co-ordinate FEN activity
22
23 in cases where the fault detection process proves to be challenging. Such co-ordination is critical
24
25 under circumstances which require that information from various FENs be shared in order to reach
26
27 a conclusive decision about the health of monitored parameters. For instance, if a node in a
28
29 pneumatic system determines that the air pressure is too low, a message may be sent to notify other
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31 nodes in the system that may mistake the consequences of low pressure on the element they are
32
33 monitoring as a fault. This can minimise the number of false alarms generated. In the deployed
34
35 system possible faults and/or the associated data from various front-end-nodes can be combined and
36
37 analysed. It's believed that eventually all remaining "known" fault conditions can be detected at this
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39 level.

40
41 The second function is to provide the communication link with the outside world. The
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43 adopted Ethernet based solution was implemented in a modular fashion following the TCP/IP
44
45 protocol. It was thus designed to be independent of operating systems and to be capable of
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47 cooperative multitasking. This level is therefore used to provide a link between the FENs and a
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49 more powerful computer residing in level three of the system. Confirmed faults and associated
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1
2 operational information can be communicated to interested users and management functions
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4 embedded at level three for action and storage. In this way further analysis tools and expert-user
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6 knowledge can be deployed to identify the occurrence of “new” faults as they arise. Any new faults
7
8 thus detected and diagnosed together with steps aimed at subsequent fault recognition may then be
9
10 added to the list of known faults, and the developed detection process added to the capabilities of
11
12 the FENs.

13
14 In practice the second level of the architecture shown in Figure 1 acts as a service
15
16 level by providing and managing these communication tasks. Since the high performance
17
18 microcontroller selected as the FEN module had the capacity to undertake these tasks it was
19
20 determined that level two activities could be incorporated into the FENs. As such the FEN that first
21
22 detects a possible fault condition assumes the role of the Connectivity node, and oversees all level
23
24 two functions. All FENs can act in this way, providing a robustness and flexibility that takes full
25
26 advantages of the capabilities of the deployed microcontroller devices. The resulting low-cost
27
28 monitoring system has excellent capabilities in terms of signal acquisition and processing, a high
29
30 level of integration, processing power, and communication facilities. Section three of this paper
31
32 presents an example application of this system.

33 **2.4 Level Three functions**

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35 Higher level management functions are undertaken at level three of the system. These
36
37 functions may be undertaken locally or remotely. They will include the diagnosis of faults that
38
39 require more advanced tools, and the continuing development of monitoring capabilities based upon
40
41 the accrued data and information gathered from the deployed microcontrollers. It is important to
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43 note that any remote user, with the correct level of authority, may access any of these nodes
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45 directly. This supports the ability to monitor device operation in real time and provides access to all
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47 buffered data to support fault diagnosis. This facilitates the continuous improvement of the
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49 diagnostic ability of each node and of the overall system.
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3. Experimental test set-up

The test rig designed and constructed to research the development of this monitoring method is shown in Figure 2. The Air Preparation unit (A) conditions the air by trapping moisture, removing impurities and adding lubrication. It also contained a regulator to maintain the supply pressure at a constant level. The Solenoid Valve (B) was chosen due to its high flow capacity, response speed, low power consumption and long life expectancy. The Pressure Transducer (C) measures the line pressure of the air supplied from the Air Receiver (D). The pressurised air is supplied to the Actuator (E), through the Solenoid Valve. The monitoring functions are integrated into the development board (F).

Figure 2. Linear Actuator Test Rig.

In the application under consideration in this research the conditioned pressure transducer signal was connected to the ADC converter and sampled at a rate of 256 samples-per-second. The ADC was configured for one sample per interrupt, and its clock was derived from the system's oscillator. Data was transmitted as soon as a value becomes available. One of the microcontroller's digital outputs was used for the switch controlling the solenoid valve. An electronic switch was designed to control the operation of the valve. A 15V DC supply is used to power the solenoid valve. A simple control algorithm was implemented to perform this testing. LEDs on the expansion board were used to represent the status of the valve and to indicate faults to the operator whenever they occur. The output sample from the ADC was scaled for an on-board LCD screen. Using the built in UART2 communications module data was transmitted to a PC allowing Microsoft Excel to be used for initial data analysis to develop the monitoring system. The same link was subsequently used to evaluate the effectiveness of the monitoring system in determining the health of the process.

