# LaVision
FOCUS ON IMAGING

ICOS

High-speed in-cylinder
gas analysis

The **Internal Combustion Optical Sensor** (**ICOS**) from LaVision provides a measurement technique for highly time resolved gas analysis directly in the combustion chamber of internal combustion gasoline, gas or diesel engines. Highly time resolved data of the relevant engine parameters air/fuel-ratio and CO_2-concentration are recorded and visualized in detail. This allows an analysis of dynamic variations for hundreds of consecutive cycles.
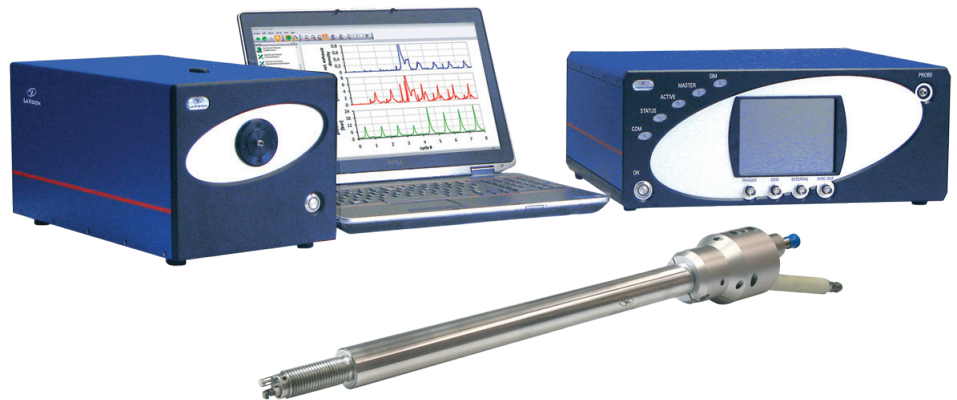
Applications ICOS
- ▶ for gasoline and diesel engines
- ▶ air/fuel-ratio – lambda value (λ) – transients
- ▶ investigations of highly dynamic engine conditions, e.g. cold start
- ▶ capable of verifying injection strategies and valve timings
- ▶ internal and external EGR rates
- ▶ exact analysis of the EGR stability
- ▶ distribution of EGR between different cylinders

Applications ICOS-CNG
- ▶ for methane or compressed natural gas (CNG) engines
- ▶ air/fuel-ratio – lambda value (λ) – transients
- ▶ investigations of mixture formation and homogeneity

Operation principle

The optical system is based on infrared absorption spectroscopy and measures relevant molecules like CO_2 or hydrocarbons. The **ICOS** system detects the specific absorption of infrared light by these molecules. It measures directly inside the cylinder and therefore the system is contactless and no gas sample extraction is needed.

Advantages
- ▶ ultra-fast response time
- ▶ crank angle resolved data
- ▶ no gas sampling, measures directly inside the cylinder
- ▶ unmodified engines, real fuel
- ▶ precise single cycle analysis
- ▶ fully resolved consecutive cycles for measurement on transient phenomena

