Digital State Validation of Reed Switch Signals in Discrete Control Systems: A Simulation-Based Assessment

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Abstract: Reed-switch-based converters are widely used in digital discrete control systems, but unstable switching conditions may reduce event-recognition reliability within digital signal-processing chains. This paper presents a control-oriented modeling and simulation-based assessment of a reed-switch-based converter with temporal digital state validation for more reliable output-state formation. The proposed approach integrates the electromechanical switching element with signal conditioning, digital state validation, and output-state generation for more reliable event interpretation. A discrete-state model with four operating states was developed to distinguish stable switching events from transient and unstable signal changes. The validation logic was examined using event-based logical simulation over 100 repeated switching cycles with a 10 ms validation interval. Under the adopted scenario-based simulation conditions, temporal validation reduced unstable transitions from 14 to 3 per 100 cycles and improved stable event recognition from 86% to 97%, while introducing a fixed 10 ms processing delay. These findings provide preliminary evidence that digital state validation may improve output-state stability and false-trigger resistance in reed-switch-based discrete control applications; however, experimental and metrological verification remains future work.

1 INTRODUCTION

Reed switch-based devices continue to attract attention in discrete control systems because of their galvanic isolation, structural simplicity, low power consumption, and stable operation under harsh environmental conditions. Compared with conventional open-contact switching elements, reed switches provide sealed contact operation, reduced sensitivity to contamination, and satisfactory durability in applications requiring repeated switching and stable electrical response [1]-[4]. These characteristics make them suitable for monitoring, relay logic, protection, and compact automation units used in industrial environments [5]-[7]. Modeling-based assessment has also been applied in transport-related engineering studies to quantify operational processes and support reliability-oriented analysis [8].

Modern digital discrete control systems require not only reliable switching elements but also accurate signal interpretation, stable event detection, and resistance to false triggering [9]-[12]. Although earlier reed-switch studies mainly focused on device design, materials, coatings, and magnetic characteristics, less attention has been paid to the control-oriented modeling of reed-switch signals within digital processing chains [1]-[7], [13]-[15]. At the same time, software debouncing, event filtering, and fault-aware signal interpretation are becoming increasingly important in automation and monitoring systems [9], [11], [12]. Therefore, the problem of validated event recognition in reed-switch-based control units remains relevant for practical discrete control applications.

In this context, the present study considers a reed switch-based converter not only as an electromechanical switching element, but also as a functional component of a digital discrete control system. The focus is placed on control-oriented modeling of converter operation, digital state validation, and functional assessment of output-state stability under repeated switching conditions. Special attention is given to switching stability, response consistency, and suppression of undesirable transient events that may reduce the quality of control-signal interpretation [9], [11], [16].

The aim of this paper is to develop and assess a control-oriented approach for digital validation of reed-switch signals in discrete control systems. The proposed method is intended to improve event recognition reliability within a digital signal-processing chain under unstable switching conditions.

The main contributions of this study are as follows:

1) A four-state control-oriented model is proposed for reed-switch signal interpretation in discrete control systems.
2) A temporal digital validation procedure is introduced to suppress unstable transitions and false triggering.
3) A scenario-based event simulation framework is used for repeated switching assessment.
4) The effect of validation is quantified in terms of unstable transitions, stable event recognition, false triggering probability, and response delay.

Scientific novelty of the study lies in the formalization of reed-switch behavior as a four-state control-oriented model, the integration of temporal digital validation into the signal-processing chain, and the comparative scenario-based assessment of raw and validated output behavior under unstable switching conditions. Unlike prior studies focused mainly on reed-switch design and material properties, the present work addresses event-recognition stability in digital discrete control systems [9], [11], [16].

2 MATERIALS AND METHODS

The study considers a reed-switch-based converter as a functional element of a digital discrete control system intended for stable event detection and reliable switching-state transmission. The proposed approach evaluates the converter within a control-oriented framework including signal acquisition, switching-state processing, digital validation, and reliability-related assessment.