1
2 In order to achieve the required speed of response it was determined to base the approach on
3
4 transient events.

5
6 The linear actuator used was a high speed precision device with a stroke of up to 100mm
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8 able to apply loads of up to 200 N. Precise adjustment of the mechanical end-position of the slide
9
10 motion was possible. To facilitate the initial calibration tests this actuator was initially fitted with
11
12 two plug-on proximity sensing units to indicate the defined actuator end-position. The sensors used
13
14 on this rig operate with a supply voltage ranging from 8 to 30 VDC, with a maximum load current
15
16 equal to 200 mA.

17
18 The operating pressures used for the testing ranged from 3 to 7 bar. The intention of this
19
20 research was to produce a monitoring system that operates at any pressure within this range. This
21
22 accommodates any possible set-up of the system and allows for localized changes in supply
23
24 pressure in any potential implementation. The experimental procedure adopted in this work initially
25
26 set the air supply pressure to a series of specific values. A set of test pieces of known dimensions
27
28 were used to restrict movement to a known end position. The calibrated test piece was placed to
29
30 limit the stroke and the end position was measured. At a given supply pressure, the time taken by
31
32 the slide unit to reach an object was then measured. A relationship between the travel time and end
33
34 of stroke was then realized. In this way, a time based monitoring system was developed. If the
35
36 travel time at a specific supply pressure and intended end position does not match to a defined
37
38 tolerance the pre-set value, assuming the same operating conditions, a faulty situation is indicated to
39
40 the operator.

41 ***3.1 Signal Acquisition and Analysis.***

42
43 To develop a robust and flexible monitoring solution, the system was evolved through three
44
45 stages. Initially two limit-switches were used to monitor the home and end positions of the actuator.
46
47 This provided details of stroke times and allowed the initialization of appropriate data acquisition
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49 and analysis tools. The next step removed one sensor and the pressure response at the inlet of the
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1
2 actuator was acquired and analysed. The patterns associated with the operation of the actuator were
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4 then used to provide potential performance indicators. Finally, the pressure transient signal alone
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6 was monitored.

7
8 The data leading to the development of the technique capable of identifying the slide end
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10 position or the object size was initially acquired using the microcontroller. The output signal from
11
12 the pressure transducer was converted into the correct format and the pressure samples were
13
14 recorded and stored in an array. Data was then transmitted to a PC for analysis. This approach
15
16 monitored only the pressure transient at the inlet to the actuator's cylinder. In this way, the cost of
17
18 the monitoring system is reduced. In addition to monitoring actual actuator travel it was anticipated
19
20 that the pressure signal measurements would also identify any faults arising during an operation.

21
22 Figure 3 illustrates the pressurization/actuation cycle for a test conducted at 5 bars with a
23
24 20mm test piece in position. It is typical of such tests and shows the effect of the response time of
25
26 the solenoid valve, which causes a delay in actuation from the trigger point (Time "0" on the
27
28 figure). Once the valve is triggered, it can be seen that air pressure takes some time to build up to
29
30 provide sufficient force to overcome friction and push the slide piston from its home position. The
31
32 transient overshoots before starting to settle during the slide motion; once it reaches the test piece
33
34 resistance to motion is encountered leading to a decreasing oscillation in the pressure signal, which
35
36 dies out with time. As soon as the valve receives the signal to close, air exits the cylinder to the
37
38 atmosphere depending on the valve's response time and the pressure falls rapidly to zero.

39
40 Figure 3. Travel time computation at 5 bar using a 20mm test piece.

41
42
43 In order to simplify the monitoring task it was desirable that the sample peak of the pressure
44
45 signal should be used to reference the effective start of the motion. It was observed from the
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47 calibration tests using the limit sensors that the sample peak always occurred a fixed time after the
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49 actual start of the motion. The actual elapsed time was found to vary in a linear fashion with test
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1
2 pressure. This behaviour effectively “fixed” the start point of the motion sensing procedure to the
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4 occurrence of the peak pressure signal.

