Real-time Detection and Reconfiguration of Sensors in Agricultural Sprayers Subject to Failures

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Apresentation topics

Introduction

Introduction

- The application of pesticides in agriculture is crucial to increase food production and pest control. However, improper application results in high costs and environmental and human health risks.
- Currently, the importance of innovations in technologies to improve reliability in agricultural spraying systems is recognized.
- A precise flow application allows to reduce the production costs, as it ensure that the correct amount in applied in the crop, while efficient pressure control aids in the quality of application.
- The correct flow and pressure control and the accuracy in the spray rate help to minimize loss and optimize the use of resources.
- Therefore, it is essential to ensure proper functioning of the instrument responsible for monitoring the flow and the pressure of the syrup (mixture of the quimical active component plus water). Any failure in these components can result in the improper application of pesticides, increasing the risk of contamination in neighboring areas and loss of product due to over-application or under-application.

Introduction

Recent works have been developed to create fault-tolerant systems in hydraulic components.

- In [1], a method is presented for analyzing the reliability and failure of agricultural sprayers using smart sensors, a microcontroller, and a controller area network protocol.
- Bayesian convolutional neural networks are employed in [2] to predict the lifespan of solenoid valves,
- In [3], an active Sensor-Fault-Tolerant Controller (SFTC) is proposed for an independent metering control system, capable of tolerating faults in input, output, and feed pressure sensors using analytic redundancy.
- A real-time fault diagnostic method for hydraulic systems is proposed in [4] using data from multiple sensors.

[1] P. E. Cruvinel, H. V. Mercaldi, P. B. Andrade, and E. A. Pen aloza, “Real-time evaluation of failure and reliability in agricultural sprayers using embedded sensors and controller area bus protocol,” International Journal on Advances in Systems and Measurements, vol. 13, pp. 161– 174, 2020

[2] G. Mazaev, G. Crevecoeur, and S. Van Hoecke, “Bayesian convolutional neural networks for remaining useful life prognostics of solenoid valves with uncertainty estimations,” IEEE Transactions on Industrial Infor- matics, vol. 17, no. 12, pp. 8418–8428, 2021.

[3] R. Ding, M. Cheng, S. Zheng, and B. Xu, “Sensor-fault-tolerant operation for the independent metering control system,” IEEE/ASME Transactions on Mechatronics, vol. 26, no. 5, pp. 2558–2569, 2020.

[4] H. Tao, P. Jia, X. Wang, and L. Wang, “Real-time fault diagnosis for hydraulic system based on multi-sensor convolutional neural network,” Sensors, vol. 24, no. 2, pp. 353–374, 2024.

Introduction

This paper presents a real-time strategy for faults analyzing, when using a flow and pressure sensors. Additionally, a sensor-based method for reconfiguring the control loop using the fluidic resistance is proposed.

- The results demonstrate the effectiveness of this approach considering a signal pressure sensor when the flow meter fails, ensuring reliability and avoiding interruption of the agricultural spraying process.

Detection and reconfiguration strategy

Detection and reconfiguration strategy

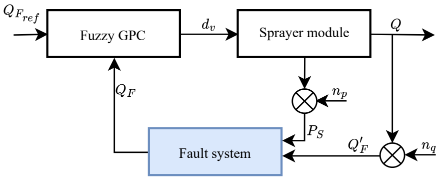

Figura 1: Block diagram of the arraignment for fault evaluation and reconfiguration system.

- P_S → Pressure;
- Q → Flow;
- $Q_{F_{ref}}$ → Flow reference;
- d_v → Control signal;
- Q_F → Flow signal;
- n_p and n_q → Noises;

$$
\begin{aligned}
n_q &= Q'_F \cdot 0.05 \cdot rand \\
n_p &= P_S \cdot 0.05 \cdot rand
\end{aligned}
\quad (1)
$$

with *rand* used to generate random numbers from a continuous uniform distribution in the range [0, 1].

Failure assessment

- The assessment of possible failure occurs by comparing the Root Mean Square Error (RMSE) index with a threshold I_f defined by the **designer through a priori knowledge**.
- If the RMSE deviation exceeds this threshold, the system identifies the occurrence of a failure.

The calculation of RMSE is given by:

$$RMSE = \sqrt{\left(Q_{PS} - Q_F'\right)^2} \tag{2}$$

where Q_F' is the reading value of the flowmeter and Q_{PS} is the estimated flow valuated considering the pressure P_S and the fluidic resistance K_t:

$$Q_{PS} = \sqrt{\frac{P_S}{K_t}}. \tag{3}$$

Evaluation of failure

Algorithm 1 evaluates the flow signal Q'_F from the flowmeter and adjusts the closed-loop if a fail is detected. In this case, the control variable becomes to be estimated by the flow Q_{PS}, derived from the pressure sensor signal P_S.