Basic layout
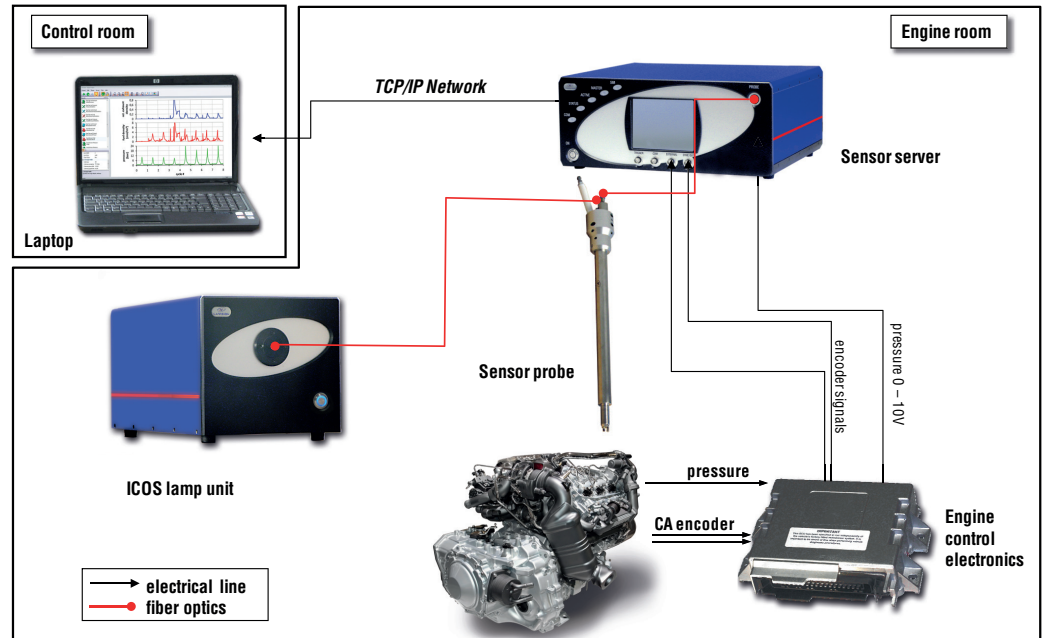
The ICOS system layout consists of:
- sensor server (**ICOS** or **ICOS**-**CNG**)
- sensor probe (refer to **ICOS Probes** datasheet)
- **ICOS** lamp unit
- pair of fiber optics
- data acquisition software **SenseID**
- data evaluation software **DaVis**

Working principle

The infrared light from the **ICOS** lamp unit is guided via optical fibers to the measurement area, a small volume at the tip of the probes (spark-plug or M5 probe) or a line across the cylinder when using a line-of-sight probe. After passing the absorption path the light is transmitted to the multi-channel detection unit inside the sensor server. The lamp unit, the fibers and the **ICOS** probes are the same for all applications (**ICOS** or **ICOS**-**CNG**). The detection, synchronization and basic processing are done by the sensor server. It is connected via TCP/IP to the client laptop computer in the engine's control room, from where the complete system is safely controlled.

Data are measured with sampling rates of up to 30 kHz without time delay and temporal smearing and is crank angle synchronized during engine operation. With this outstanding temporal resolution measurements of the dynamics of transient phenomena can be performed. The **ICOS** design is insensitive to contamination of optics and allows long operation periods.

ICOS

The **ICOS** system consists of four detection units. One unit provides a measurement technique for highly time resolved analysis of the **fuel density** inside the cylinder. The system is equipped with an ultra-fast detector for the measurement of the light absorption by hydrocarbons inside the **ICOS** probe´s absorption path. In combination with the cylinder pressure the local air/fuel-ratio is derived from the fuel density.

Two other units determine the **CO_2-concentration**, from where the EGR rate is calculated. With the measurement location inside the cylinder the internal EGR rate is also be derived for each individual cycle, thus allowing the analysis of EGR stability over many consecutive cycles. This information can be used to evaluate for example different valve timing strategies.

The fourth detection unit is the **reference** receiver to identify and/or correct disturbing noise effects on the measured signals, like influence from soot or droplets.

Example
Fuel detection

The diagram below shows an example of the crank angle resolved fuel density evolution of a catalytic converter heating point measured at the spark plug. The corresponding λ-value curve is derived from the fuel density and in-cylinder pressure.

