Serving the data needs of multiple applications with one data source—*an industry application case study*

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Abstract: Automation of a technical process involves the feedback of sensor data for the automated control of particular aspects of the process itself. The same feedback data can be used for other applications such as health monitoring of systems or to update a graphical user interface or to analysis process performance. In order for this data to be utilized effectively, a system architecture must be designed to provide such functionality. This architecture must accommodate the dependencies of the system and sustain the required data transmission speed to ensure stability and data integrity. Such an architecture is presented in this paper, which shows how the data needs of multiple applications are satisfied from a single source of data. Also it will show that the flexibility of this architecture enables the integration of additional data sources that can be used to protect the performance of applications that consume the data as the order of data dependencies grows.

Keywords: data reuse, process control automation, data acquisition, test automation, aircraft fuel control systems

1. INTRODUCTION

Automation of technical processes is becoming more prevalent across most industries. Whether the goal is to maximize process throughput, reduce waste or modernize tools used for business operations, automation opens up opportunities that improve a business's bottom line [1].

One such opportunity is the reusability of process data for technical or non-technical applications, e.g. to determine the overall health of systems through analysis of process data that contain information about the operating condition of different components. This could be the basis for a preventive maintenance strategy involving fixing faults with minimal cost implications before they become failures that could cost substantial amounts of money [2].

When a technical process has to be automated it is essential to feedback well-conditioned data from the process's sensors [3][4][5]. This requires either new or existing data acquisition (DAQ) system(s) to be employed in the collection of this data. The specification of the DAQ system must meet the needs of the process and the automation systems. Although this is extremely important, it is crucial that the data from existing systems is suitable to be reused for automation. In such cases modifications can be made to the data to ensure it is in an appropriate format or the automation systems can be designed to accommodate mismatches with the existing systems e.g. different update rates.

In industries like the Maintenance Repair and Overall (MRO) sector of civil aviation most traditional DAQ (or t-DAQ as it will be called) systems are used in the delivery of data for business processes [6]. Within this context the main purpose of such systems is to acquire data from specific sensors, process such data using hardware instruments and make it available for retrieval by Remote Terminal Units (RTUs) through an appropriate digital communication link protocol, while simultaneously displaying the data on a monitor [7].

In order to reuse data for other applications besides automated process control, a t-DAQ and sensor systems should be evaluated on their capability to meet the requirements of two types of data consumer applications: time critical and non-time critical. Then the mechanism of managing the process of extraction and reuse of data should be implemented within a software centric environment.

Our definition of a time critical application is one that needs to know about its dependent process at least > 50 times/second. A non-time critical application is an application that requires information about its dependent process < 20 times/second.

In this paper, we present a software centric architecture that enables the reuse of data from one data source; and is scalable for the integration of additional data sources. The concept is based on having a live table whose content is the process data collected through the DAQ system and merged with additional features like an instrument name tag, data type tag & a description—to make it identifiable, extractable and reusable.

The context of our discussion is based on the automation of the test of fuel control systems used on civil transport aircraft engines [8]. Process control automation is the core application that reuses the process data from a t-DAQ system that will be introduced later.

In Section 2 the requirements of applications that will reuse process data from our t-DAQ system is reviewed. Next is an outline of the automated process control application structure in Section 3, which leads to a review of the limitations of a raw numeric data-only reuse architecture based on the t-DAQ—with results. In order to reduce these limitations, a "featurized" data reuse architecture is proposed in Section 4. And its implementation is treated in Section 5 with results and analysis of its impact. Finally a conclusion is given in Section 6.

2. REQUIREMENTS & SPECIFICATIONS OF DEPENDENT DATA REUSE APPLICATIONS

The role of each application designed to reuse the test data is to fulfill different tangible business benefits. For example, a Fault Detection & Diagnosis (FDD) application reuses measured process data to detect faulty operation of systems, can learn its *signature pattern* and what failure it could lead to eventually [2]. This function could then be used to automatically manage moderate faults or activate an alarm before a failure occurs. As a result the number of unplanned downtime is reduced because there is a mechanism to establish the "ball park" of likely root cause(s) and thus increase the availability of test systems for the test process.

