An integrated OEM and retrofit Spray quality monitor system for agricultural Sprayers

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Abstract

Increasing demand for effective Spray application due to cost and environmental concerns pose pressure on optimization of spray application. Spray quality is to be understood as the degree to which a set of inherent characteristics of the spray fulfils requirements. Previously real-time automated in-process spray quality monitoring of sprayers with a multitude of nozzles has practically not been possible. A new system solution for measurement and assessment of spray quality is being presented.

The sensor technology assessing spray quality is based on continous wave Doppler Radar measuring movement related spray characteristics. The integral information is aggregated in a Radar signature in the frequency domain – the Power Spectral Density PSD. The Spray quality assessment is based on evaluating the deviation of the actual Radar signature of the spray of one nozzle from a reference Radar signature – the actual average signature of all nozzles of the respective subset of nozzles of a sprayer.

Basics

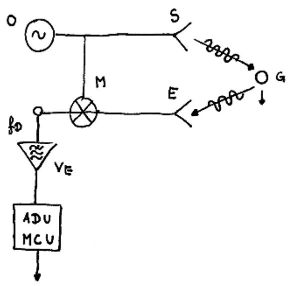

Fig. 1: Doppler Radar

The CW **c**ontinuous **w**ave radar includes a mixer M which mixes the transmitted signal O, f_O and the received signal f_S and outputs the resulting low-frequency oscillation signal f_D, the so called beat frequency. The frequency $f_D = |f_O - f_S|$ of the mixed signal output is proportional to the speed v of the moving reflector G. The speed of light c_O is constant and the angle α refers to the angle of attack between the radar system and the measured object. Consequently,

$$f_D = 2 \cdot f_O \cdot \frac{v}{c_O} \cdot \cos(\alpha)$$

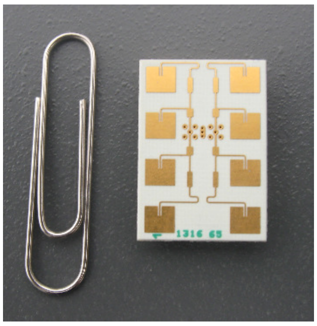

Fig. 2: Radar Frontend

The 24 GHz CW Doppler Radar Frontend deployed for the SprayMon is a small MMIC **m**onolithic **m**icrowave **i**ntegrated **c**ircuit based surface-mounted device with patch array antenna (see Fig. 2). Its antenna diagram (see Fig. 3) shows large opening angles in azimuth and elevation. The working principle of this Radar can be thought of as being one large camera pixel containing a wealth of information.

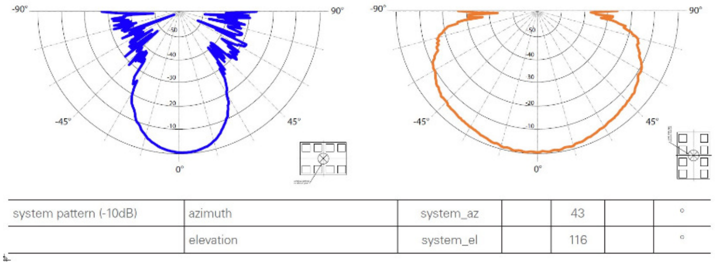

Fig. 3: Antenna diagram of the Radar

Further, the amplitude of the beat signal f_D is proportional to the reflected power according to the so-called radar equation

$$\frac{P_e}{P_s} = \frac{g^2 \cdot \lambda^2 \cdot \sigma}{(4\Pi) \cdot D^4}$$

with P_e being the power of the received signal, P_s being the power of the transmitted signal, λ being the wavelength of the transmitted signal, σ being the radar cross-section of the reflecting object(s), D being the distance between the radar sensor and the reflecting object, and g being the antenna gain in case of a common transmit and receive antenna.

In the measurement setup, the transmission power P_s, the wavelength λ of the transmitted signal, the distance D of the radar sensor to the object and the antenna gain g are constant. The power P_e of the received signal and thus the power of the oscillating mixed signal after mixing the transmitted and received signals, i.e. the amplitude of the beat signal f_D, is therefore proportional to the radar cross section (RCS) σ of the spray which varies with the particle size distribution and the volume flow of the spray.

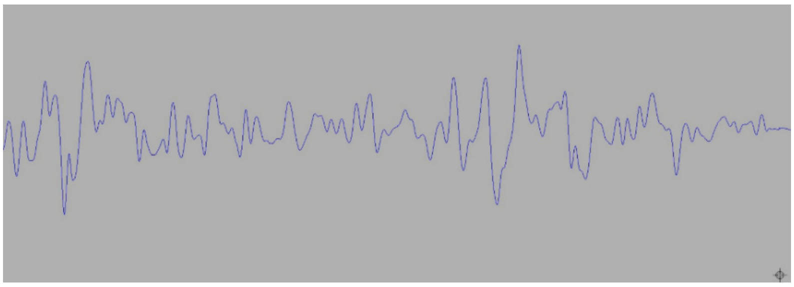

Fig. 4: Excerpt of a beat signal record in the time domain

The beat signal (see Fig. 4) is sampled and stored in a data array and transformed from the time domain into the frequency domain by FFT **F**ast **F**ourier **T**ransform.

