Real-time acquisition, processing and visualization of large datasets during a wind tunnel campaign

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Abstract: An integral part of the Clean Sky 2 SA^{2}FIR wind tunnel test rig is the Advanced Data Acquisition System (ADAS) which acquires all relevant sensor signals, and processes, visualizes and stores the resulting data. All data is collected, processed and stored in the distributed Data Processing and Display System (DPDS). This paper provides a concise overview of the ADAS and focuses on the digital hardware infrastructure and associated software.

Keywords:
Wind Tunnel Instrumentation, Data Acquisition System, Data processing, Data storage, software

1. Introduction

In the Research & Technology project SA^{2}FIR, an acronym for “Simulator of Aerodynamic and Acoustic Fan IntegRation”, a generic test rig for wind tunnel testing is being developed to investigate the behaviour of a turbofan propulsion simulator.

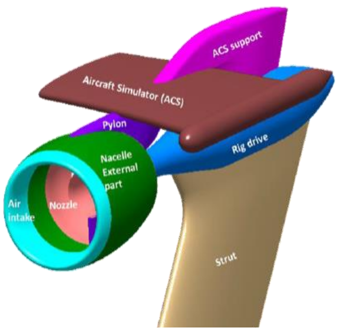

Figure 1 SA^{2}FIR test rig

In support of this project, an Advanced Data Acquisition System (ADAS) is developed by NLR that forms an integral part of the SA^{2}FIR test rig. ADAS acquires all relevant sensors signals, and processes, visualizes and stores the resulting data. The envisaged life cycle of the test rig spans 25 years.

The development of the SA^{2}FIR ADAS builds on extensive experience gained by NLR in the development of the Z08 telemetry system, in 2012 [1]. The SA^{2}FIR ADAS differs in that it has approximately twice the rotation rate, five times as many channels, and a much wider temperature envelope. Higher data rates required an increase of the contactless data transfer rate from 100 Mbit/s to 1 Gbit/s.

The SA^{2}FIR ADAS will initially be used in two wind tunnel test campaigns, i) in the DNW Large Low-Speed Facility (LLF) in Marknesse, the Netherlands and ii) in the ONERA S1MA wind tunnel in the Modane Avrieux Center, France.

2. Data Acquisition System Outline

The SA^{2}FIR ADAS contains three data acquisition subsystems:

i) Rotating Data Acquisition System,
ii) Model Data Acquisition System,
iii) Inflow Data Acquisition System.

2.1 Rotating Data Acquisition System

The Rotating Data Acquisition System (RDAS) consists of a Rotating Data Acquisition Unit and a Contactless Power and Data Transfer (CPDT).

RDAS is mounted immediately behind the Rotating Shaft Balance (RSB) and within the model's booster. The RDAS takes care of all measurements in the rotating domain.

Table 1 RDAS Sensor overview

Sensor type	Location	#	Resolution	Sample rate
Pressure	fan blades, fan disk, booster	120	24-bit	132 kS/s
Strain gauge	RSB, fan blades		16-bit	11 & 33 kS/s

For the transfer of electrical power from the stator to the rotor and for the bi-directional exchange of digital information the NLR-patented Contactless Power and Data Transfer (CPDT) is used [2]. It provides efficient transfer of electrical power through a special bisected transformer, alongside with 1 Gbit/s communication channels.

2.2 Model Data Acquisition System

The Model Data Acquisition System (MDAS) performs the measurements in the (stationary) nacelle and wing section of the model and consists of five custom-designed subsystems. Each subsystem utilizes a 1 Gbit/s fiber optic connection to transmit measurement data.

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Table 2 MDAS Sensor overview

Sensor type	Location	#	Resolution	Sample rate
Pressure	Nacelle, Wing section	700	24-bit	132 kS/s
IEPE microphone				
Strain gauge			16-bit	11 & 33 kS/s
Thermistor				10 S/s
Pressure		1000	16-bit	10 S/s

2.3 Inflow Data Acquisition System

A range of 165 in-the-flow sensors is measured by the Inflow Data Acquisition System (IDAS). This is also where the clock and synchronization signals for all system parts of the ADAS are generated. The IDAS is composed of off-the-shelf data acquisition equipment manufactured by National Instruments.