The Automated Process Control application: It is required to set different processes at specified set conditions accurately, using process data from the t-DAQ. The business benefit of this application is one of improved machine utilization, reduced total test time and associated variable overhead costs, e.g. electricity bills.

The FDD application: A requirement for the function of the FDD application is to have it online for active prevention rather than as a corrective advisory tool. Therefore, if the process data is first stored and retrieved for FDD, this will cause a delay which is unsuitable for our application. Our goal is to have the FDD application "advising" the APC application on strategies to manage faults and prevent failures from occurring [2][9][10].

The VR application: This uses real-time process data in a format that gives a visual representation of the process, known popularly as Virtual Reality (VR). For our application, this is a 'live schematic' of the test process with real time colour variations that depict whether respective test systems and test piece are operating within designed/specified ranges.

A VR application lends itself well to the cognitive faculties of operators. Where traditional display of process states as numbers requires an operator to mentally augment what is happening, a VR tool reduces the burden of generating such mental models and only needs an operator to observe which systems are operating as expected (*normal*: green), about-to-fail (*warning*: amber) or have crossed a maximum threshold (red). For this application the VR is a not time critical.

The D-board application: This implements analytical concepts to extract intelligent business information from available test process data. It would serve managers' needs to know process quality, operating capacity, anticipate unplanned maintenance and systems health in real-time. The D-board application is not time critical.

The Automated Data Entry & Recording application: This function is undertaken by operators who would read screens displaying numeric values of the states of different test process media and type these into a processing application for onward logging into a business database. In our application, the function of data recording requires that test data from the t-DAQ be extracted and transmitted to another application which *parses* the data on to the business database [11].

The ADER application has a time requirement that all recorded data should be extracted simultaneously, when the set process conditions are in *steady state* [11].

Table 1 shows a summary of the requirements of all the applications that would reuse test data from the t-DAQ as part of the automation of the test process. It covers crucial functional aspects such as the minimum frequency at which an application needs its data; the volume of test data each needs to execute its function correctly and the variety/types of data—whether numeric, textual or logical. These are summarized in Table 1. From this table it is clear that the frequencies of data speed required range from less than 1 Hz for the D-board, up to 50 Hz for the APC application which has the least variety of data.

Table 1: Requirements of consumer applications

	Time criticality (max. delay)	Data size	Data variety
ADER	1 sec	20	3
VR	1 sec	20	3
APC	< 0.020 sec	3	2
FDD	0.5 sec	52	6
D-board	300 sec	32	4

Nonetheless, it is obvious that physically connecting wires to the analog input terminals of the t-DAQ system, in order to connect multiple DAQ devices for each application is impractical. The risk of lose connections and electrical loading issues could cause inaccuracy of measurements; excluding other non-functional costs.

A software based design is seen as a practical way to extract the data from the t-DAQ through its digital communication port for reuse by the APC, ADER, FDD, VR and D-board applications. This concept is shown in Fig. 1.

It is obvious that in order to use one DAQ system to supply data to all of these applications, it must be capable to transmit data at the rate required by the application with the highest data frequency requirement—the APC application, at >50 Hz.

Note that the number of process data which has to be retrieved from the t-DAQ system for the APC, FDD, VR & ADER applications is 20; then 32 sets of data for the D-board and FDD are digital signals that are not integrated into the DAQ system.

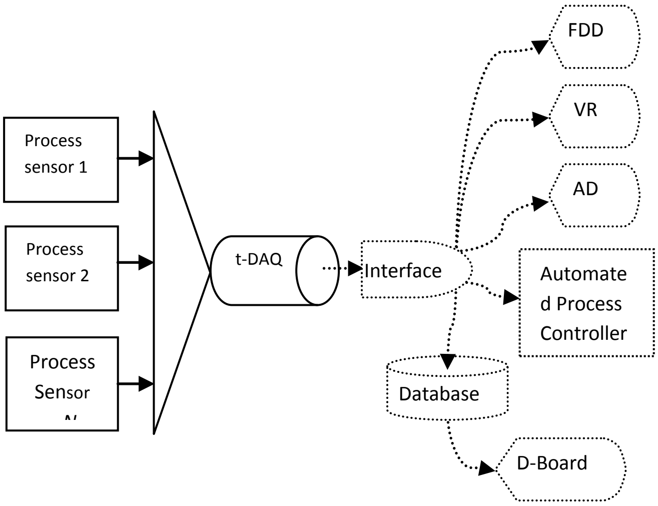

Fig. 1: Architecture of a single data source for multidimensional data reuse

Having understood the challenge that has to be overcome with the t-DAQ system, an attempt has to be made to prove that the t-DAQ could support the automation of the test process and its different aspects fulfilled through each application that reuse the test data.