5
6 The second point needed to establish travel time must clearly correspond to the instant at which
7
8 motion ceases, defined in this work as the end position. For clarity in Figure 3 the high frequency
9
10 component of the pressure signal has been smoothed using a moving average filter. A filtering
11
12 process was also deployed on the raw signal to extract the dominant component information.
13
14 Careful investigation of responses for different end of stroke positions at each pressure identified
15
16 that the squared rate of change could be used to identify the motion end point. Figure 3 again
17
18 illustrates the procedure developed. The squared rate of change plot exhibits a clear peak
19
20 corresponding to contact with the test piece. By establishing a threshold the designated “contact
21
22 point” can easily be determined. Once again, through the initial calibration of this motion using end
23
24 position sensors, good correlation was found between the established threshold point and the actual
25
26 motion end point. The threshold value is shown in Figure 3 at 400 for a test at 5 bar This threshold
27
28 was used except for pressures above 4 bar; the threshold below four bar was 250 to 300.

29
30 The microcontroller device deployed in this research was selected to provide the processing
31
32 power and mathematical capability needed to identify both the start point and end point from the
33
34 two samples and complete the analysis of travel times fast enough to facilitate effective process
35
36 monitoring. This is a relatively simple procedure; the travel time is computed as the difference
37
38 between contact time and home position time. In all tests the sampling rate used was 2 kHz. This
39
40 procedure was applied for each supply pressure acting upon multiple objects.

41
42 Curve-fitting procedures were developed to obtain a surface capable of acting as a process
43
44 model using a non-linear least squares technique to fit the actual data. Figure 4 shows the surface
45
46 representing the resulting travel time measurements. The concept being developed in this research
47
48 is to model this surface to allow predicted travel times to be generated for any combination of
49
50 pressure and end position.
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1
2 Figure 4. The generated surface relating travel time, end position & pressure.

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4
5 The surface model function used was of the form;

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7
8
$$z = \frac{A + x}{B + Cy} + Dy$$

9

10 Where, x is the end position in millimetres, y the applied pressure in bar, and z the travel time in
11 milliseconds. The modelling procedure was found to converge after eight iterations at which point
12 the parameters were estimated. The model was then exported to a more powerful mathematical
13 modelling process to tune the parameters so that the best possible fit is achieved with a single set of
14 parameters per surface. In the set up presented here the fitting parameters obtained were:

15
16
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18
19
20 $A = -102.3, B = -0.53, C = -0.43$ and $D = 0.9$.

21
22 The actual surface and the model were found to correlate well. Their computed correlation
23 coefficient is 0.998, which signifies the goodness of the model performance. The model performs
24 well in the estimation of travel time as compared to the time obtained from information extracted
25 from the pressure transient.
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30 31 32 **4. Monitoring System Development**

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34 The system outlined above was applied to the monitoring of actuator operations running at
35 rates of four cycles per second. The maximum motion tested was $\pm 100\text{mm}$, and it was found that
36 the actuator end position could be determined with a precision of 1mm. Hundreds of cycle tests
37 were undertaken for each of eight different end positions at a number of known pressures. In each
38 case the end position was correctly assessed by the system before the actuator returned to the “start”
39 position. It was thus established that the system had met an important requirement; that diagnosis of
40 an error should be possible before the commencement of the next cycle. These tests established that
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2 the system was able to operate flexibly with different end positions, which reflects the needs of
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4 “pick and place” production systems.

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6 In order to deploy the system within a production environment it is proposed that an
7
8 operator will initially supervise a number of test cycles to calibrate the system to introduce a new
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10 product or set up and if required supervise the adjustment to the estimation parameters to suit the
11
12 application in hand. To test this facility, actuator operations were undertaken at a series of
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14 “intermediate” pressures, i.e. 4.75 and 5.75 bar, for which no previous tests had been performed.
15
16 Since the performance surface for the actuator was embedded within the microcontroller it was
17
18 possible for the system to match the anticipated performance with that measured to indicate
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20 satisfactory operations. This procedure was undertaken at level one of the deployed monitoring
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22 system. At this level the operator communicates directly with the dsPIC via simple controls.
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24 Operator involvement was necessary in these initial tests to effectively establish the calibration of
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26 the new set-up by confirming that a correct operation had occurred. It was found that between ten
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28 and fifteen such cycles were sufficient to position the new set-up on the existing surface, following
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30 which unsupervised operation could continue. It should be noted that, once such an activity has
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32 been enacted, the results are added to the existing surface information and the activity does not have
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34 to be repeated. This is vital in a production environment, where several process variations may be
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36 normally present. Using this system each variation will be captured upon its first implementation
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38 and saved for future access. Similar actions were applied to the introduction of “new” end positions.