Table 3 IDAS Sensor overview

Sensor type	Location	#	Resolution	Sample rate
Microphone	In-flow	165	24-bit	33 kS/s
Accelerometer				
Strain gauge			16-bit	33 kS/s
Thermistor				10 S/s
Thermocouple				

3. Data Processing and Display System

The Data Processing and Display System (DPDS) gathers, processes, displays, and stores the data streams from the RDAS, MDAS, and IDAS subsystems and the wind tunnel facility. It consists of: a single Front-End Cluster (FEC) containing computers which interface with the data acquisition hardware and wind tunnel.

A twin of Proprietary Data Processing (PDP) clusters, one for each of the two clients. The rationale for 3 clusters is the clients' desire for data segregation/masking which is elaborated on in section 4.2.

The interconnections from the FEC cluster to the two PDP clusters are dedicated point-to-point LAN links, to enforce the segregation. The inter-process and inter-node communication within each cluster uses NLR's Distributed Real-time Automation and Control Host Multi-Platform Executive (DRACHME) software kernel.

3.1. DRACHME software kernel

The distribution of data and commands within each cluster is based on the DRACHME software kernel. DRACHME has been developed over the years for the control and data acquisition of wind tunnel facilities and complex wind tunnel models. Such software normally includes dedicated custom-built, third-party and/or commercially available data acquisition and control systems.

Figure 2 DPDS Overview

In order to meet the demanding requirements for these modern systems NLR has developed a software kernel that provides the distributed functionality for high-speed synchronized data acquisition, data processing, control, automation and data storage tasks.

This kernel has the following key features:

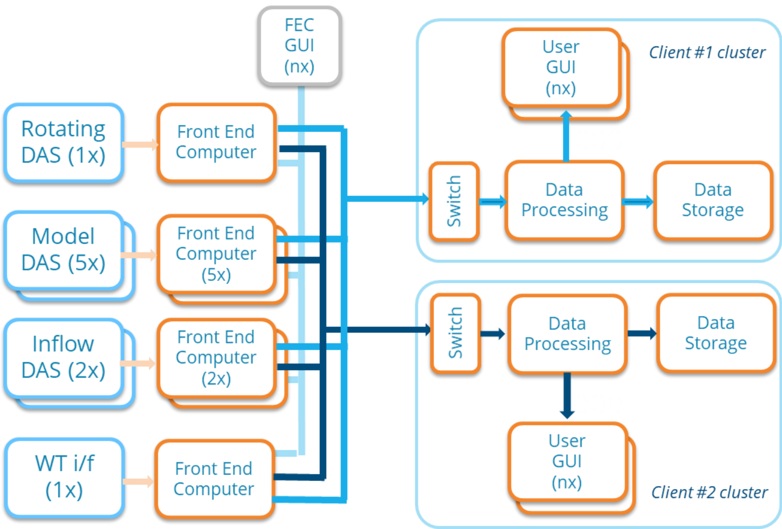
Scalable: Dependent on the customer needs the software can be deployed on a single computer (node) or on a network of interconnected nodes with automatic (re-) configuration of peer nodes.

Real-time data sharing: Data acquired by any measurement device can be distributed in real-time between tasks and user interfaces. Information is shared based on a subscription mechanism in order to minimize network and system load.

Automation and control: A command mechanism enables the control of all tasks running in the system. Commands can originate from a user interface or any task or script on any node of the cluster. Tasks can use a message mechanism to provide event feedback. Scripting can be used to control automation in a flexible way.

Multi-platform: The DRACHME kernel operates on Linux, Windows and Android platforms. This simplifies the interfacing with existing systems as they only need to interface with DRACHME on their native platform. It also provides flexibility with respect to specific operating systems features. For SA^{2}FIR, only the Linux version is used.

The DRACHME kernel takes care of the communication between tasks. It provides a mechanism for the sharing of data, commands and messages. This modular approach allows the user to easily expand the system or to redistribute the system load without having to reprogram the tasks or to reconfigure the system. Basic tools such as table and graph displays, message viewers and loggers, and command user interface are available. Users can easily



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extend this tool set and create their own graphical user interfaces using the Qt toolkit.

