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Reducing the Dead Zone Time effect of Actuators in Sensor-Based Agricultural Sprayers under S-shaped Functions Gain Scheduling Management of a Generalized Predictive Control (GPC) Strategy

Deniver Reinke Schutz
Vilma A. Oliveira
Paulo E. Cruvinel

Embrapa Instrumentation
University of São Paulo

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Apresentation topics

Introduction

Introduction

- Pesticide application is essential for food production but involves risks to health, ecosystems, and high costs.
- Technological innovations aim to reduce these risks and costs while improving spraying system reliability.

Traditional pesticide application using agricultural sprayers is typically uniform across fields, regardless of spatial variations in pest and disease density, often leading to inefficiencies such as over- or under-application.

Introduction

Effective flow rate and pressure control ensures optimal droplet size and distribution, enhancing spray effectiveness. Together, these factors help minimize resource waste, improve efficiency, and support sustainable farming practices.

The reliability of flowmeters, pressure sensors, and proportional valves in spraying systems is crucial. Failures in these components can cause over- or under-application of pesticides, leading to:

- Higher costs,
- Environmental harm,
- Compromised pest control, and
- Increased risk of ecosystem contamination through drift or runoff.

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Introduction

From an automatic control perspective overshoot and positive steady-state error can cause **overapplication**, leading to wasted inputs, higher costs, and environmental harm. Conversely, long rise time and negative steady-state error may result in **underapplication**, reducing treatment effectiveness and harming crop health.

In fact, the regulation of flow rate and pressure in agricultural sprayers are predominantly achieved using linear controllers.

- Proportional-Integral-Derivative (PID) controllers
- Generalized Predictive Control (GPC)

Advanced control strategies, such as adaptive algorithms, can significantly improve the reliability and adaptability of sprayer systems, enabling them to respond effectively to changing field conditions and enhancing overall application accuracy.

- Artificial Neural Networks (ANNs) to introduce non-linearities into GPC strategies.
- Adaptive GPC controller using discrete-time fuzzy model for parameter scheduling.

Introduction

This research work, a study is presented replacing a fuzzy logic based GPC by a sigmoid function to simplify gain scheduling and reduce the time processing required for the adaptive parameters.

- The stability analysis is presented.
- A sensitivity function analysis is also conducted to determine boundary values for λ and δ to satisfy robustness conditions against noise and disturbances.

- **As a new technology, such intelligent control and topology allow to increase quality and efficiency of the application of pesticides by agricultural sprayers.**

S-shaped function based GPC Strategy

Strategy

The developed S-shaped function based GPC strategy incorporates a gain scheduling stage for the cost weighting parameter λ, to update the matrix of the standard GPC.

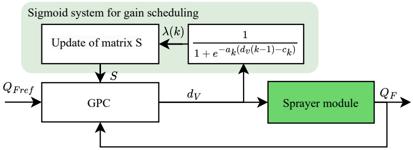


Figura 1: Adaptive GPC with λ scheduling via a sigmoid function, based on the last control signal *dv*.

The proposed sigmoid-based GPC is formulated as the following optimization problem:

$$\min_{\Delta u(k+i),\, i=0,1,\cdots} J(\Delta u, r, y) =$$

$$\sum_{i=1}^{N_p} \delta \| \vec{r}(k) - \vec{y}(k) \|_2^2 + \sum_{i=1}^{N_c} \hat{\lambda}(k) \| \Delta \vec{u}(k-1) \|_2^2 \quad ($$

subject to

$$C \Delta \vec{u}(k-1) \leq r_t$$

$$\forall\ \lambda(k) = \lambda_{min} + (\lambda_{max} - \lambda_{min}) \cdot f(u(k-1))$$

The function $f(u(k-1))$ represents the output of a sigmoid function, resulting values between zero and one that span the range between λ_{min} and λ_{max}, depending on the previous control input

S-shaped function

Dynamically adjust the weighting parameter $\lambda(k)$ to improve controller performance, particularly in dead-zone regions.

