Robust Power-Event Detection for Automated Testing of Situation-Aware Edge Devices

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Abstract—A situation-aware embedded device assesses situations based on multiple sensor inputs and performs automated response functions such as power cutoff or auxiliary-power transfer. Automated testing of these functions requires consistent detection of the start and end points of power events in measured waveforms. However, selecting the first sample that satisfies a fixed threshold condition may identify an incorrect event interval because of brief voltage dips, noise, and near-threshold conditions. Auxiliary-power transfer also requires consideration of the event order between channels. This paper proposes a power-event detection method that combines an adaptive threshold based on the waveform baseline and variability, a persistence condition, and an event-ordering condition. In the Drop test, the method excludes a leading dip and selects the sustained-fall interval. In the Recovery test, the transfer is considered complete only when the auxiliary power crosses the threshold upward after a sustained fall of the main power and remains at or above the threshold for the required hold time. Evaluation on measured waveforms showed that the proposed method selected event intervals that matched the reference criteria, including cases in which the baseline method misidentified event points. These results indicate that the proposed method can reduce premature and out-of-order detections in automated power-event timing. Beyond device-level testing, the method supports pre-integration verification of autonomous power responses in sensor and edge nodes deployed in networked ICT systems.

Index Terms—situation-aware embedded devices, power event detection, automated testing, edge-device verification, industrial IoT

I. Introduction

A multi-sensor embedded system integrates multiple sensor inputs to identify surrounding conditions or specific events and performs predefined functions accordingly [1]. In this paper, a system that performs such sensor-based situation assessment and automated response functions is referred to as a situation-aware embedded device, whose response functions may include power cutoff and auxiliary-power transfer. Sensor and edge nodes with these functions are used in networked industrial, smart-energy, and communication infrastructure, where an incorrect assessment of a power response can conceal whether a node satisfies its required response and recovery behavior. Repeatable device-level verification of power-event timing is therefore required before these nodes are integrated into broader ICT systems. Voltage dips and short interruptions are a recognized concern in equipment immunity testing [2], although the procedure considered here is a device-level functional test rather than a standardized immunity test. Verifying these operations requires consistent determination of the Drop and Recovery durations from measured waveforms. Conventional waveform timing measurements define transition instants using reference-level crossings [3]. In the fixed-threshold implementation used for comparison, the transition is located at the first sample that satisfies the threshold condition. This selection, however, may fall earlier than the actual sustained transition when the waveform contains brief dips or noise. In addition, when the normal baseline voltage is close to the threshold, the capture boundary may be selected as the start point. In a Recovery test, failure to verify the event order between the main-power fall and the auxiliary-power rise may cause an invalid transition to be classified as a valid Recovery event.

To reduce such misdetection, this paper proposes a power-event detection method that combines an adaptive threshold based on robust median and median absolute deviation (MAD) estimation [4], a persistence condition, and an event-ordering condition. In the Drop test, the method excludes a brief leading dip and selects the sustained-fall interval. In the Recovery test, a transfer is considered valid only when the auxiliary power crosses the recovery threshold upward from a low state after a sustained fall of the main power and remains high for the required hold time. This study presents a device-level analysis procedure that combines robust threshold adaptation, persistence checking, and cross-channel event ordering, using a fixed parameter set for each power-response test type.

II. Proposed Power Event Analysis Method

A. Common Preprocessing and Baseline Estimation

The baseline voltage B_c of channel c is estimated as the median over an initial reference window at the beginning of the captured waveform. This median-based estimate is less sensitive to isolated transients and a limited number of event-affected samples within the window. The final steady-state voltage S_A of the auxiliary-power channel A, used for Recovery-duration detection, is estimated as the median over a final reference window. The variability σ_c of the initial reference window is computed as a MAD-based robust noise estimate [4]. Here, $c \in \{P, A\}$, where P and A denote the main-power and auxiliary-power channels, respectively. The persistence condition is converted into a consecutive-sample condition based on the configured hold time and the measurement sampling interval.