3.2. Front End Computer cluster

The Front-End Computer cluster consists of ten Front End Computers (1x RDAS FEC, 6x MDAS FEC, 2x IDAS FEC and 1x Wind Tunnel InterFace FEC). Each Front-End Computer gets its data from a DAS, using a dedicated Ethernet interface, used as a point-to-point connection between the DAS and the FEC to improve the communications reliability.

The FEC's Controller program reads the signal arriving at this Ethernet interface, and takes care of further distribution of its data contents, both within the FEC cluster and to the two Client Clusters. Each DAS has a preview information generation process and a Graphical User Interface (GUI).

Each GUI can display the information of the per-channel segregation mask and trip. This information is provided by the FEC's Controller process. The GUI can be used to update the system's configuration and sensor calibrations settings, as well as the per-customer mask, of the controller as necessary. Both the preview information generating processes and the GUIs can also be used on the PDP cluster, be it without the facility to change settings or masking information.

For the RDAS, the presentation of the mask/settings/trips and the of the information generated by the preview process has been combined into a single GUI. The RDAS preview/GUI displays the following information from the controller and preview tasks: Goodman diagram, Temperatures, Pressures and Strains.

In case of the MDAS and IDAS subsystems, the main preview information of the data is in the form of a Fourier spectrum of the acquired data. For these subsystems, a number of channel spectrum preview tasks are active. Each preview task provides the spectral preview information of a single channel. A user-selected number of so-generated spectra can be jointly viewed in a number of spectrum preview GUI programs.

3.3. Proprietary Data Processing cluster

There are two mutually isolated Client clusters, the Proprietary Data Processing (PDP) clusters.

Each PDP cluster consists of a PDP control computer and Data Backup System (DBS). The basic functionalities of the Controller program running on the PDP Controller act as a central data-exchange between the FEC's and the data storage, data (pre-) processing, and presentation. The DBS system serves as a long-term storage system for the acquired data.

4. SA2FIR Special Software features

The Data Processing and Display system (DPDS) provides the functionality to apply all computations and corrections that are necessary to convert the raw data from the Data Acquisition System subsystems to engineering units and to display these values in a proper way for the two Clients.

The DPDS includes special features to support the high-performance requirements:

- Sample synchronization
- Data privilege segregation/masking
- Sensor Health Monitoring system
- Data (pre-)processing and presentation
- Data storage, daily and long-term.
- Data processing

4.1. Sample synchronization

One of the major requirements for the ADAS is that most samples be strictly synchronized. For this purpose, a master sample clock signal is generated and distributed, which is enslaved to an IEEE-1488/PTP source derived from a GPS time-base. It is distributed to all system parts that perform data acquisition with a per-system tuned delay that ensures that the resulting channel-to-channel and system-to-system latency difference throughout the system is below 1 µs.

4.2 Data privilege segregation/masking

The information of all data acquisition systems of SA^2FIR is subject to privilege segregation: a part of the signals is privileged to be seen and stored/processed and monitored by one customer (client) only. Which signal(s) are privileged to which customer can be configured in the FECs. A correspondingly masked data-stream is sent to the respective customer's Proprietary Data Processing (PDP) cluster by means of a dedicated Ethernet link.

4.3 Health Monitoring system

SA^2FIR is a system with a large number of sensors. While the individual sensors are quite robust, the environment they are used in is at times extremely hostile. In order to be able to detect defective sensors early, the ADAS includes an interface that is used to monitor the health of all relevant sensors. To this end, a simple spectral image of the relevant sensors is exported periodically. The characteristics of this image are inspected by an Airbus-provided Artificial Intelligence algorithm, which is tasked with the decision if the sensor is still trusted to operate correctly. The ADAS imports this decision result, and presents them to the operator(s).

4.4 Data pre-processing and presentation

The twin PDP Clusters are functionally identical. Each twin member performs its operations on the masked data for one of the two clients. The first purpose of the PDP is to receive and merge the masked data streams from the FECs and distribute the contained information for pre-processing presentation and/or storage.