For completeness, the network of sensors used during the test procedure includes pressure transmitters, temperature sensors, fuel flow meters, turbine tachometers, Linear Variable Differential Transformers (LVDT), resolvers and relays.

3. AUTOMATION & THE LIMITATIONS OF A SINGLE DATA SOURCE

To discuss the limitations of the t-DAQ system appropriately, the structure of the APC applications that deliver the primary benefits of automation of the test process is presented first.

Three of the APC controllers have the structure shown in Fig. 2. It can be observed that the data from the t-DAQ is pivotal for each APC to correctly set its process to the commanded set condition using process feedback data.

The t-DAQ system that has been the focus of this study is a Daytronic System10 product. It has a processor that is capable of updating its 'holding' memory with data scanned from analog input channels at a frequency of 3 kHz. This is the memory from which data is supplied to RTUs using an RS232 digital communication protocol with BAUD settings of 5-7-2-0 [7].

As a result the number of actively installed channels will determine how frequently memory is updated—more channels will result in less and less channels in more.

The total number of installed active channels is 100 analog inputs. Of this number, 20 channels are required for the test procedure being discussed and 3 out of the 20 channels are used for closed-loop process control for the purposes of automation.

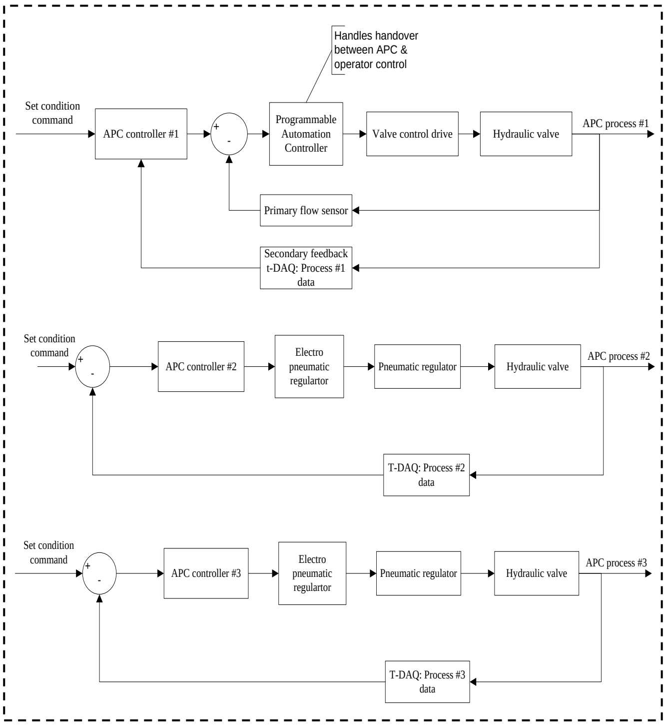

Fig. 2: Structure of the APC applications

Given the BAUD setting of the t-DAQ system's serial communication link, the minimum interval at which data can be extracted from its holding memory by a dependent RTU application is 30 milliseconds with overheads [7].

Although the BAUD setting could be changed to increase the bit rate of transmission, there are other business systems that are configured to work with this setting, so it cannot be modified. Hence it is being used.

These mean that dependent applications must accommodate this inherent delay and could only be served through a software interface. Reason being only one application can access the data at a time to avoid data jamming which undermines data integrity

Theoretically, the inherent time delay incurred by using the t-DAQ system means that the APC application with a high data frequency requirement cannot be supported, as shown in the chart of Fig. 3.

Fig. 3 shows the response of one of the processes, APC process #3. Besides the approximate 400% overshoot of the process relative to the commanded set point, the oscillatory response affirms that the delay incurred to get process data to the APCs cannot be accommodated. Therefore the benefits of automation cannot be realized.

