Technology White Paper

Science behind Collo and how it works

Table of Contents

What is Collo technology?

Collo is a solution for measuring liquids directly in the industrial process, continuously and in real-time. Collo can measure a wide range of changes in still or flowing liquid in the following main categories:

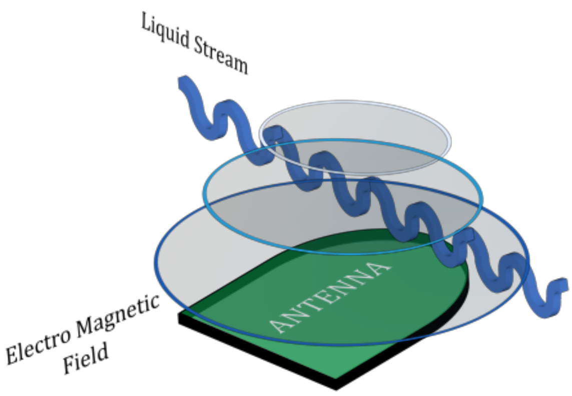
- separate phases (e.g., solids, oils, or gases in liquid), and dissolved chemicals

Collo can be used in a wide range of liquids from plain liquids such as water or alcohol up to more complex ones like slurries, gels, emulsions, pastes, creams, or suspensions. It is applicable for opaque and non-opaque fluids, both high and low solid loadings. It can be used with liquids with any number of chemical components and different phases. Examples include measuring coatings and their additive [1], adhesives and polymer dispersions [2], ceramic slurries [3], or simply measuring the impurities in the drinking water.

> One of Collo's key strengths is that it's universally applicable for any complex or simple liquid, regardless of how "thick" or "thin" the liquid is, and regardless of how many or how few chemical components it may contain. It's very sensitive to changes in the liquid, which enables accurate process control.

The solution uses a range of advanced technologies that enable an Electro Magnetic Field (EMF) in Radio Frequency (RF) to be emitted into the liquid. Collo senses changes in the EMF and processes them digitally, transforming these changes into physical quantities.

The heart of Collo is the RF resonator developed in multiple university dr-level projects such as [4, 5] that emits a narrowband EMF into the liquid. The system sweeps through a frequency range creating a spectrum of the liquid's EM-response and calculates specific features from the spectrum in real-time. The generated EMF is a directional and short-range field. The used frequencies and emitted energy are harmless, like signals in standard telecommunication systems like mobile phones.



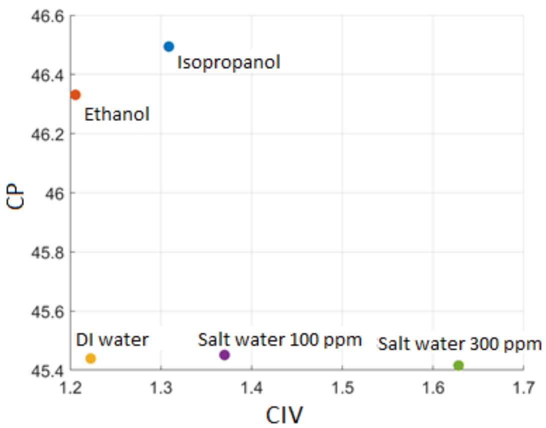
When EMF is injected into liquid, the field is distorted differently depending on the liquid. Different types of liquids have different spectra. Minute changes in a liquid's chemical or phase composition change the frequency response. Even subtle phase changes, such as small solid particles or oil micelles in the surrounding liquid, interact with the EMF. Collo recognizes these changes in its frequency response which is processed with Collo's proprietary algorithms to determine the fingerprint of a liquid and link it with liquid physical parameters.

1.1 Science behind Collo

The RF resonator, related electronics, and signals processing have been researched and developed for years. The principle behind the measurement is in the electromagnetic field that Collo emits in the liquid, and the field vibrates particles and molecules in the liquid. From this EMF, Collo measures parameters related to the dielectric constant, also known as relative permittivity.