After the double injection the fuel density rises during compression to TDC and decreases again with the beginning of expansion. The cycle shows an abnormal delayed combustion. Ignition takes place at 28°CAaTDC, while the fuel signal disappears significantly later. The drop in the fuel density at 100 °CAaTDC marks the appearance of the flame front locally at the probe tip.
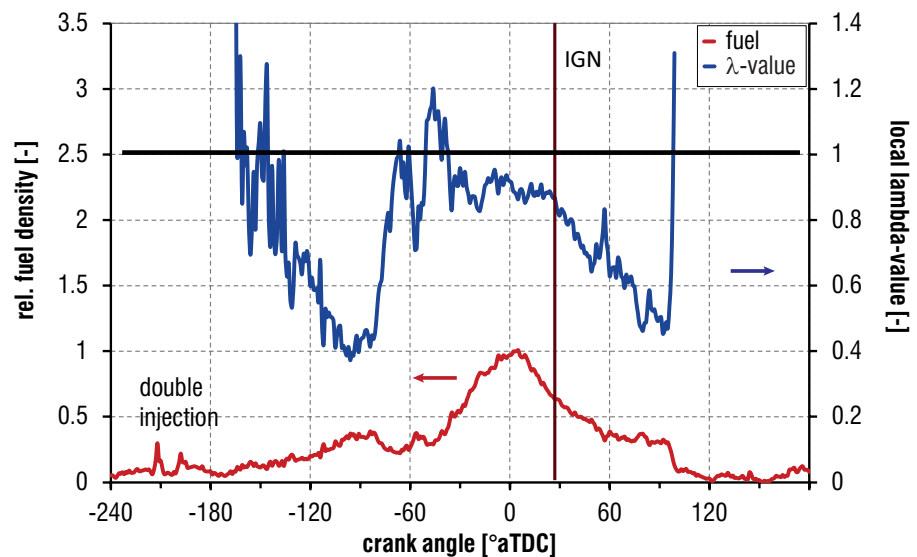
Figure 1: Fuel density and lambda-value evolution of a single cycle with delayed ignition.

Example
Internal EGR detection

The **ICOS** system is capable of detecting the CO_2-concentration and from this the EGR rate is derived. An example of the correlation between the applied external EGR rate and the measured EGR rate for two different engine speeds in a truck diesel engine is shown in Figure 2. The bars indicate the EGR fluctuations over 100 cycles. The offset between the measured and applied EGR-values (dashed line) is the internal EGR rate at a given condition. The results show a higher standard deviation of the EGR rate at higher engine speeds. The amount of internal EGR rate changes with engine speed and applied external EGR rate, proving the strong influence of these engine parameters on the cylinder internal air flow structure.
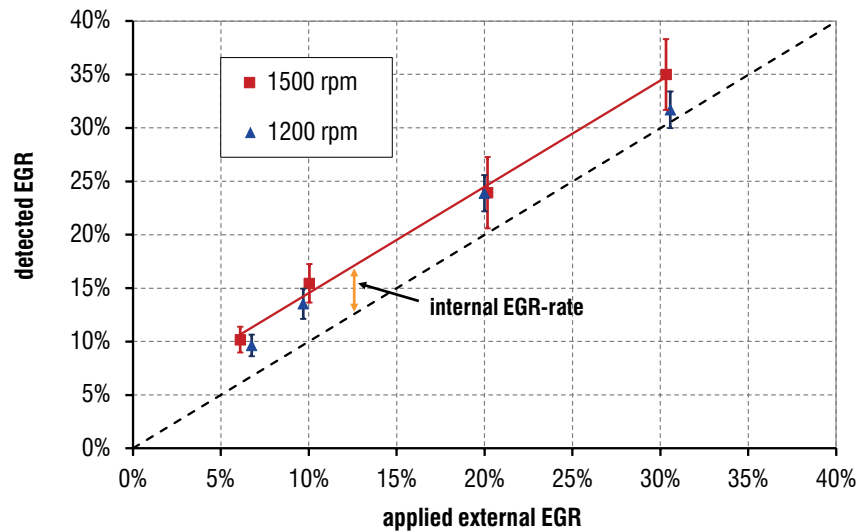
Figure 2: Internal EGR rate derived from the difference between applied and detected EGR rate for a diesel truck engine.

System specifications
ICOS

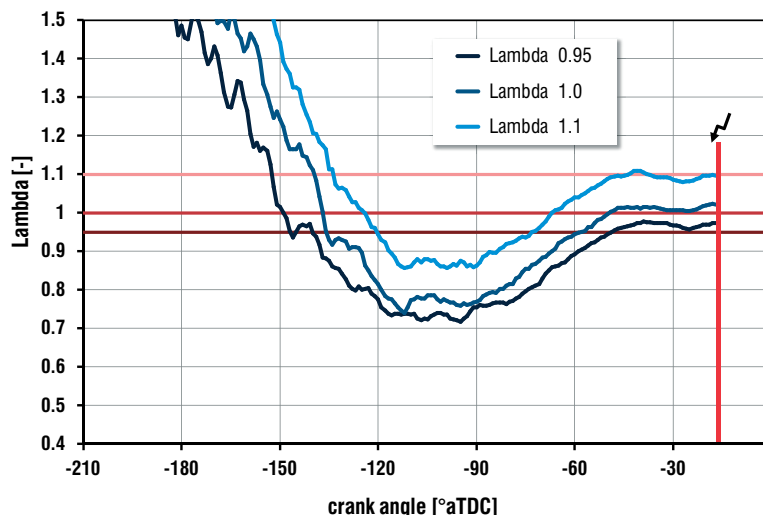|	
Measuring principle	multi-channel NDIR light absorption
Measured quantities	fuel density (air/fuel-ratio) and exhaust gas concentration (EGR rate)
Measurement error air/fuel-ratio	< 2 %
Measurement error CO_2 concentration	< 0.2 vol% CO_2 (5-30 bar, up to 12vol% CO_2)
Acquisition rate	30 kHz
Response time	33.3 µs
Data acquisition	crank angle resolved multiple cycles