An option to mitigate this limitation of the t-DAQ is to buy an additional serial card and configure it for a higher bit rate. The other option is a modern DAQ device integrated with three new sensors for the processes of the APC. This is the preferred and selected option. Thus a form of a sensor hardware redundancy is also achieved.

A review of how data from these two sources could be managed led to the design of a data reuse architecture. It is based on a "featurized" live table of test process data for reuse by all of the automation applications.

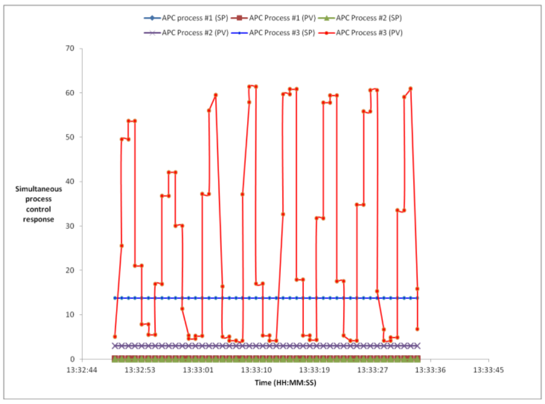

Fig. 3: The oscillatory, overshooting response of process #3 under the control of APC #3 when all applications reuse data from traditional DAQ system

4. THE FEATURISED DATA REUSEARCHITECTURE (FeDRA)

Research on architectures for practical application of data reuse on a systems level shows little work is being done in this area. Reviewed publications were micro implementations focusing on specific technical constraints like efficient retrieval methods to extract data from memory or the reuse of data to reduce the cycle time of a technical mechanism. For example one case study focused on data reuse architecture for MPEG video coding [12][13][14][15].

Most published works in the literature focus on data reuse algorithms or mechanisms for technical applications that are narrow in scope and focus on one dimensional data reuse objectives.

The challenge here is the management of the dataset; make it easily retrievable and efficiently accessible to every application that needs it. None of these can be achieved with just the raw process data alone. More so, this dataset must be live and have no copies.

It was established that additional information about each test data is essential to make it accessible, retrievable and reusable by a dependent application.

In order to achieve this, meta data is generated from the channel configuration of the t-DAQ system for each test data. These meta data are the data name, the data's channel number, a numeric tag, its value (the actual data) and the data's type (e.g. short or long integer).

Each data is combined with its meta data in a cluster and these clusters of 'featurized' test data are built into a live table (an array of sorts). This is the premise upon which the data reuse architecture is based.

Furthermore, the disciplines of software engineering and computer programming already solved the challenge—of a single, live data source—through the *singleton design pattern* [16]. The design enforces the existence of a single copy of data in active memory in the lifetime of an application. This concept can be found in the application of databases for example.

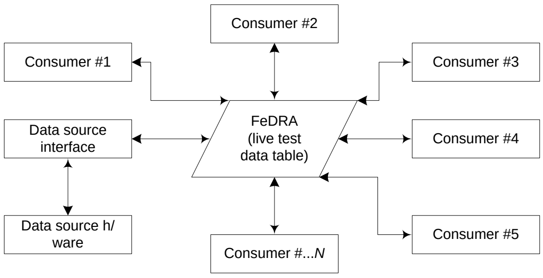

Fig. 4: Structure of a standalone FeDRA

A substantial number of applications can reuse data from a single source based on FeDRA (Fig. 4). However the impact data reuse on each application's ability to fulfill its requirement(s) must be understood first.

Having established the basis for FeDRA, its other aspect is how the data is shared. It is worth introducing how FeDRA was adapted for the new data source for APC applications. Another FeDRA (#2) is created. It inherits some of the (characteristic) meta data of the FeDRA (#1) for the t-DAQ.

Both FeDRA #1 & #2 are *daisy chained* (Fig. 5), to form a so called dc-FeDRA. This means that although three of the APC process data are duplicated, each set of data maintain the representation of the process media state whilst also being visible to all consumer applications.

