Fast and reliable measurement modules for advanced narrow-band sensing applications in the millimeter wave domain

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Process analytic instruments are used in many domains of industry (pharma, food, cosmetics, biotech…) to monitor real-time inline industrial processes. Some benchmark studies on the stability of colloidal particles in a suspension, show that the mm-W sensor in [1] is 1000 time more sensitive than conventional IR and Raman instruments. Likewise, mm-W sensor can be used for liquid phase composition analysis, for the drug formulation, etc. Many industrial production companies as end user of mm-W sensor technology would benefit from it by improving product quality and production yield.

The sensor design is based on a special filters and resonators defined by their resonance frequency which shifts in terms of amplitude and frequency when the permittivity of the material under test (MUT) is varying. Such sensor requires fine-tuning in order to maximize the sensitivity of the sensor in regard to the permittivity change. The hardware zero-function (HZF) aims an automation of this procedure. In order to obtain the sharpest filter or resonator response, the response of the sensor should converge to zero. In terms of impedance, the fine-tuning should match the reference impedance of the receiver, i.e. the millimeter-wave vector analyzer (MVNA). Therefore, 2 gradient descent algorithms with 2 degrees of freedom were introduced tackling the situations where only the magnitude is known and where the magnitude and the phase are known. Having both information on the phase and the magnitude enhanced the speed and ensured the convergence to the global minimum of the HZF. However, due to hardware constraints, only the magnitude could be used leading to instability of the algorithm. In the first solution, the influence of the 2 degrees of freedom can be mapped on a Smith chart as a coordinate moving around a circle and a shift of the circle center. Hence, the decisions are taken to bring the circle crossing and the coordinate on the circle converging to the center of the Smith chart. In the second solution, less information on distance in between the coordinate of the sensor response and the center of the Smith chart is given. That algorithm doesn't provide convergence in every case. Nevertheless, for the applications targeted, the parameters of the algorithm are designed to avoid any sticking in a local minimum for a specific MUT. The phase-and-magnitude and magnitude-only algorithms converge in respectively an average of 100 and 400 steps. Each steps last around 0.5s, hence *50 sec* and 6 *min* 40 *sec* respectively.

The future work for the improvement of the sensor will be the compensation of drift and instabilities such that one can distinguish the sensor output variations induced by changes of the sample under test from fouling phenomena and spectral and thermal drifts of the sensor system. This can be partially achieved first by tight control of the temperature of the whole system.

With the enhancement of the sensor cited in the previous paragraphs, the mm-W sensor will be able to measure concentrations in a 1000 times smaller liquid volume than most advanced micro-volume concentration measurement instruments (e.g. Nanodrop). Therefore, pharmaceutical laboratories would benefit from mm-W sensor technology by having a novel measurement technique that would enable to perform measurements with higher sensitivity, on a smaller volume in addition to being label-free, immobilization-free, real-time, etc.

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REFERENCES

[1] J. Stiens and al., "Change detection in (bio)chemical liquids with ultrasensitive label-free and immobilization-free sensors operating the GHz-THz range," in *4th International Symposium on Sensor Science*, July 2015.