2.1 Structure of the Reed Switch-Based Converter

The investigated converter includes a reed switch, a magnetic actuation source, a signal-conditioning stage, a digital processing unit, and an output interface. In the proposed control chain, the reed switch generates the raw discrete signal, the conditioning stage suppresses input disturbances, and the digital unit validates the event before output-state generation. The general operating structure is represented as follows: Magnetic actuation → Reed switch → Signal conditioning → Digital state validation → Output signal generation → Monitoring/logging. The overall architecture is shown in Figure 1.

2.2 Principle of Operation

The converter operates by changing the reed-switch contact state under external magnetic actuation. The resulting raw input is processed by the digital unit rather than accepted directly as a valid control event, because repeated operation, vibration, or unstable actuation may generate transient switching effects. Therefore, the converter operates in two interconnected domains: the electromechanical domain, where physical switching occurs, and the digital domain, where the raw signal is validated and transformed into a stable control output.

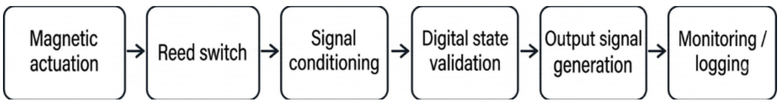

Figure 1: Block diagram of the reed switch-based converter for digital discrete control systems.

2.3 Modeling Approach

The converter behavior was modeled as a discrete-state system defined by the current input condition and the validated output state. Four states were considered for functional assessment: State 0 - no actuation; State 1 - switching detected, validation in progress; State 2 - stable confirmed actuation; State 3 - unstable transition. The state-transition logic was defined as follows: S0 → S1 when a change in the raw input is detected; S1 → S2 when the input remains stable during the validation interval tv; S1 → S3 when oscillation or instability is detected during validation; S3 → S0 when the transient event is rejected; and S2 → S0 when release is confirmed after stable return of the input signal. In the present study, tv = 10 ms. The model was implemented as an event-based logical simulation under repeated switching conditions. The state-transition logic is illustrated in Figure 2.

2.3.1 Simulation Scenarios and Metric Definition

The functional assessment was performed using predefined event-based input scenarios relevant to discrete control and signal-validation tasks [9], [11], [12]. Four scenario groups were considered: nominal actuation, short-term oscillatory switching, weak magnetic actuation, and disturbance-related input fluctuation. For each scenario, the same intended switching event was first analyzed at the raw signal level and then re-evaluated after digital validation. The model used binary input-state sequences and the same validation interval for all scenarios. A total of 100 repeated switching cycles were analyzed. For each cycle, the output was classified as confirmed, rejected, or unstable. Stable event recognition was defined as the ratio of correctly confirmed events to the total number of intended switching events, while false triggering probability was defined as the ratio of incorrectly confirmed events to the total number of cycles. The scenario set is summarized in Table 1.

2.3.2 Simulation Assumptions and Implementation Settings

The simulation was implemented as a deterministic event-based logical model using binary input-state sequences. The model did not include full electromechanical dynamics, material degradation, temperature drift, or long-term wear effects; therefore, the results should be interpreted as a functional assessment of validation logic rather than as a complete physical model of reed-switch behavior.

2.4 Digital State Validation Procedure

To improve switching reliability, the raw reed-switch signal was processed using a temporal validation algorithm intended to distinguish stable events from short-term transient changes caused by contact bounce, vibration, or electromagnetic interference. The logic included detection of raw-state change, activation of the validation interval, repeated signal checking, and confirmation or rejection of the transition. The corresponding validation logic is shown in Algorithm 1.