The **ICOS-CNG** system consists of two detection units, one for the hydrocarbon detection and the second unit is the reference receiver for measured signal correction. The detection for the gas (methane or CNG) uses two ultra-fast detectors for the measurement of the light absorption by the gas molecules in the **ICOS** probe´s absorption path. From the gas concentration the local air/fuel-ratio is derived by the evaluation of the signals with a spectral database in combination with the cylinder pressure. The gas mixture formation within hundreds of cycles can by analyzed by this system.

Crank-angle resolved lambda-values inside a gas engine with direct port injection are measured with the **ICOS-CNG** system using a spark plug probe. The engine runs at constant conditions and is operated with methane. The diagram below shows the evolution of the lambda-value at the spark plug location with an early injection at different applied air/fuel-ratios. The process of mixture formation leads to a change from lean to rich mixture before stabilizing at the time of ignition.
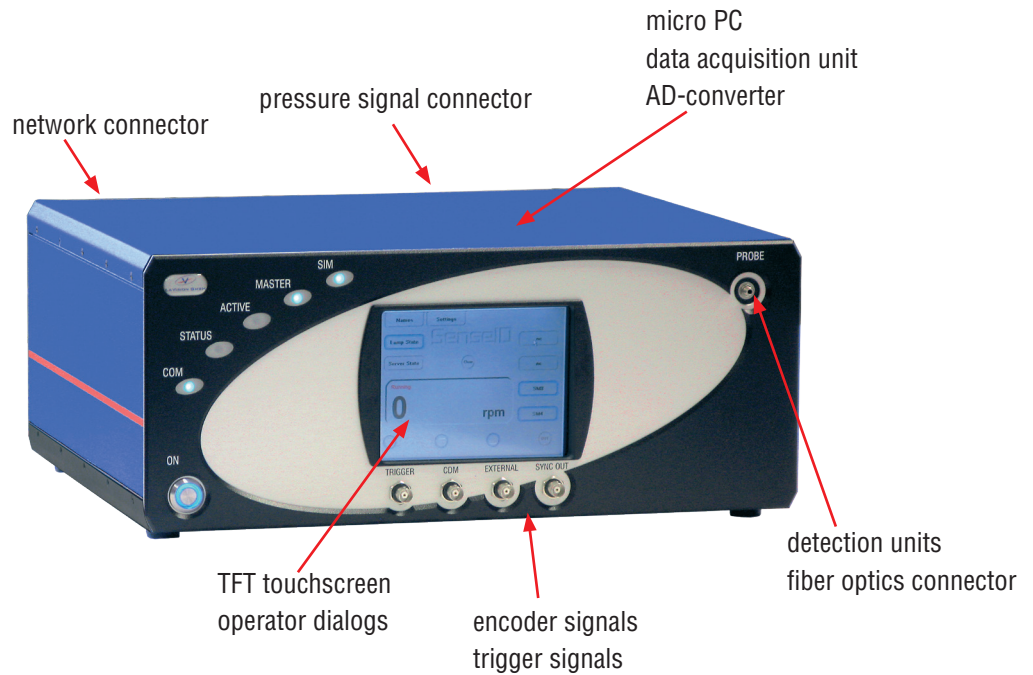
Figure 3: Crank angle resolved cylinder-internal lambda-value evolution in a methane gas engine with port-fuel injection at different applied lambda-values

