LDA Data Acquisition by ILA R&D

The idea

Conventional LDA Data Acquisition with hardware processors is limited in time resolution by the processor speed and the data transfer rate between PC and processor. Furthermore, the system setup is not flexible due to the limited hardware configurations. To achieve the highest time resolution and degree of adaptability to experimental requirements, ILA R&D provide a new PC-based LDA software platform, in combination with powerful A/D-converter cards and maximum sampling frequencies of up to 5 GHz.

System architecture

The ILA LDA Data Acquisition System typically consists of a LDA-Controller and a PC with integrated A/D converter cards. The controller contains the power supply, the laser head control units, 6 calibrated 4-20 mA analogue input channels with 0,5 ppm uncertainty, and the analogue data-processing units such as analogue filters and downmix circuits. By integrating the A/D converter into the PC, the system can easily be customized in terms of maximum sampling rate, number of channels and resolution up to 16 bit to the specific requirements of scientific customers. The number of cumbersome cable connections is also minimized. This architecture provides maximum flexibility for integrating different hardware components, and best conditions for fast data transfer and data processing. The completely parallel multithreaded data processing code uses all available computing cores in the PC CPU and offers scalable processing power that is faster and more flexible than conventional hardware processors.

A/D converter for Present-Day Research Challenges

ILA R&D provides scalable solutions for LDA Data Acquisition by combining a wide range of A/D-converter cards with powerful PC systems and smart LDA software solutions.

Max. Sampling Frequency	50 MHz to 5 GHz
Resolution	8-16 bit
Max. input frequency	2 GHz for 5 GHz sampling frequency
Max. bandwidth	200 MHz (highest analogue filter distance)
Min. Bandwidth	3 kHz (min. analogue filter)
Min. transient time	12 ns for 5 GHz sampling frequency and 64 samples
Record interval	Fitted to burst length

The wide range of components and the system architecture provide cost-effective and future-proof solutions. So a conventional 2D LDA system can easily extended by additional channels for a 3D-upgrade or an additional optical temperature or profile sensor.

LDA Control Qt: Acquisition and Processing Software

To provide a fast and flexible acquisition and processing software, LDA Control Qt combines a user friendly GUI with online signal monitor, auto set functions and Python interface for customized data evaluation and processing.

Easy to use but flexible

Taking minimum and maximum velocities as input, the autoset function calculates all necessary parameter for the data acquisition. All parameters are stored in a file. The preconfig function contains defined settings for specific velocity ranges. Advanced users have full access to all data acquisition parameters. A built-in calculator provides all the necessary theoretical dimensions of the measuring volume.

User friendly GUI

The GUI is intuitive in layout and control, with free arrange- and dock able windows. Interactive control of trigger level, software and hardware filters combined with autoset functions leads to a fast and easy handling of the software. The standard display shows the live Doppler burst in the time domain and the FFT result in the frequency domain to evaluate the noise level. The histogram can be displayed for frequency or velocity. An online monitor tracks the current frequency, velocity, validation rate and validation percentage, turbulence degree and statistical uncertainty, providing complete control over the acquisition process. A Laser State Monitor shows the status, laser power and temperature of each laser system. The laser power can be adjusted from 30% to 100%.

New advanced acquisition modes for highest system performance

The basic idea of the new LDA acquisition system is to combine multi-core processing power, fast buffer storage of the A/D-cards and fast SSD-Memory into a flexible measurement tool for the changing experimental challenges of scientists. Different acquisition modes offer solutions for the different measurement requirements:

- Standard Mode: live view of the measurement results; every result is immediately displayed; this is particularly useful for system setup and fine tuning of the acquisition parameters.
- FIFO Mode: all amplitude-triggered burst are buffered on the A/D card and evaluated on the fly by the multi-threaded software; this is useful for high data rates, up to 200kHz, and has no storage restrictions for long time measurements.
- Long Sample mode: sampling of the complete time signal into the card storage; the automatic off-line evaluation of the signal allows spectral burst detection and adaptive filtering and FFT for the highest data rates only limited by the sampling frequency, and record length limited by the A/D card buffer size to a maximum of 4 GSamples.
- Streaming mode: sampling of the complete time signal onto the SSD hard disk, automatic off-line adaptive evaluation for highest data rate only limited by the sampling frequency; the recording length is only limited by the size of the SSD hard disk.

FFT Processing

The FFT algorithm is optimized for multi-threaded data processing, using all available cores in the PC. The FFT routine uses double precision variables for highest accuracy. Window functions, curve fitting, burst center and burst length algorithms are implemented to reduce noise and to enhance the signal-to-noise ratio. The bursts are validated by the adjustable amplitude ratio and adjustable burst threshold. Additional spectral filters are used to define valid frequency ranges, and to isolate specific frequency ranges from potential noise sources.

Advanced adaptive Algorithms

The concurrent use of high multi-core computation power, fast storage models and integrated A/D-Cards enables new adaptive algorithms for burst analysis without losing time resolution due to limited computing power. Data is stored in fast dual-ported ring buffers or on the SSD, so adaptive algorithms for burst detection and processing perform well even in difficult signal conditions. The spectral burst detection is not performed on a signal amplitude basis: It can therefore detect small Doppler signals, even if they are under the noise level. Adaptive digital filtering is used to acquire signals with high dynamic range where unwanted frequencies have not been removed by fixed analogue filters. This is essential for measurements in boundary layers using profile sensor technology, which provide an outstanding spatial resolution near walls. Burst center and burst length algorithms remove detected noise outside the burst and enhance the input signal quality for the FFT.