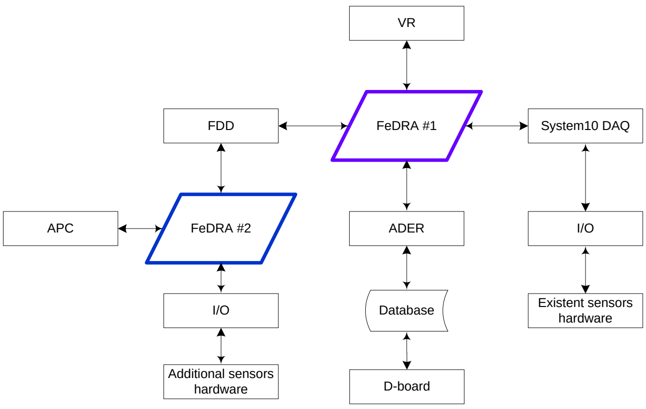

Fig. 5: Adapted data reuse architecture based on the daisy chaining of FeDRA #1 & FeDRA #2

Since the APC application is the only time-critical application according to its requirements. By design it utilizes data from FeDRA #2, whilst all of the other applications reuse data from FeDRA #1.

Except for the D-board application, all the other applications are local to the test process operation.

Therefore data communication models such as the server client model used for remote application communications and based on a protocol like TCP/IP are deemed an unnecessary complexity for this application. For example there is the commercial product, LabVIEW™ Current Value Table which is similar to the FeDRA concept but implements a server client communication model [18].

For this application designated communication lanes that are established between each consumer application and its FeDRA table initially (Fig. 4). Where both FeDRAs publish a copy of their live table of test process data at a rate above the minimum required.

However, considering that the number of consumer applications could grow in the future and these communication lanes would need additional programming to add new consumers, they are replaced by proxy global copies of each FeDRA table. These are updated each time a test data's value of either FeDRA tables changes. Thereby a consumer application with access to this global copy can retrieve test data, then search for a required test dataset and execute its function to meet its requirement(s).

Nevertheless, a fundamental limitation of the FeDRA, is that the speed of retrieval of data elements by applications that will reuse them is directly proportional to the size of data it contains and the volume of data that each application requires [4,6]. In a broader consideration, this is a challenge for all applications concerned with multidimensional data reuse.

$$\text{Interval of data retrieval (seconds)} = retrieval\ rate\ per\ data\ element \times volume\ of\ data\ required$$

5. RESULTS

The performance of the APC application will be used as a benchmark to evaluate the impact of using appropriate data reuse architecture. Based on Fig. 3, the goal is to increase the frequency at which data is supplied to the APC applications based on the result of Fig. 3).

When the data collected from the t-DAQ system is reduced to three for the APCs alone, the results in Fig. 6 show an improved performance of process control. Also it validates that the performance of the APC applications is indeed affected by the limitations of the t-DAQ.

Upon installation of the additional sensors and implementation of the dc-FeDRA, Fig. 7 shows even better performance of the APC application. In particular, the near elimination of the oscillatory response of APC process #3. There is an overshoot of about 20%, a steady state error of 8% and an impulse response to a decrement in set point (which can then be dealt with by further tuning of the APCs).

The new parallel sensors were integrated into a National Instruments analogue input module PXIe-6361. It has a data acquisition rate of 2 MHz spread across the number of active channels. Therefore the APCs could each receive process data up to a rate of ~666 kHz [19].

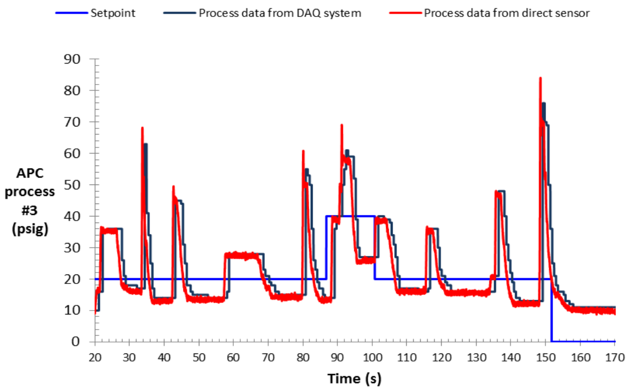

Fig. 6: An oscillating process #3, after the number of data retrieve from the installed DAQ system reduced to three