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40 In many industrial settings the same operator can be required to oversee several elements of
41
42 the process. Using this system it is possible that operator attention can be immediately drawn to any
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44 faults arising in the processes in real time so that prompt action can be taken, thus reducing
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46 operational cost and optimising performance. When needed to, for example following the
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48 installation of a new or replacement actuator, the operator can also interact with the system to re-
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50 define surface parameters and to manage the integration of the entire monitoring function based
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2 upon the collective expertise of each element retained within the system memory. This local control
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4 is represented by level two in the architecture, through which access may be gained to previously
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6 created performance surfaces stored within the management level PC. This ensures that the
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8 monitoring of any re-configured pneumatic systems can benefit from previously acquired
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10 performance surface information relating to the actuator hardware deployed. This facility is also
11
12 important if more advanced fault detection and process management tools are to be deployed. The
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14 architecture facilitates the adoption of a “plug and play” facility, allowing the system to expand as
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16 required and supporting a flexible approach to process monitoring. This allows the surface models
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18 embedded within the devices to be continuously improved to accommodate different process set-
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20 ups, allow for different actuators etc. Fault diagnosis at this level can also help the development of
21
22 improved process design, operation and management.

23
24 The research reported in this paper supports the deployment of a pressure based fault
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26 diagnosis system as a potential solution to monitoring the performance of any parts handling
27
28 systems that are based upon linear pneumatic actuators. Initial tests have shown that the approach is
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30 both flexible and robust and can support reliable fault diagnosis. Most importantly the processing
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32 speed and power of the deployed microcontrollers means that this diagnosis can be accurately made
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34 in real time. In the tests outlined above diagnosis was achieved for cycle times of 0.25 seconds. In
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36 practice the microcontroller at the heart of this system operates at the micro-second level and can
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38 respond much faster than this if needs be. This suggests that the approach can accommodate the
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40 needs of many such implementations, potentially including high speed production processes. It also
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42 indicates that a single node may actually be used to monitor a number of linked actuator actions,
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44 with the individual performance surfaces being accessed as appropriate. Further investigations into
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46 the implications of these findings are ongoing but the expectation is that a single module will be
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48 capable of monitoring the operation of a complete transfer system containing multiple actuators.
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18
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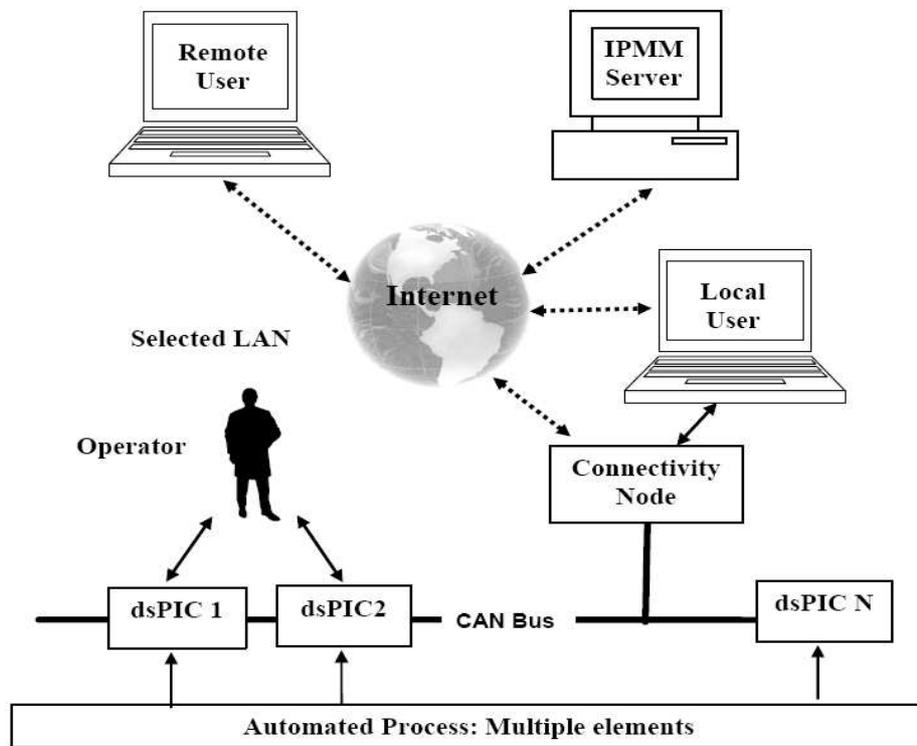