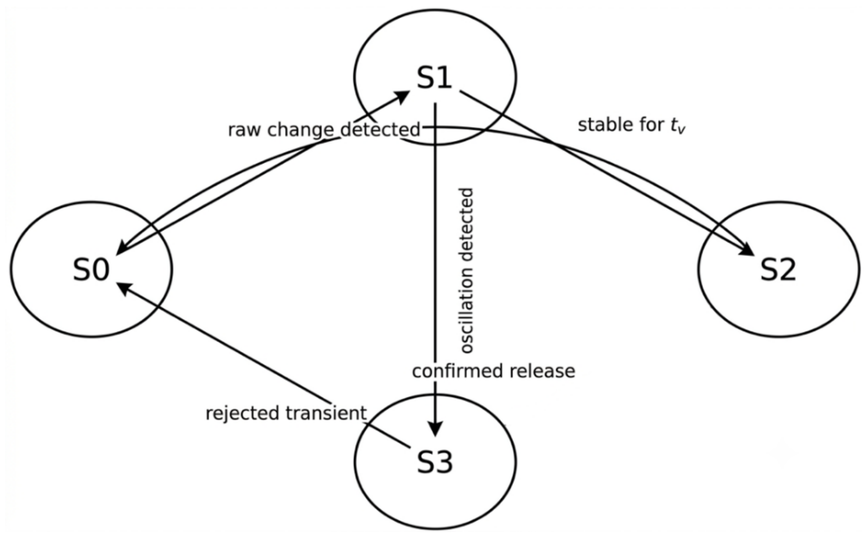

Figure 2: State-transition diagram of the proposed converter model.

Table 1: Simulation scenario set used in the study.

Scenario ID	Scenario description	Raw input behavior	Expected validated behavior	Main purpose
S1	Nominal actuation	Single stable binary transition without oscillation	Confirmed event after validation interval	Baseline case for correct switching recognition
S2	Contact bounce / short oscillation	Multiple short-term toggles after initial switching	Rejection of unstable pulses or delayed confirmation after stabilization	Evaluation of debouncing capability
S3	Weak magnetic actuation	Incomplete, inconsistent, or unstable switching change	Classification as unstable or rejection of non-persistent transition	Assessment of robustness under uncertain actuation
S4	Disturbance-related fluctuation	Noise-like transient input changes caused by vibration or external disturbance	Rejection of false transitions	Evaluation of false-trigger resistance

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If raw_state ≠ stable_state:
    start timer tv
    monitor input during tv
    if input remains unchanged:
        confirm output_state
    else:
        reject transition
        classify event as unstable
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Algorithm 1: Digital state validation logic.

This procedure follows the general principles of software-based debouncing, event filtering, and fault-aware signal interpretation used in digital control and sensor systems [9], [11], [12]. In the present study, the validation interval was set to 10 ms. The confirmation sequence is illustrated in Figure 3, and a representative timing example is shown in Figure 4.

An example of the raw and validated signal behavior with a 10 ms validation interval is shown in Figure 4.

2.5 Reliability-Related Evaluation Criteria

The reliability-related assessment was limited to digital event-interpretation performance rather than full physical or metrological characterization of the reed-switch device. The main quantitative indicators were unstable transitions per 100 cycles, stable event recognition, false triggering probability, and validation-induced response delay. These criteria are consistent with reliability-oriented interpretation in control, monitoring, and diagnostic systems [10]-[12].

3 RESULTS AND DISCUSSION

3.1 Simulation Results and Practical Interpretation

Representative raw and validated signal behavior is shown in Figure 4, while the aggregated comparative results are summarized in Table 2.

The results presented in Table 2 correspond to a scenario-based logical simulation and should be interpreted as model-level evidence of the effect of temporal validation under predefined switching conditions rather than as experimental performance data.

Under nominal actuation, the converter produced a stable output with only minor transient effects. However, under repeated switching, weak magnetic influence, or disturbance-related scenarios, the raw reed switch signal showed short-term oscillations and uncertain intermediate transitions that could degrade event recognition quality. After applying digital state validation, these unstable input changes were either rejected or delayed until confirmation, which improved event recognition reliability and reduced false triggering. The main quantitative effect of this validation procedure is summarized in Table 2.