Algorithm 1 Evaluation of failure

Input: Reading from the pressure sensor (P_S), reading from the flowmeter (Q'_F), fault threshold defined by the designer (l_f).
Output: Flow (Q_F)
Initialize
$Q_{PS} \leftarrow \sqrt{\frac{P_S}{K_t}}$ (3)
$RMSE \leftarrow \sqrt{(Q_{PS} - Q'_F)^2}$ (2)
$Q_F \leftarrow Q'_F$
if $RMSE > l_f$ **then**
    Failure alarm for the operator.
    $Q_F \leftarrow Q_{PS}$;
end if
Return:Q_F

K_t identification

The hydraulic relationship for the spraying system operating under turbulent flow regime is given by:

$$\Delta P_S = Q^2 \, K_t \tag{4}$$

where K_t, P_S, and Q are, respectively, the fluid resistance, the pressure, and the flow of the spraying system.

- It has become feasible to estimate the flow of the system through pressure readings, also in both directions [1].

[1] R. F. Magossi, E. A. Pe naloza, S. P. Battachharya, V. A. Oliveira, and P. E. Cruvinel, "Emulating a sensor for the measurements of the hydraulic resistances of nozzles in agricultural sprayers based on the use of the point-wise thévenin's theorem," International Journal on Advances in Systems and Measurements, vol. 10, no. 3-4, pp. 184–193, 2017

K_t identification

- To find the fluid resistance, an open-loop experiment was conducted on the SPDA using 2 bars with 7 MagnoJet® M063/1 CH06 nozzles on each bar.

Starting from an initial condition, with the valve V_{P1} fully open ($\theta_{vp} = 0$) and with a PWM signal duty cycle $d_v = 0$ for 2 seconds, $d_v = 70$ is applied for 7 seconds, closing the return of Valve V_{P1}. Then, $d_v = 0$ is applied for 7 seconds, keeping it stationary. Finally, $d_v = -100$ is applied for 7 seconds, opening the return of V_{P1}.

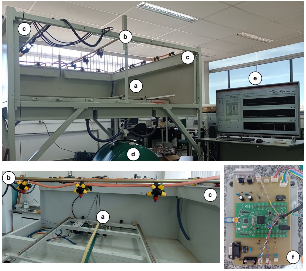

Figura 2: Agricultural Sprayer Development System (SPDA): (a) system that simulates the movement of the sprayer, (b) spray bars, (c) gutter for agrochemical, (d) agrochemical dumping tank, (e) user interface, (f) board STM32F407-Discovery.

K_t identification

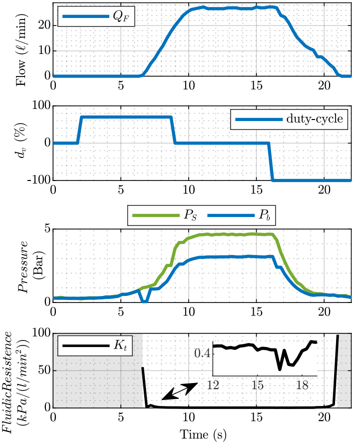

Figura 3: Open-loop experiment for obtaining the fluid resistance K_t.

- It can observe that at average operating point of the proportional valve $\theta_{vp} = 80$ rad [1], the fluid resistance behaves linearly, thus it can be approximated to an average value of $K_t = 0.41$.
- In the highlighted segments from 0 to 6.3 s and from 21 to 22 s, since the flow was null the fluid resistances were indeterminate.

[1] K. R. Felizardo, H. V. Mercaldi, P. E. Cruvinel, V. A. Oliveira, and B. L. Steward, "Modeling and model validation of a chemical injection sprayer system," Applied Engineering in Agriculture, vol. 32, no. 3, pp. 285–297, 2016.

Simulation results

Simulation results

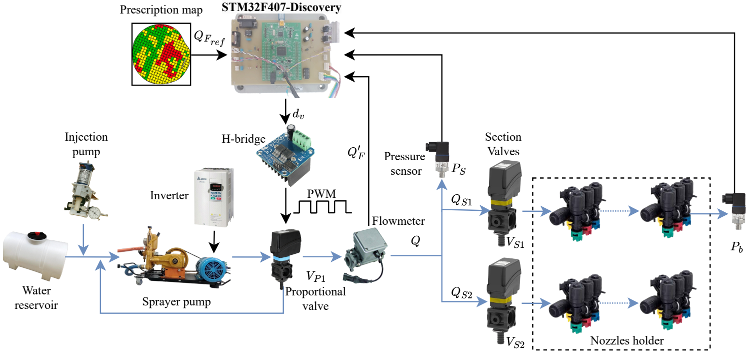

Figura 4: Sprayer module diagram of SPDA.