Within the dead zone:

- Smaller values of $\lambda(k)$ are applied.
- This leads to larger control increments $\Delta u(k)$.
- Facilitates driving the control signal d_v out of the dead zone.

Outside the dead zone:

- Larger values of $\lambda(k)$ are used
- Reduces unnecessary control effort and enhances system stability.

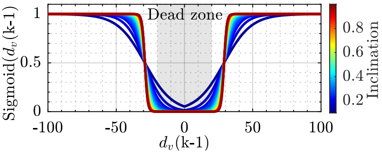


Figura 2: Proposed sigmoid S-shaped function with different inclinations.

$$f(d_v(k-1), a_k, c_k) = \frac{1}{1 + e^{-a_k(d_v(k-1)-c_k)}} \tag{2}$$

where the parameter a_k determines the inclination or spread of the transition region, while c_k specifies the midpoint of the sigmoid region.

Sensitivity analysis

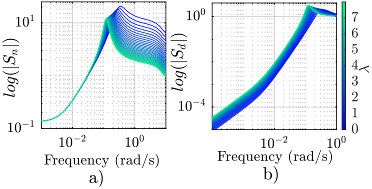


Figura 3: Sensitivity analysis curves for noise a) and disturbance b) with variable λ

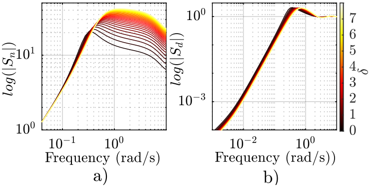


Figura 4: Sensitivity analysis curves for noise a) and disturbance b) with variable δ

- **Sensitivity Analysis of λ and δ**
- **Varying λ ($\delta = 1$):**
  - Increasing $\lambda \Rightarrow$ decreases S_n (improves noise robustness)
  - Increasing $\lambda \Rightarrow$ increases S_d (worsens disturbance rejection)
  - Trade-off between noise suppression and disturbance rejection
- **Varying δ ($\lambda = 1$):**
  - Decreasing $\delta \Rightarrow$ increases S_n (less noise robustness)
  - Increasing $\delta \Rightarrow$ decreases S_d (better disturbance rejection)
  - Trade-off between aggressive and conservative control
- **Key Insight:**
  - λ and δ exhibit opposing effects
  - Careful tuning is required
  - Gain scheduling is recommended for robust performance

Simulation and Results

Simulation

Simulate and compare the performance of Sigmoid-based GPC, Fuzzy GPC, and conventional GPC for controlling a proportional valve in a sprayer module.

Controller Settings:

- GPC: $N_p = 20$, $N_c = 4$, $\lambda = 1$, $\delta = 5$
- Fuzzy GPC: adaptive λ via fuzzy system
- Sigmoid GPC: adaptive λ via sigmoid function ($c_k = 16$, $a_k = 0.4$, $\lambda_{min} = 0$, $\lambda_{max} = 5$)

Simulation Setup:

- Two bars, 7 MagnoJet® nozzles each
- Step reference based on four different nozzle types
- Input constraint: $-100 < dv(k) < 100$ (PWM duty cycle)
- GPAD method used for constraint handling