The values presented in Table 2 were obtained from an event-based logical simulation of 100 repeated switching cycles under identical input scenarios. The comparison was performed between the raw reed switch signal and the validated output signal using a 10 ms validation interval.

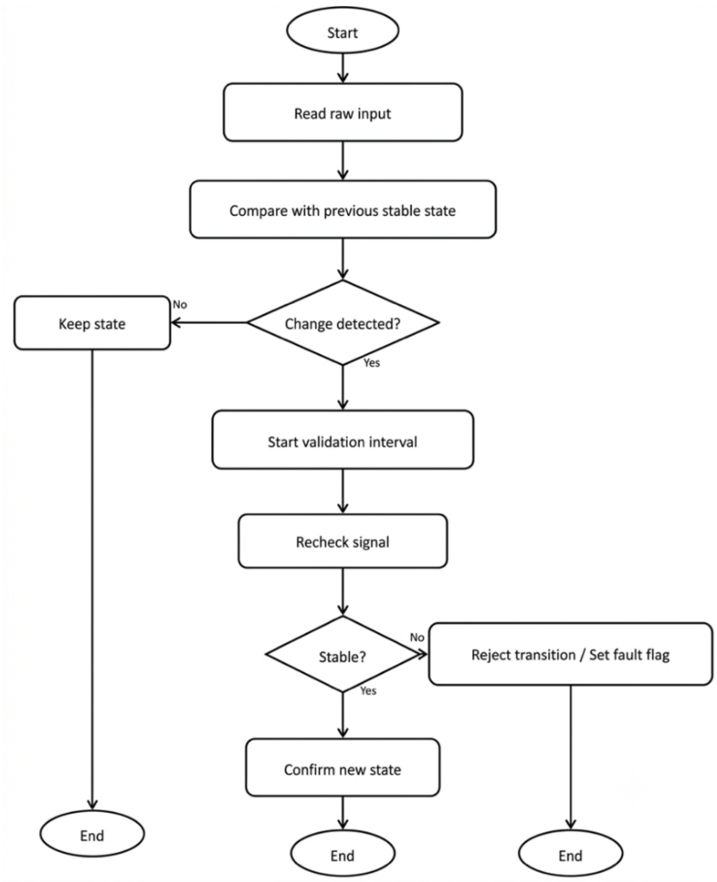

Figure 3: Flowchart of the digital state validation procedure used for switching-event confirmation.

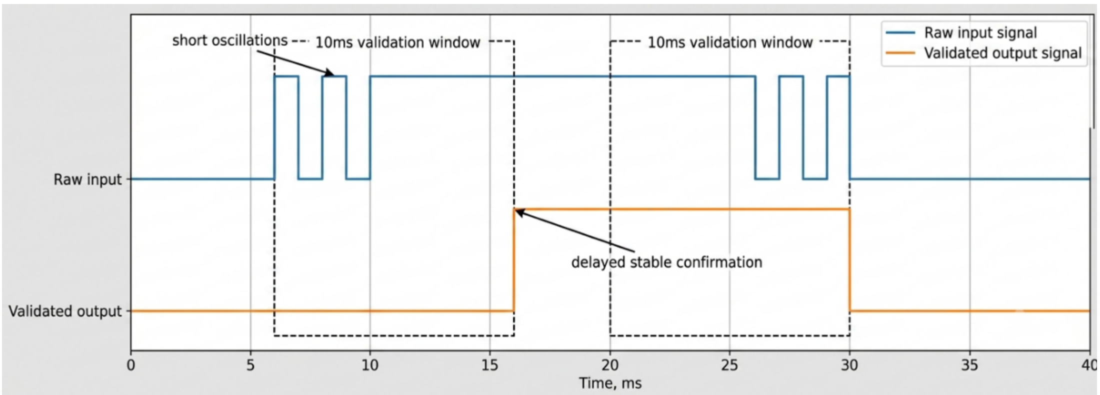

Figure 4: Representative timing diagram illustrating raw signal instability and digital validation of switching events with a 10 ms validation interval.