Measuring principle	multi-channel NDIR light absorption
Measured quantities	methane or CNG concentration (air/fuel-ratio)
Measurement error air/fuel-ratio	< 5 % (5-30 bar)
Acquisition rate	30 kHz
Response time	33.3 µs
Data acquisition	crank angle resolved multiple cycles

![LaVision - FOCUS ON IMAGING]

Sensor server

The sensor server contains the detection units and synchronizes the data acquisition with the **ICOS** lamp unit and the engine rotary encoder signals. All the recorded data are mapped to engine´s crank angle. The complete sensor system can be synchronized with other measurement equipment or the engine test bed by additional trigger lines.

network connector

pressure signal connector

micro PC
data acquisition unit
AD-converter

TFT touchscreen
operator dialogs

encoder signals
trigger signals

detection units
fiber optics connector

Specifications

|	
Dimensions (W x H x L)	450 mm x 192 mm x 390 mm (incl. connectors)
Weight	18.9 kg
Power supply	100 – 230 VAC
	50 – 60 Hz
	max. 2 A
	fuse 4 A slow

ICOS lamp unit

The LaVision **ICOS** lamp unit is a light source with a broad infrared emission spectrum. The wavelength ranges from visible to far infrared. This permits the detection of many different molecules with the same light source. The light of the lamp is modulated by a very fast chopper wheel with 30 kHz. Modulating the light suppresses interfering light from the measurement location, e.g. thermal or flame emission.

lens adjust screws

exchangeable bulb module

SMA fiber connection
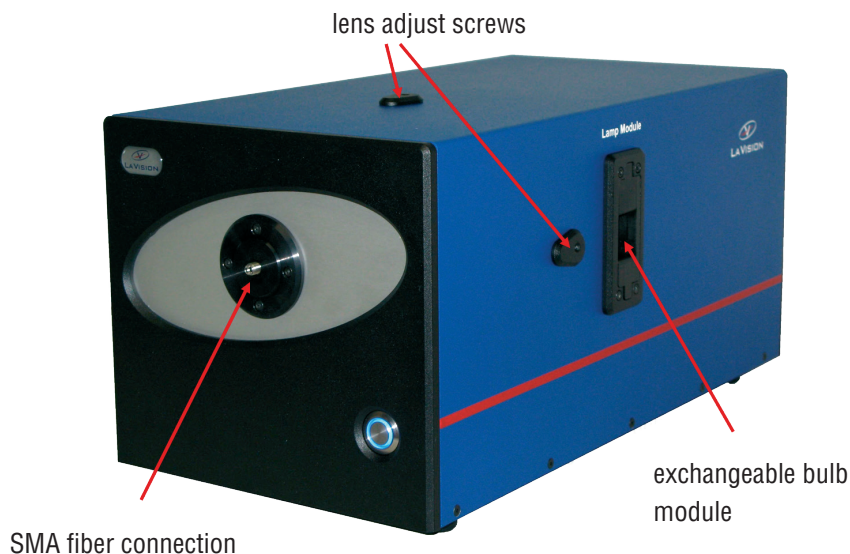
To supply up to four sensor probes simultaneously with light, a 4 port SMA fiber connection module is also available.

Specifications

|	
Dimensions (W x H x L)	219 mm x 209 mm x 428 mm (incl. connectors)
Weight	11.2 kg
Power supply	100 – 230 VAC
	50 – 60 Hz
	max. 3.5 A
	fuse 6.3 A slow