Figure 1. IPMM Microcontroller based monitoring system architecture.

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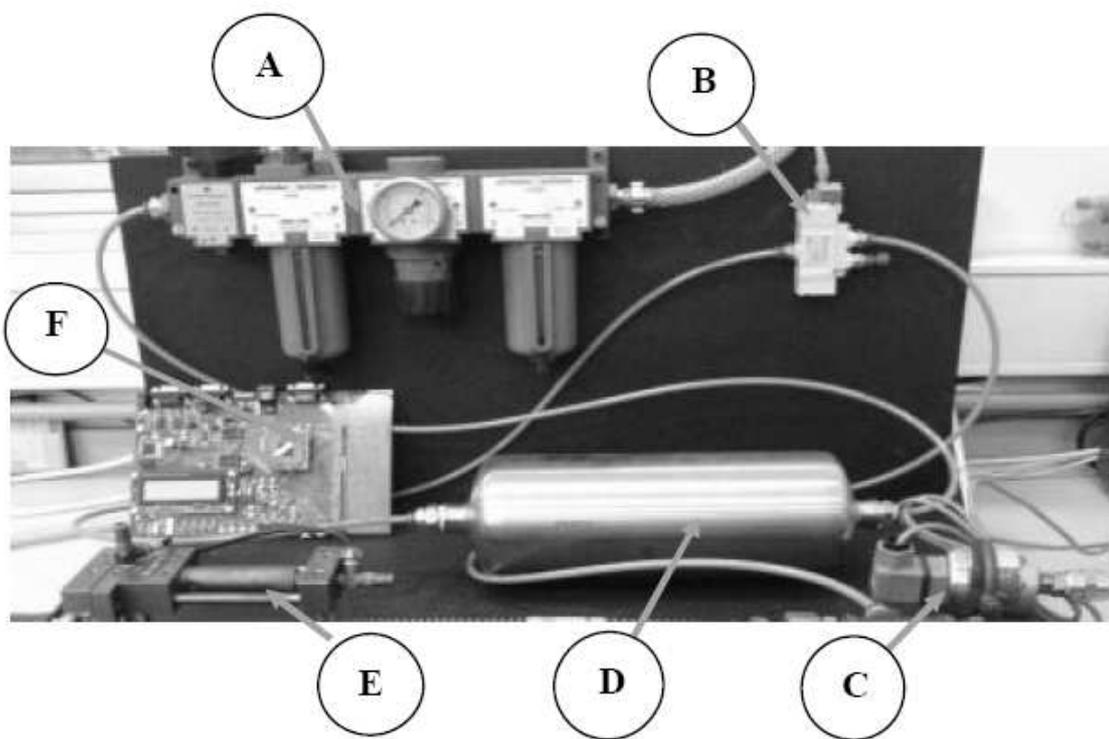


Figure 2. Linear Actuator Test Rig.