The dielectric constant has two parts: The imaginary part of the dielectric constant is related to ion viscosity and loss tan and is strongly interlinked with the *dissolved chemical*. The real part of the dielectric constant is related to overall permittivity, which is strongly interlinked with specific physical properties of the substance, such as *separate phases*. In other words, the EMF carries a small amount of energy in the measured substance and some of it is transferred into the material; this depends on the different phases within the measuring field and Collo uses this for its analytics.

Based on the above, each substance can be characterized by its dielectric constant. If characteristics are known, a mixture ratio or changes in solid content can be measured by monitoring the dielectric constant. For example, sand has the real part of a dielectric constant close to 4, whereas water has 80. Should you mix sand and water with the ratio of 1:1 the overall constant would be roughly (80 + 4) / 2 = 42. Should you have different sand with another dielectric constant, you would also recognize that. In more detail, both components, the imaginary and real parts of the dielectric constant, depend on the field variation frequency. Consequently, more information can be obtained from a liquid when more than one measurement frequency is used.



1.2 What is a fingerprint of liquid

A liquid fingerprint is a set of parameters that identify the liquid. Collo's frequency response enables accurate detection of liquids.

For Collo to identify liquids correctly, it needs to be taught what the liquid is. When the liquid in the process consists of multiple components or has a "recipe,"

Collo can identify the relative concentrations and composition of the liquid, when it first knows the fingerprint of the individual components. After the teaching process, it can accurately measure the composition, detect changes in chemicals, and identify many features in solids and different phases.

The below figure shows a simple example of a fingerprint of five different liquids in 2 dimensions. When salt is added to water, the feature (CIV) linked with dissolved chemicals changes, whereas the permittivity (CP) changes when water is replaced with ethanol or isopropanol.

2 Collo compared to other technologies

Because Collo has an extensive range of applications, it is challenging to summarize how competing technologies differ for each specific application. In the following, we have collected a range of key features which make Collo stand out from the competition.

2.1 Classification of Collo: Inline, multi characteristic process analyzer

Collo provides clear benefits compared to offline analyzers, which can only be used in the lab with manual samples from the process. With offline analyzers, there is always a significant delay between taking the sample from the process and having the results at hand. During this time, several changes may have occurred in the process, which may require different process parameters. Wrong process parameters can lead to poor quality, wasted energy and materials, and suboptimal productivity as too much time can be spent in individual process steps. In addition, manual sampling and related measurement procedures such as sample diluting may alter the sample and lead to wrong conclusions.

Thus, process analyzers are used to get more timely information. Process analyzers are either inline or online analyzers, the main difference being that inline analyzers have sensors placed in the process. In contrast, online analyzers are connected to a process indirectly, for instance, as a side-stream measurement. In this terminology, **Collo is an inline analyzer, measuring directly from the process, in real-time, continuously.**

Process analyzers have different capabilities based on the technology they use. Process analyzers fall into two categories: *Single characteristic sensors* such as dissolved oxygen, chlorine, aluminum, ammonia, fluoride analyzers, and *multi characteristic sensors* like pH/ORP, conductivity, near-infrared, turbidity, liquid density, MLSS, TOC analyzers. Also, Collo belongs to this latter group with the key benefit that it has comprehensive capabilities in the multi characteristic space and the ability to distinguish between changes caused by phases or dissolved chemicals. The below table compares different process analyzers with Collo.

		Electrochemical	Optical	Electrical	EM-field
					
Example Companies	Collo	ThermoFisher AntonPaar ABB Endress+Hauser			Speag Keysight
Multivariable measurements	•••	••	••	•	•
Applicability to different liquids	•••	•	••	••	••
Measuring volume	•••	•	•	•	••
Durability	•••	••	••	•••	••
Maintenance/ calibration	•••	•	••	••	••
Process data analysis	•••	•	•	•	•

2.2 Recognition of different phases and chemicals

There are very few solutions that enable measuring such a wide range of properties that Collo can measure. Collo measures changes in chemicals and relative phase amounts. Collo measures these simultaneously and provides a comprehensive view of the type of changes occurring in the liquid process.