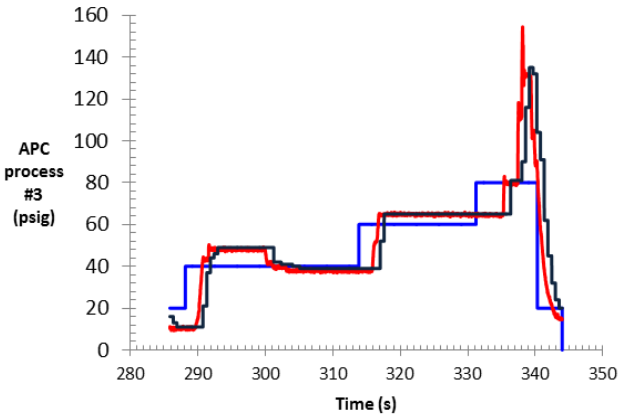

Fig. 7: The installation of parallel sensors complemented with the derivative CVT architecture, enabled the APC #3 to yield better process control performance

The results demonstrate that the sharing of data between applications that need it at a frequency of say 2 Hz and those that need it at a frequency of >50 Hz, is a design challenge that can be solved in different ways. This is one of the drivers behind modern data acquisition systems being software oriented. In our case, one data source is for time critical applications and the other for non-time critical applications. This will differ for other data reuse applications in the field.

It can be seen that data from both FeDRAs give similar representations of the state of process #2 (Fig. 8), apart from the 1.8 seconds time difference due to delays in data extraction from the t-DAQ. Though these data may drift apart owing to the natural degradation of sensor hardware, hardware redundancy concepts could be introduced in the FDD application to compensate for this automatically.

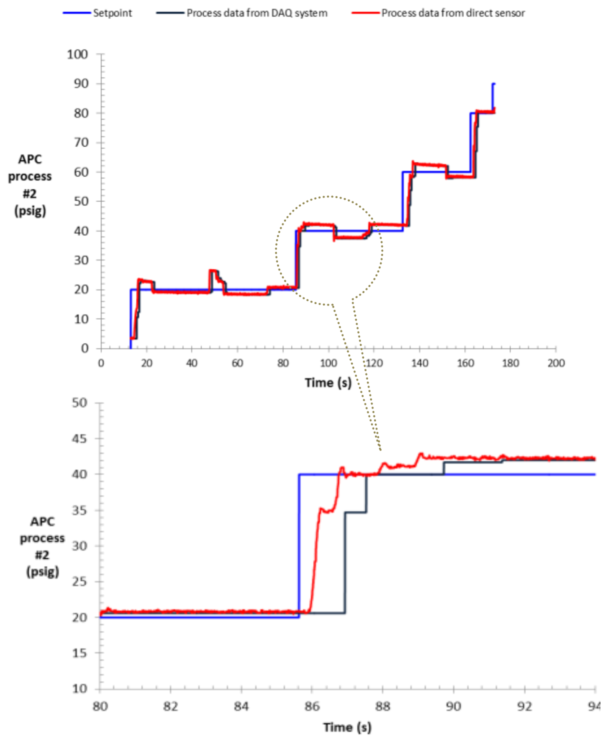

Fig. 8: Process #2 is impacted less by the delay in process data communication as the data size is decreased to three

6. CONCLUSION

It has been shown that although a single data source could serve multiple consumer applications, this is impractical if these applications are a mix of time critical and non-time critical applications. Especially if an extant DAQ system is only accessible via a single interface.

Using a software oriented architecture, FeDRA, the number of applications that could reuse the same test data was made possible, but at the expense of achieving a pivotal objective—of automation of process control.

Nonetheless, with dc-FeDRA, the addition of data sources for time critical applications was easily managed all other applications to reuse data from a legacy data acquisition system.

One of the side outcomes of our work illustrates that stretching the utility of legacy systems could hurt the benefit of applications which can deliver business benefit from modern technological concepts such as automation.

Therefore to use one data source to serve multiple applications a software centric design is recommended, using a highly capable data acquisition system for a similar type of application. However the time requirements of all applications that reuse the same data must be understood and accommodated within the design of those systems.

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