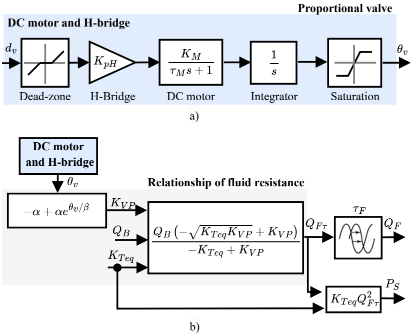


Figura 5: Block diagram of the sprayer module

Results

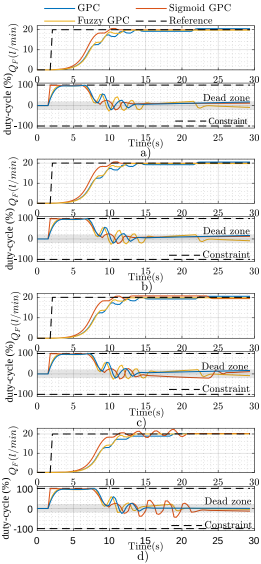
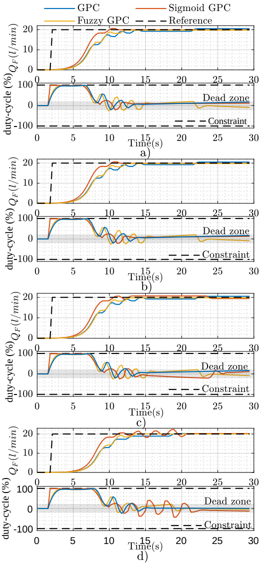


Tabela 1: Performance of the controllers with different nozzles

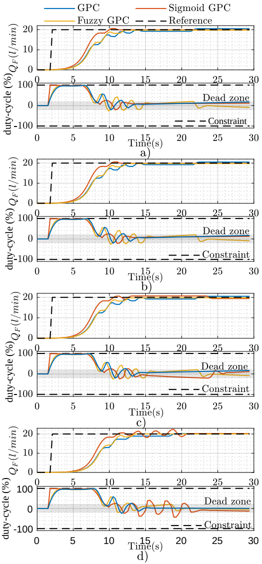
Controller	IAE (l/min)	OS (l/min)	Rise time (s)
	CH06		
GPC	2.11	0.51	11.1
SGPC	1.61	0.62	8.4
FGPC	1.96	0.51	8.6
	CH03		
GPC	2.22	0.6	11.4
SGPC	1.73	0.51	8.4
FGPC	2.00	2.00	9.9
	CH01		
GPC	2.22	0.6	11.4
SGPC	2.00	0.61	8.5
FGPC	2.17	0.51	9.9
	CH0.5		
GPC	2.48	0.2	12.7
SGPC	2.18	2.4	9.6
FGPC	2.31	0.1	11.1

Results



- **Sigmoid-based GPC Performance:**
  - Shorter rise time and lower steady-state error in most simulations
  - Oscillations observed for CH0.5 nozzle (Figure 8 d) between 10-22 s
- **Fuzzy GPC Performance:**
  - Moderate performance, balancing IAE and OS
  - In CH03, FGPC shows high OS (2.0 l/min) despite reducing IAE by 10.4% compared to GPC

Results



- **IAE and Rise Time::**
  - SGPC outperforms GPC and FGPC in IAE and rise time
  - For CH06 nozzle: SGPC reduces IAE by 23.7% and rise time by 8.4 s (vs. 11.1 s for GPC and 8.6 s for FGPC)
  - SGPC also reduces IAE by 10.8% for CH01, maintaining comparable rise time
- **Overshoot (OS):**
  - SGPC exhibits higher OS in some cases (e.g., CH05, 2.4 l/min vs. 0.1 l/min for FGPC)
  - Indicates a trade-off between error minimization and transient response smoothness

Conclusion

Conclusion

- The sigmoid function ensures continuity and differentiability of the system, particularly around the dead zone region, enabling smooth transitions and improved adaptability in system behavior.
- Sigmoid-based GPC improves system response and effectively handles dead zone nonlinearities.
- Sigmoid function enables bounded parameter scheduling, facilitating stability analysis.
- Sensitivity analysis assists in determining suitable bounds for GPC parameters under noise and disturbances.
- Demonstrated practical effectiveness: reduced actuator wear and minimized errors due to abrupt reference changes.
- Future work: embedded implementation of sigmoid-based GPC with lower complexity and faster processing than fuzzy logic.
- Suitable for real-time applications in resource-constrained environments.

A Model Based Intelligent Sensor to Control Sprinklers in Spray Actions

THANK YOU!!!

Deniver R. Schutz: deniver@usp.br
Vilma A. Oliveira: voliveira@usp.br
Paulo E. Cruvinel: paulo.cruvinel@embrapa.br