The PDP has ample processing performance, to perform data pre-processing and to calculate and present a spectral representation of up to 50 selected dynamic channels, for inspection and monitoring, during and/or in-between measurements.

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The same preview information generation processes and Graphical User Interface programs mentioned in section 3.2 are used for this purpose. Two Data Processing and Display (DPD) stations on each of the PDP Clusters enable the customers to inspect the PDP preview and display parameters in real-time.

4.5 Data storage, daily and long-term

Within each PDP cluster a high-bandwidth PDP RAID receives and stores the merged and masked, but otherwise unmodified raw measurement data streams from the PDP. It does so on command. The PDP RAID has enough storage capacity (34 TB) to store the acquisition results from all sensors for one complete day of measurements. The data will be copied to the Data Backup Computer and RAID (DBR) with a net storage capacity of about 500 TB (expandable to 1000 TB) between measurements days. The PDP and DBS are connected by means of a dedicated 25 GBit optical network link for rapid data transport between the two.

4.6 Data processing

Directly after a measurement, the PDP computer is used to perform the processing of the data to provide the engineers with information for first analysis of the measurement results. The measurement results are converted into customer's specified data file formats (e.g. Tardis, DatX, and HDF5). In this conversion the raw measured data is not modified so that it is possible to later re-process the same unchanged raw measurement results using, for instance, other calibrations and/or processing corrections.

5. Software obsolescence management

In view of the very long-life cycle of the system an obsolescence management plan has been complied which address the aspects related to hardware and software. Proper management of obsolescence for this system requires an active primary obsolescence management process which already started during the development.

The SA^2FIR software has been designed to be open, adaptable and scalable. The projected lifetime of SA^2FIR is 25 years. The starting point of the SA^2FIR system is a generic wind tunnel test rig with a number of dynamic data-acquisition systems. It is foreseen that this will not be the same as the situation after 25 years of operation. When looking back now, at the design and implementation of the initial Z-08 system and, over a similar time span, it can be observed that there has been a significant evolution of both the practices and features of computerized data-acquisition systems. Just as it was not really possible to accurately predict the current situation 25 years ago, it is not really possible to predict what SA^2FIR will look like in 25 years' time. Inspectable and standards-compliant systems has proven to be valuable over such time spans. The SA^2FIR software presented here will attempt to honour these traditions.

The software design of the SA^2FIR system itself has no pre-imposed limitations. The system is of course limited by both the hardware performance of the computers, the networking throughput of the inter-computer communication, the disk storage capacity. The design of the software has however gone to some length to avoid imposing any extra limits: The system is as scalable as reasonably possible.

This includes a modular design, where functionality can be expanded by adding functional units, or as-needed-concentrated.

6. Conclusion

NLR developed an advanced data acquisition system for a generic engine test rig for wind tunnel use. The data acquisition subsystems are bespoke developments, supporting a total of 120 rotating and 1865 stationary measurement channels at high sample rates. A large amount of data is synchronously collected, processed in real time and stored in the distributed Data Processing and Display System.

7. Acknowledgement

This project has received funding from the Clean Sky 2 Joint Undertaking under the European Union's Horizon 2020 research and innovation programme. This work has been performed in co-operative effort with Airbus Operations SAS and Safran Aircraft Engines.

8. References

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14 Glossary

ADAS	Advanced Data Acquisition System
CPDT	Contactless Power and Data Transfer subsystem
DAS	Data Acquisition System
DPD	Data Processing and Display
DPDS	Data Processing and Display System
DSS	Data Storage System
DRACHME	Distributed Real-time Acquisition and Control Host Multi-Platform Executive
FEC	Front End Computer
GUI	Graphical User Interface
IDAS	In-flow Data Acquisition System
IEPE	Integrated Electronics Piezo-Electric

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MDAS	Model Data Acquistion System
NLR	Royal Netherlands Aerospace Centre
PDP	Preview and Data Processing
RDAS	Rotating Data Acquisition System
RSB	Rotating Shaft Balance
SA^{2}FIR	Simulator of Aerodynamic and Acoustic Fan IntegRation

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