B. Drop Time Detection

The baseline method defines the Drop start point as the first sample that satisfies a preset fixed voltage-change condition relative to the baseline. Consequently, a brief voltage dip or transient noise may be misidentified as the onset of an actual power fall.

The proposed method determines the adaptive voltage-drop margin required for fall detection using the channel baseline voltage B_P and the variability σ_P of the initial reference window. This margin is the larger of a preset minimum voltage change and a noise-based term derived from

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the variability, preventing the detection threshold from becoming excessively sensitive when the noise level is low. The proposed method detects the Drop start point as follows. The Drop start threshold is defined as the baseline voltage minus the adaptive voltage-drop margin. The start of the first interval in which the voltage remains at or below this threshold for at least the configured hold time is selected as the Drop start point. Thus, a leading dip occurring in a single sample or over a short interval is excluded from the start-point candidates. The Drop end point is defined as the start of the first interval in which the voltage remains at or below a predefined operating limit for at least the configured hold time. The Drop duration is the time difference between the start and end points.

C. *Auxiliary-Power Transfer (Recovery) Time Detection*

The baseline method selects, as the Recovery start point, the first sample at which channel P and channel A simultaneously fall below their respective preset start thresholds. The end point is determined as the first sample, after the start point, at which channel A exceeds a preset end threshold. However, if both channels satisfy the start condition from the very first sample of the measured data, the capture boundary can be incorrectly selected as the start point.

The Recovery start point is determined by applying the Drop start-point detection procedure described in Section II-B to channel P. The recovery threshold of auxiliary-power channel A is defined relative to the baseline voltage B_A by taking the larger of a voltage-rise margin based on the variability σ_A of the initial reference window and a voltage-rise margin based on the full swing from the baseline voltage to the final steady-state voltage S_A. This approach suppresses misdetection of minor fluctuations in low-noise waveforms while preventing an excessively low threshold that does not adequately reflect the full transition size in waveforms with a large voltage swing. The recovery-threshold margin is lower-bounded by a preset minimum voltage change. After a sustained fall of the main power is detected, the Recovery end point is defined as the first upward crossing of the recovery threshold by the auxiliary-power channel, provided that the channel was previously in the low state and remains in the high state for at least the configured hold time. The end point must occur strictly after the start point; if the two are detected at the same sample, the transition is not accepted as a valid Recovery event. The Recovery duration is the time difference between the start and end points.

If no valid upward crossing is detected, no Recovery duration is produced. The low-state precondition and the hold-time requirement exclude cases in which the auxiliary-power channel is already in the high state before the start and prevent a brief rising or falling noise spike from being treated as a valid transition.

III. Experiments and Results

A. *Measurement Setup and Data Composition*

Voltage waveforms were measured using the analog inputs of a Saleae Logic 8 at 1.25 MS/s, corresponding to a sampling interval of 0.8 µs [5]. The Drop and Recovery tests used a falling condition on the power channel and a rising condition on the auxiliary-power channel, respectively, as hardware triggers. Table I summarizes the evaluation data.

TABLE I. Evaluation Data Composition

Category	No. of waveforms	**Characteristics**
Drop	16	Includes 6 with a brief leading dip
Auxiliary-power transfer	6	Includes 3 with baseline voltage near the fixed start threshold
Invalid-event input	9	No sustained event or order violation
Abnormal voltage	3	Out-of-range voltage

B. *Comparison and Evaluation Criteria*

For both the Drop and Recovery tests, the baseline method was compared with the proposed method. For each test type, a single parameter set was fixed for the final batch analysis and applied to every waveform of that type without per-waveform adjustment. For the Drop test, the reference start point was manually identified from the original waveform as the onset of the sustained voltage fall. For the Recovery test, the auxiliary-channel hardware rising trigger was used as the reference end point, while the start point was manually identified from the original main-power waveform. The Drop end point was determined for both methods using the common operating-limit and hold-time criterion defined in Section II-B. Invalid-event inputs were defined as waveforms with no sustained transition or with an event-order violation. Three additional waveforms observed during device testing, in which the measured voltage fell outside the expected operating range, were evaluated separately as abnormal-voltage cases. These references are functional criteria for identifying misdetection rather than independently measured ground truth; therefore, the evaluation compares the selected intervals and whether a valid duration was produced.