SenseID

The measurement software **SenseID** from is developed for data acquisition and controlling of the LaVision **ICOS** measurement systems. The software is optimized for measurements on internal combustion engine test beds. Primary parameters are continuously output in real time on the intuitive and application oriented online data display. All of the measured data are synchronized to the engines rotary encoder signals. Hundreds of consecutive measurement cycles can be recorded.
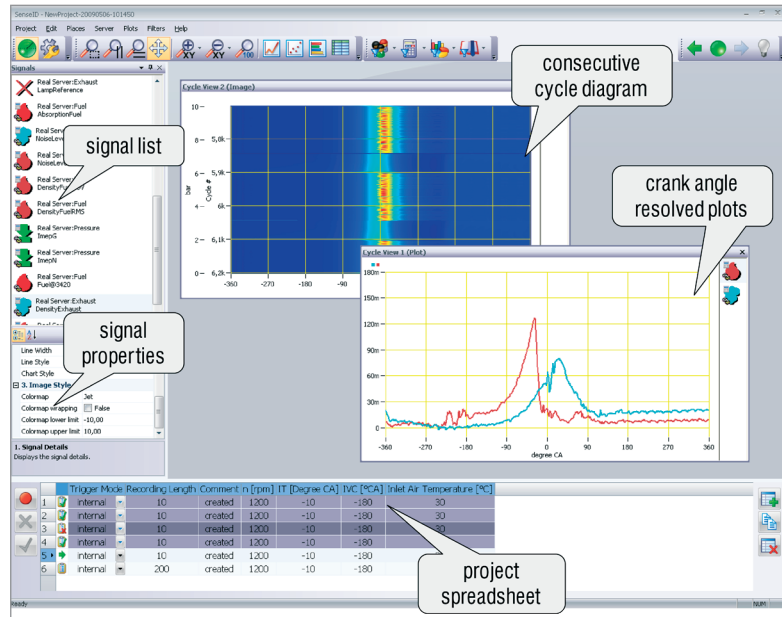
DaVis analysis and evaluation

The LaVision sensor software package for **DaVis** is for the evaluation and comparison of the data acquired by the **ICOS** measurement system. Models are used to calculate the engine application relevant air/fuel-ratio and apply a calibration model to reveal λ-values. The software evaluates the CO_2-concentration and EGR-rates.
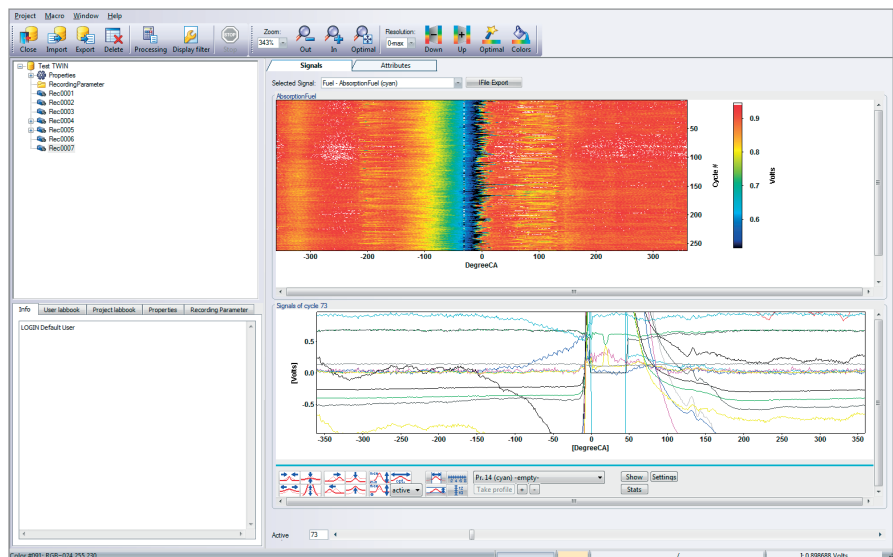
Engine access

The **ICOS** system has three different options of optical access:

Probe	Advantages
Line-of-sight probe	Suitable for any engine condition, especially high loads, measures the integral average across the cylinder. Recommended choice for temperature measurements.
Spark plug probe	Very convenient access to any production type engine by replacing the spark plug by the M12 or M14-probe, while maintaining full ignition capability. Measures locally at the spark plug.
M5 probe	Minimally invasive probe fits into standard M5 pressure transducer bores. Measures locally at the cylinder wall.

Please refer to our "**ICOS Probes**" datasheet for more details.

Ordering information

Part number	Description
1106045	ICOS
1106048	ICOS-CNG
1106002	ICOS lamp unit
1104205	Laptop computer for control
1105110	Sensor software SenseID
1105320	DaVis 10, analysis version for data evaluation
1106005	Pair of fiber optics cable, 2 m
1106003	Pair of fiber optics cable, 4 m
1106006	Replacement bulb for incandescent lamp

May-23