Table 2: Simulation-based comparative evaluation of converter operation before and after digital state validation.

Evaluation criterion	Without digital validation	With digital validation	Observed effect
Unstable transitions per 100 cycles	14	3	Reduced by 78.6%
Stable event recognition	86%	97%	Improved
False triggering probability	0.14	0.03	Lower
Response delay	0 ms	10 ms	Acceptable
Practical control stability	Moderate	High	Improved

Under these adopted simulation conditions, the number of unstable transitions decreased from 14 to 3 per 100 cycles, which corresponds to a 78.6% reduction. At the same time, stable event recognition increased from 86% to 97%, and false triggering probability decreased from 0.14 to 0.03. These results indicate that temporal validation can significantly improve the reliability of output-state formation when the raw input contains short-duration oscillations or disturbance-related changes.

From a practical viewpoint, the reduction in unstable transitions is important for relay-type, interlocking, event-registration, and discrete monitoring applications, where even a short false transition may trigger an incorrect control response or produce an erroneous event log. The increase in stable event recognition indicates that the proposed validation logic improves the consistency of command interpretation rather than the intrinsic switching physics of the reed element.

From the control-system viewpoint, the proposed approach improves signal interpretation and output-state consistency rather than the intrinsic physical properties of the reed switch. In the validated mode, unstable transitions are suppressed or rejected, which supports more reliable event confirmation in discrete automation tasks.

The adopted 10 ms validation interval represents the main trade-off of the proposed method. On the one hand, this delay reduces the probability of accepting short unstable transitions as valid switching events. On the other hand, it introduces a fixed response delay before final state confirmation. For many discrete monitoring, protection, relay, event registration, and interlocking tasks, such a delay may be acceptable because correctness of state recognition is more important than an immediate raw transition. However, in high-speed real-time control loops, a 10 ms delay may become restrictive. Therefore, the validation interval should be treated as an application-dependent design parameter rather than as a universal constant for all reed-switch-based control devices. Accordingly, the proposed validation logic is more suitable for low- and medium-speed discrete control tasks than for high-speed closed-loop control applications requiring near-immediate state confirmation.

The obtained results also help position the study more clearly with respect to earlier research. Many previous studies of reed switches focus mainly on structural design, fabrication technology, coatings, magnetic characteristics, or application-specific use of switching elements [1]-[7], [13]-[17]. In contrast, the present work addresses a different problem level, namely control-oriented interpretation of reed switch behavior within a digital discrete control system [9]-[12]. Thus, the contribution of this study lies not in structural redesign of the reed sensor itself, but in the formalization and preliminary assessment of a temporal validation strategy for improving event recognition stability under unstable switching scenarios.

3.2 Study Limitations

The present results should be interpreted within several limitations. First, the assessment was based on event-driven logical simulation rather than hardware testing. Second, the study did not quantify switching-time dispersion, actuation and release thresholds, hysteresis, or long-term cycling durability. Third, the adopted 10 ms validation interval was assessed only within the selected scenario set and should not be generalized to all reed-switch applications. Therefore, the reported findings should be interpreted as preliminary functional evidence of the usefulness of temporal digital validation rather than as a complete hardware-level or metrological characterization of the converter.

4 CONCLUSIONS

This study presented a control-oriented simulation-based assessment of digital state validation for reed-switch signals in discrete control systems. Under the adopted simulation conditions, the proposed validation logic reduced unstable transitions from 14 to 3 per 100 switching cycles and increased stable event recognition from 86% to 97%, while introducing a fixed 10 ms response delay.

These findings should be interpreted as preliminary functional evidence of the usefulness of temporal digital validation in discrete control applications where correct event recognition is more important than immediate raw-state transmission. At the same time, the present work remains limited to logical simulation and does not yet include full hardware-level or metrological verification.

Future work should include oscilloscope-based signal analysis, switching-time measurement, actuation and release threshold evaluation, hysteresis assessment, repeated cycling tests, and experimental validation under practical operating conditions.

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