Stop criteria

Different criteria are available for stopping the data acquisition. The measurement can be stopped once a certain number of evaluated bursts is reached, or after a maximum measuring time, or after reaching an adjustable level of statistical uncertainty. This saves measuring time. Additionally an adjustable minimum measuring time can be set to ensure a sufficient averaging time in slowly changing flow conditions.

Sigma 3 Filter

An optional sigma3 filter can be used to cut off velocities outside an interval of three times of the standard deviation.

File exchange

Files are stored in ACSII format, CSV-format for EXCEL or Tecplot format.

Python Interface

LDA Control Qt offers a Python interface for data processing. By transferring the filename and location of the measurement results to a python interface, the data is available for calculation, display and documentation by Python routines. Python is freely available and includes numerous possibilities for data processing and documentation. The routines can be automatically started by LDA-Qt. ILA delivers a set of helpful routines for post-processing data like calculation new physical quantities, plotting data, vector diagrams etc. Modules for 3D plot, bias correction, profile sensor measurement etc. are available. These routines can be used as an example for advanced calculations by scientific users. The complete integration of the Python interface is planned for 2019.

For customized signal processing, the sampled data is copied to the SSD and available to user- defined algorithms based on the time-dependent detector signals with the Python interface. Scientific users can use LDA-Qt as a shell handling the hardware and data acquisition process and implement their own signal-processing routines outside LDA-Qt.

Remote control

LDA Control Qt contains a software module named “LDA net remote” which enables users to communicate with the LDA-software. Via this interface, other software packages can perform the following tasks:

- Control LDA-Qt remotely
- Retrieve detailed measurement values like velocity, turbulence degree, traversing positions etc. from the LDA-Qt,
- Run LDA-Qt in slave mode

Using a standard TCP/IP Interface, LDA-Qt can communicate with a very wide range of software and hardware interfaces. For instance LDA-net remote was used to handle LDA-Qt as a slave within a wind tunnel automation software platform, to produce completely automatic calibration procedures for sensor calibration.

Over current protection for PM

The ILA Photo-multipliers are protected against overcurrent, because their high-voltage supply immediately limits the PM current to a safe range. So measurements in rotation machinery or near to walls are safe and without risks of damaging the PMs.

Traverse control

The LDA-Qt software can integrate different traversing systems to perform automated measurements along different types of measuring grids. The traversing module supports up to eight ILA traversing axes with DC-motors and encoders as well as standard stepper-motor systems, e.g. from ISEL. Traversing axes up to 1µm resolution are available. The communication is run over TCP/IP or RS232 Interface. The integrated grid generator offers Cartesian or cylindrical coordinate systems. For volume flow measurements, grids on the base of heavy lines are available. Customized grids on the base of ASCII can also be used. The traversing system can work in combination with optional beam calculation software to consider the effect of refraction on curved windows and interfaces.

Phase averaging

LDA measurements in rotating machines require modules of phased averaging. ILA offers different modules to detect different encoder signals and to calculate the rotation angle connected to the burst. The software calculates the phase averaged velocity distribution and allows an overlay of sub-cycles. Additionally, hardware synchronizers modules are available for the generation of synchronized TTL pulses synchronized with complex sequences.

Traceability

Because the uncertainty of LDA systems is characterized by very high long-term stability and transparent traceability, ILA Systems are often used for the quality management of calibration systems. The following key elements are essential for the calibration of an LDA system:

- Uncertainty of the calibration standard: LDA optics are calibrated by measuring the fringe distance of the interference pattern inside the measuring volume on the surface of a rotation disk. The uncertainty of this velocity standard is part of the complete uncertainty budget. The uncertainty of the ILA velocity standard is about 0.05%. This is of course not the uncertainty of the calibrated LDA system.
- Calibration Constant (averaged fringe distance): The deviation of the fringe distance inside the measurement volume is the most significant part in the uncertainty budget of an LDA system. This fringe distance is measured on a rotation disk with known surface velocity. The calibration constant is calculated by averaging the fringe distance distribution over the length of the measuring volume. ILA systems typically provide a deviation of about 0.2%, less than most other systems.
- A/D-Card and FFT-software: The uncertainty of the A/D-Card and the LDA software is calibrated with a traceable signal generator. This uncertainty is about 3-12 10-6 depending on the sampling frequency and number of samples.

The combined uncertainty of a typical LDA system is about 0.2%. Values less than 0.1% should be checked for suspect calculations of the uncertainty budget. ILA systems can of course be provided with a PTB certificate. Because of its outstanding accuracy, an ILA LDA system was chosen by the PTB Braunschweig as a transfer standard for a key international comparison. After one year of measuring around the world, the deviation of the ILA LDA system was less than the uncertainty of the PTB calibration standard of 0.1%.

Profile Sensor

The spatial resolution of conventional LDAs is limited by the size of the measurement volume. ILA developed together with the TU Dresden and the PTB Braunschweig solutions to detect the position of the particle inside the measurement volume. Therefore the special resolution is maximized to less than 1% of the length of the measurement volume. These profile sensors are the best solution for making measurements in boundary layers or in flows with high velocity gradients. Standard ILA systems can easily be upgraded to profile sensors.

Customized solution

Because all optical and electronic LDA components are developed in-house, ILA is able to customize each LDA system to the specific requirements of each scientific or industrial customer. From the 2x2 Watt 2D LDA System with 3 m focal length to the industrial cost-sensitive OEM sensor.

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