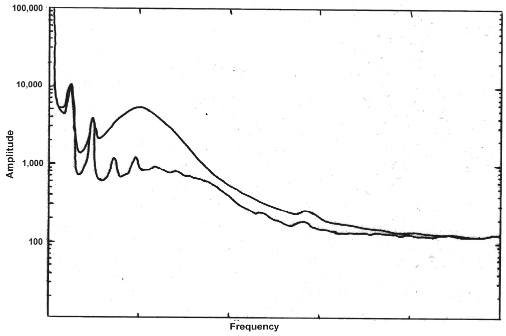

Fig. 5: Spray Radar signatures

The FFT – the **P**ower **S**pectral **D**ensity PSD of the Doppler Radar signal f_D is deployed as the Radar signature characterizing the spray quality.
Exemplary Fig. 5 shows the huge difference (Note: Amplitude is log-scaled) of Spray Signatures of a Teejet TP8001 SS flat spray nozzle known good (upper curve) and with a needled tip inserted (lower curve).

For the SprayMon application the system is calibrated / tared under known good condition so the same nozzles (of a subset) do have the same Radar signature output level. While spraying the average Radar signature of all same nozzles is computed and compared to the Radar signature of the one nozzle being evaluated at the same time by means of a distance parameter.
Summarizing the method and procedure for detecting, characterizing and assessment of the quality of the spray [1, 2]:

- a CW Radar Frontend
- transmits a Radio frequency signal towards the spray
- receiving the signal reflected from the spray
- having Doppler shifted Frequencies.
- Send and receive signal are mixed resulting in the low frequency so called beat signal
- which is transformed in the frequency domain resulting in a power density spectrum
- representing the Radar signature
- characterizing the quality of the spray.
- The quality is being assessed by the distance of the given Radar signature of the spray from the average of all signatures of the same nozzle subset.

System

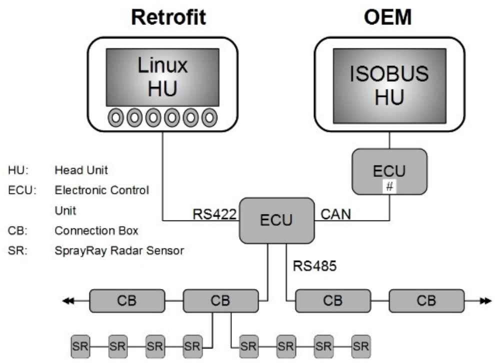

Fig. 6: SprayMon OEM & retrofit system

Functional components of retrofit and OEM SprayMon Systems (see Fig. 6) are:

- CW Doppler Radar (see Fig. 2) modules SR (see Fig. 7) with analogue interface

- multi-plexed in daisy-chain to CB connection boxes with integrated digital signal processing and enumeration and subset grouping functions,

- flexible number of CB connection boxes covering the spray from nozzles over partial or full boom length daisy-chained to a

- master ECU module which does interface either

- via RS422 fieldbus to a MSO Linux on-board computer head unit (see Fig. 8) with proprietary protocol and monitoring software (see Fig. 9) or

- via CAN bus e.g. with an ISOBUS ECU.

Fig. 7: SprayRay sensors on boom

Fig. 8: MSO SprayMon head unit

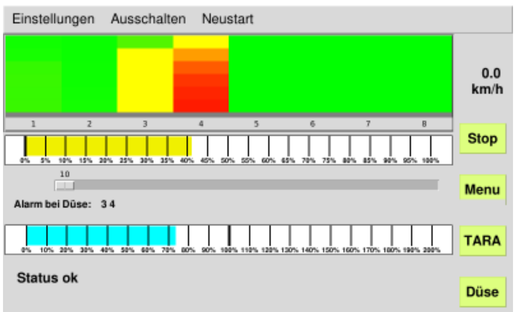

Fig. 9: SprayMon software main screen

The MSO SprayMon spray monitoring software implemented on a Linux touch-screen on-board computer (see Fig. 9) features a waterfall diagram with colour-coded degree of quality of the spray of every nozzle over time, a slide-control for setting the alarm threshold by the operator, a bargraph showing the actual maximum deviation and a bargraph showing the actual total throughput percentage compared to the throughput when tared (see Fig. 9). It provides for functions for grouping subsets of same nozzles, diagnosis of CAN messages and storing and recalling different configuration setups.

OEM Implementation

In joint cooperation with a major agricultural sprayer OEM „Horsch Leeb AS GmbH" an integrated system solution has been implemented. Primarily the solution is targeted towards monitoring the spray of the nozzles in the area being invisible for the operator behind the tank of the sprayer. The system can be scaled up to monitor all nozzles of the sprayer.

The protocol handling the bi-directional communication is basically derived from SAE J1939 with a different set of parameter groups specifically implemented in close cooperation for and by the OEM customer Horsch Leeb AS GmbH.

The implementation in a specific control / head unit application is reaping the benefits of additional information from the superordinate control system e.g. nozzle pulse width modulation, nozzle switching patterns, turn compensation, section control part-width switching etc.

Summary

A new system method, system solution and implementation for in-process measurement and assessment of spray quality for sprayers is described. Improvement of spray application quality, reliability and safety has been achieved.

[1] Europäisches Patentamt Anmeldung 17190505.2

[2] United States Patent Application Pub.No.: US 2019/0049559 A1