Simulation results

- For simulation it has been used the MatLab® software to control a proportional valve V_{P1} in a spraying module.

For the simulation procedure, it is considered the following conditions:

1. The pressure sensor is operational and it is not subject to failures.
2. The sensor fail occurs at the intermediate operating point of the system, when its fluid resistance can be represented by an average value.

In the **first simulation test**, a **total loss fault** of the flowmeter signal was introduced, while in the **second simulation test**, **random gain faults were added** using the *rand* function of MatLab®. Both faults were implemented between the intervals of 105 and 183 s.

Simulation results

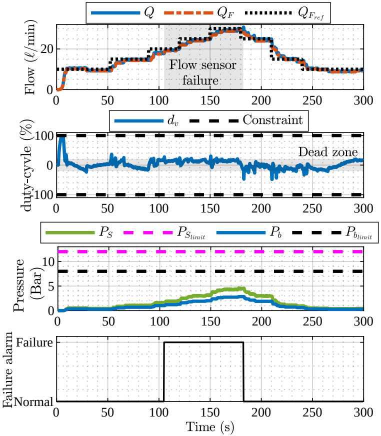

Figura 5: Simulation for total loss of flowmeter signal.

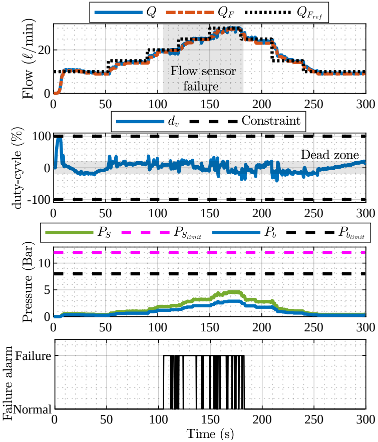

Figura 6: Simulation for gain failure in the flowmeter signal.

Simulation results

Analyzing the results, it was observed that despite the flowmeter failures, **the system successfully detected them and reconfigured itself in a closed-loop fashion using the pressure sensor**. The change between sensors during the operation, after the observed fail, occurred without significative signal losses, leading to a **robust operation**.

Experimental results

Experimental results

The fuzzy GPC described in [1] and the fault analysis and reconfiguration system were embedded using a STM32F407-Discovery and the C# language.

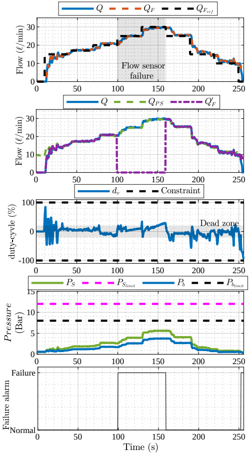

Figura 7: Flow responses of the sprayer operating with M063/1 CH06 nozzle for a stair reference.

- 7 M063/1 CH06 nozzle nozzles spaced at a distance of 50 cm;
- Working speed equal to 10 km/h;
- Spray pump flow rate equal to 40 l/min;
- Failure occurred in the flowmeter signal between 99s and 163s.

Points where the flow reaches zero, corresponding to **when the return of proportional valve is fully open**, the estimated flow Q_{Ps} was great than zero, **indicating a false positive fault**. This occurs due to the fact that the pressure sensor model A-10 from Wika® **presents a deviation in its signal when occurred absence of flow**.

Experimental results

- The results confirm the opportunity to exchange the sensors during the operation, which **improved reliability**, as well as the practical and experimental effectiveness of using fuzzy GPC control in conjunction with the analysis and **reconfiguration system for flow control**.

- By understanding the fluid resistance at the average operating point of the proportional valve V_{P1}, **it is feasible to identify the fault**, **communicate it to the operator** and **reconfigure the control loop** using the pressure sensor.

Conclusion

Conclusion

- In this work, a **sensors based-method was shown to aggregate value and robustness to agriculture sprayers**. The **opportunity to exchange sensors in agriculture sprayer during the operation showed reliability improvement**. Results obtained by simulations were confirm using real data considering variations in flow and pressure in a sprayer bar.

- **The use of fluidic resistance has proven promising in the control loop reconfiguration strategy** through pressure sensor, preventing interruptions in the spraying process caused by flowmeter failures. Additionally, the utilization of the STM32F407 Discovery has been found to be ideal for embedded implementation

- As a perspective for future work, it is being consider methods for obtaining fluidic resistance in real time.

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THANK YOU!!!

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