Collo can measure any phase mixed in liquid (solids, oils, gases). It can be used to recognize changes such as relative increase or decrease in the amount of one phase, change in dry mass or particle size, or it can be used to recognize phase reactions such as gelation, thixotropic reactions, agglomeration or sedimentation/homogenization of one phase.

The amount of, e.g., solids mixed in the liquid does not limit the measurement. Many solutions, such as turbidity sensors, work only with “thin” liquids with a low solids level. Collo has no concentration limits and works with thick liquid of any concentration between 0-100% solids.

Collo can also detect any change in the amount of a chemical in a liquid with high sensitivity, unlike single characteristics sensors. The sensitivity is typically in the PPM range but varies depending on the material. Variation is typically below PPM (e.g., 0.1 PPM) to 10 PPM. The sensitivity depends on how close the properties of the individual components (materials) are to each other in the liquid. Low sensitivity may cause issues for some multi characteristic sensors, such as capacitive sensors in some applications.

Collo’s sensitivity is more than sufficient for typical chemicals and solids applications. The most challenging applications are microbiological, such as bacteria, where research is still ongoing to determine how well Collo could perform in related applications.

2.3 Contactless technology makes Collo robust and low maintenance

RF waves travel through the air and other non-conducting surfaces. Thus, it is possible to measure liquids, for example, through a plastic container. The contactless feature has other benefits as well. Collo is non-sensitive to process material buildup, as we will discuss later.

Another key benefit of this feature is that the Collo sensor can be coated with any non-conducting material. This can be important, for example, in food-related applications, where the sensor can be coated with food-safe material.
Many sensors require frequent maintenance and have limitations in terms of erosive wear of particles in the liquid (like concrete, ceramic slurry, mud etc.)

Collo uses a robust sensor, and it does work under pressure and with abrasive materials. For example, the Collo probe has been installed in a ceramic slurry process where it has worked for more than a year in a row without maintenance.

Because of its contactless technology, Collo does not get blocked by the process material buildup. This is a common problem for many sensors using light-based technologies, but Collo is extremely low maintenance. It does not need to be pulled out of the process.

2.4 Insights with analytics, not just data

Many analyzers provide measurement data as an output, which in many cases requires know-how and training to make it valuable and actionable information for process control. Collo is a fully digital system and thus can be easily integrated with any automation system.

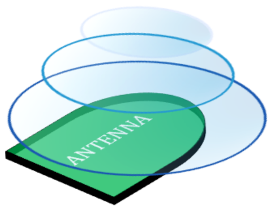
In terms of data delivery, our approach is service-oriented. Our team of experts works with customers to develop systems that provide understandable insights to process control personnel to help them adjust the process correctly and achieve maximum benefits.

Using artificial intelligence, Collo-system learns via user inputs and captures process data over time. A simple example of this is temperature compensation. Changes in liquid temperature also change the measured features, but Collo can learn to omit this. When installed into the customer's liquid process, Collo can be temperature compensated to remove the effect of temperature on the measurement.

2.5 Small size

Collo can fit into a small bag instead of requiring a truck container. The sensor head is the size of a 2-euro coin. Collo Inline can be fitted into pipes through a standard 2” flange. The sensor size is 180 x 55 mm. Collo Lab Analyzer can also be installed through a standard 2” flange, sensor head length 200 mm, width 39.5 mm and probe stem length can be tailored.

Sensor
Below is a schematic of Collo RF-sensor that creates the EM-field. The sensor is size of a coin. Similar sensor is used in all our solutions.



Collo Inline
Collo Inline can be connected to a pipe or vessel with DN 32/PN40 and DN50/PN40 inlet.

Collo Lab Analyzer
Collo Lab Analyzer is 39.5 mm wide and can be directly immersed into a process vessel.

3 Application examples

Below you can find some examples of how our customers use Collo technology. We have divided the examples by the two main components that Collo measure: relative changes in two non-mixing phases (e.g. solids, oils or gases in liquid) and changes in mixed chemicals.