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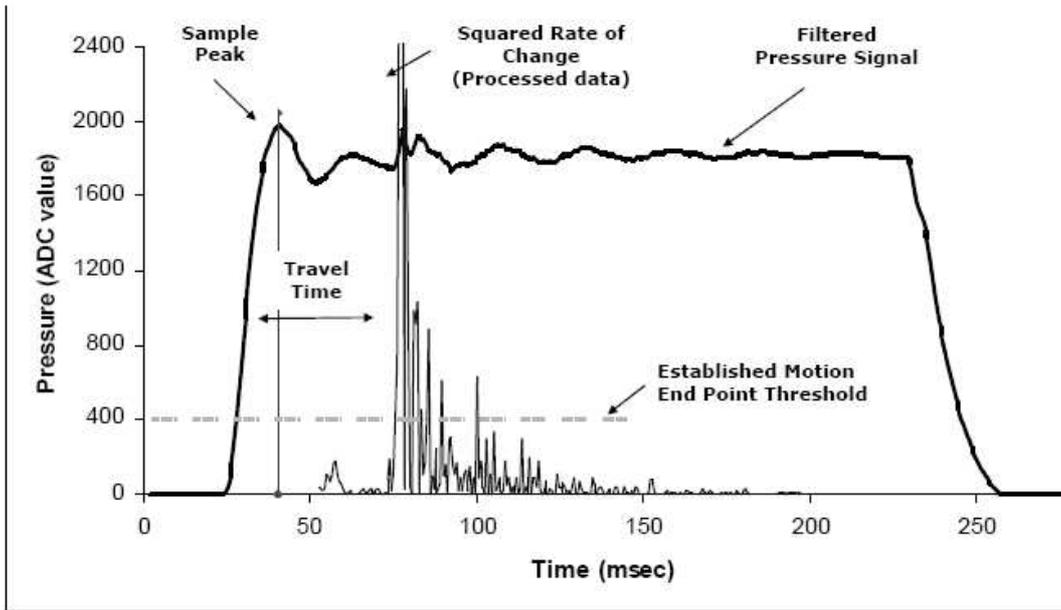


Figure 3. Travel time computation at 5 bar using a 20mm test piece.

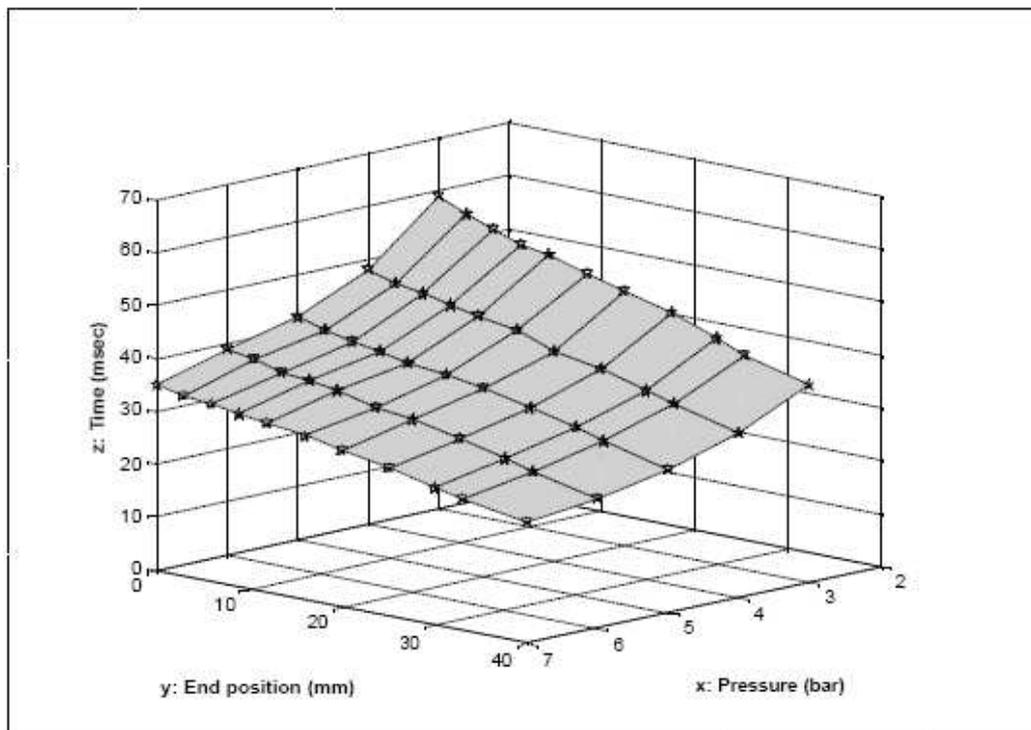


Figure 4. The generated surface relating travel time, end position & pressure.