C. *Results*

Fig. 1 illustrates the Drop start-point difference and the ordering of the proposed end point, hardware trigger, and baseline end point during the auxiliary-power rise. In 6 of the 16 valid Drop waveforms, the baseline method selected a brief dip preceding the sustained fall as the start point. Accordingly, the baseline method yielded a longer Drop duration in these waveforms than that obtained from the manually identified sustained-fall onset. The proposed method excluded the leading dip and selected the sustained-fall interval in these 6 waveforms; it selected the same valid start and end intervals in the remaining 10. Because both methods used the same end-point criterion, the difference in Drop duration resulted from their start-point selection.

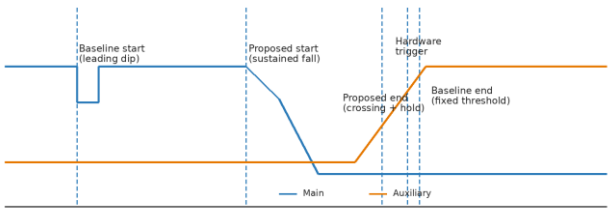

Fig. 1. Conceptual comparison of Drop start-point and Recovery end-point detection (synthetic and not to scale).

In the Recovery test, the normal baseline state already satisfied the start-threshold condition of the baseline method in 3 of the 6 valid waveforms, so the capture boundary was selected as the start point. The baseline method produced a positive Recovery duration in all 6 waveforms, but only 3 matched the reference criterion. The proposed method

matched the reference criterion in all 6. The mean absolute end-point difference from the hardware rising trigger was reduced from 17.2 sample intervals for the baseline method to 1.5 sample intervals for the proposed method. The baseline deviation exceeded 10 sample intervals in all 6 waveforms, whereas all proposed-method deviations were within 1–2 sample intervals. These values indicate agreement between the two detection times rather than absolute timing accuracy, since the hardware rising trigger is itself defined by a configured threshold condition.

Both methods rejected all 9 invalid-event inputs, indicating that the added conditions preserved the baseline rejection behavior. In a supplementary set of 3 abnormal-voltage captures, the baseline method falsely accepted one Recovery waveform, whereas the proposed method rejected all 3. Owing to the small sample size, this result should be interpreted as supplementary evidence. Table II summarizes the comparison results.

TABLE II. COMPARISON OF THE BASELINE AND PROPOSED METHODS

Evaluation Item	Baseline Method	Proposed Method
Drop sustained-fall interval selected	10/16	16/16
Recovery event matching the reference criterion	3/6	6/6
Mean absolute Recovery end point–trigger difference (sample intervals)	17.2	1.5
Valid-duration output for invalid-event inputs	0/9	0/9
False acceptance for abnormal-voltage cases	1/3	0/3

IV. CONCLUSION

This paper presented an analysis procedure that combines an adaptive threshold, a persistence condition, and an event-ordering condition to detect power-cutoff (Drop) and auxiliary-power-transfer (Recovery) durations. The proposed method improved reference-consistent detection from 10/16 to 16/16 in the Drop test and from 3/6 to 6/6 in the Recovery test, while reducing the mean absolute Recovery end-point difference from the hardware rising trigger from 17.2 to 1.5 sample intervals. Both methods rejected all 9 invalid-event inputs. In the supplementary set of 3 abnormal-voltage captures, the baseline method falsely accepted one Recovery waveform, whereas the proposed method rejected all 3; this small set should not be interpreted as a general robustness result. Although the evaluation was conducted at the device level, the procedure is applicable to pre-integration verification of autonomous power-response functions in sensor and edge nodes used in networked industrial and ICT services. Because this case study used a limited set of measured waveforms, future work will compare the method against hysteresis-based, filtering-based, and hold-time-augmented fixed-threshold detectors, include an ablation of the individual conditions, and extend the evaluation to a broader range of devices and operating conditions.

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