1. **Relative changes in two non-mixing phases**
    a. Dry mass: The concentration level of solids in liquid is known as dry mass (the mass after all liquid is evaporated). Analysis of dry mass is a common measurement problem for many industries.
        i. Collo has been used to measure dry mass by identifying specific features from the data matrix that correlate with the dry mass in the ceramic slurry process and in vegetable puree process.
    b. Particle sizes: in many industrial processes, the particle size can change during processing.
        i. Collo has been used to measure particle sizes in lime-related applications when particle size is close to a micrometer.
    c. Sedimentation and homogenization: In some industrial applications the spatial place of solid mass needs to be measured. In some applications the solids need to stay homogeneously in the liquid, in others, it needs to be sedimented on the bottom.
        i. Two Collo sensors can be installed into different levels of the vessel to detect and measure the level or speed of sedimentation. We have applied this approach in minerals production and in one chemical solution.
        ii. Homogenization is important in nearly all mixing processes. Collo can measure and detect for example, the point when more mixing is no longer increasing homogeneity level, thus optimizing the time and energy used for mixing. Collo has been used for this purpose in paint manufacturing.
    d. Agglomeration: In some process's agglomeration, de-agglomeration or re-agglomeration is critical step in the process.
        i. Collo has been used for this purpose in a chemistry application where particle isoelectric point was studied
    e. Gelation: In the gelation process (e.g., sol-gel synthesis) particles form interlinks with each other. Being able to monitor the formation of these interlinks is very helpful.
        i. Collo is used in a medical application to monitor the gelation process.
    f. Thixotropy: thixotropy is a phenomenon where particles form loose contact with each other. Understanding the extent of this is essential, e.g., in paint and ceramics manufacturing.
        i. Collo is used in an industrial setup on ceramics production to measure thixotropy.
    g. Phases: In several chemical applications, material phases can change. For example, a solid can dissolve or chemical components can react and solidify.
        i. Collo has been used in various chemical syntheses to confirm the formation of solids or dissolving of solids.

h. Bubbles in liquid: In some applications it is important to confirm that the liquid does not contain bubbles or contains the right amount of bubbles.
    i. Collo has been used in an industrial setup to confirm no bubble exists in water and in another setup in pulp processing, it has been used to confirm the right amount of bubble formation.

2. Chemicals in liquids

a. Controlling and ensuring the correct chemical composition: Collo is very sensitive to changes in chemical composition it can be used to confirm and with automation devices added to control that a liquid has the right amount of selected chemical.
b. Detecting impurities or changes in liquid: Collo

3.1 Multivariable analysis with Artificial Intelligence for extremely complex liquids

Do you have a complex liquid? Do you struggle with the process? Don't know what's causing your problems? Collo utilizes artificial intelligence, which, when combined with other measurement data, can be used to identify the "x-factor" from your process that causes issues.

4 More information

Collo technology can offer significant benefits in various industries for optimizing liquid processes, and generating savings in improved quality, reduced materials and energy spending, increased productivity and liquid process automation.

Contact us to discuss how Collo can help you: sales@collo.fi

5 References

[1] J. Silvonen, N. Järvelä, M. Koppanen, M. Järveläinen, A. Ojuva and E. Levänen, "Online monitoring of polysaccharide solution concentration by electromagnetic field, electrical conductivity and spectrophotometry measurements.," *Chem. Pap. ,* vol. 75, p. 5885–5894, 2021.

[2] S. Zakeri, M. Järveläinen and E. Levänen, "In-line monitoring of ceramic resins used in stereolithography via high-frequency dielectric analysis," *OSA Optical Sensors and Sensing,* 2021.

[3] T. Salpavaara, M. Järveläinen, S. Seppälä, T. Yli-Hallila, J. Verho, M. Vilkko and E. Levänen, "Passive resonance sensor based method for monitoring particle suspensions," *Sensors & Actuators: B. Chemical.,* vol. 219, p. 324–330, 2015.

[4] T. Salpavaara, Inductively Coupled Passive Resonance Sensors: Readout Methods and Applications, vol. Publication 1524, Tampere: Tampere University of Technology, 2018.

[5] M. Järveläinen, Towards In Situ Methods for Characterization of Porous Materials, Tampere: Tampere University of Technology, 2016.