Analysis of Critical Scientific Software

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Outline

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   - Testing for Trapezoidal Input
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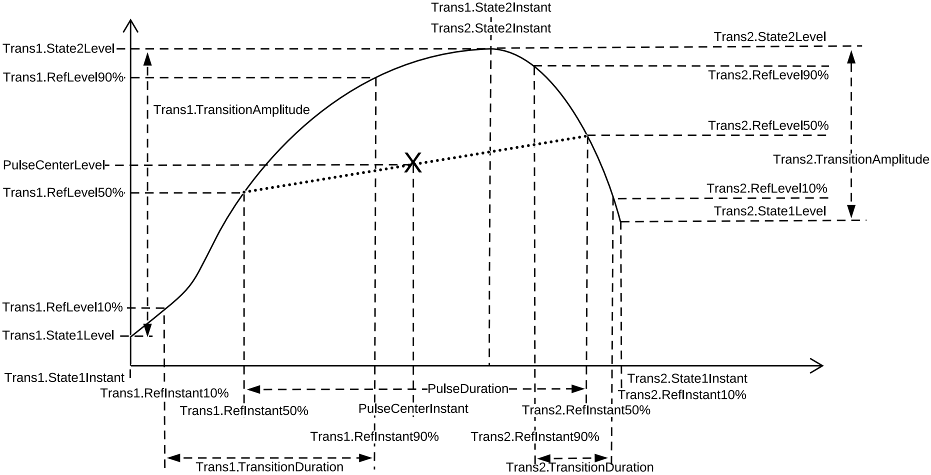
Goal

- An industrial partner in need of FDA certification for a medical device.
- We were provided with a Matlab function from the software for a blood pressure cuff.
- Goal: identify approaches aimed at increasing confidence in code.

Context

- A reading of a blood pressure cuff is decomposed into waveforms.
- Waveforms are input to the Matlab function.
- The function calculates parameters of a pulse as defined by *the IEEE Standard on Transitions, Pulses, and Related Waveforms IEEE Standard 181:2003.*
- Code is about 100 lines long and scarcely commented.
- Besides the code, we were provided with 5 sample pulses.

IEEE Points for Pulse



Proposed Approaches

- Requirements specification,
- Basic testing of the function for a specific input: trapezoidal signal,
- Investigate noise robustness,
- Interval analysis,
- Static analysis,
- Contracts.

SRS

- Requirements for the function were poorly documented as comments in the code.
- Benefits of SRS: better communication, needed for assessment of software vs requirements, basis for testing, basis for future changes.

Proposed Template

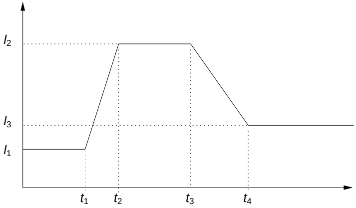
1. Introduction
    - Purpose of the Document
    - Scope of the Software Product
    - Terminology Definition
    - Organization of the Document
2. General Software Description
    - Software Context
    - User Characteristics
    - Software Constraints
3. Specific Software Description
    - Goal Statement
    - Data Definitions
    - Assumptions
    - Theoretical Model
    - Non-Functional Requirements
4. Software Validation Plan

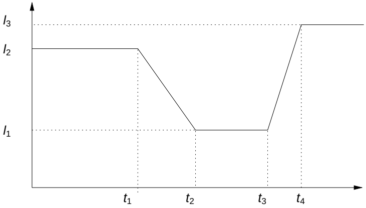
Example Assumptions

1. The signal consists of two single transition waveforms.
2. The first transition is positive-going.
3. The second transition is negative-going.
4. A given reference level may intersect with the signal at multiple points. Between multiple instants select, the one that occurs closest to the low, or first, state instant.
5. There are at least 3 sampled data points.
6. The sampling frequency is high enough to avoid aliasing.

Trapezoidal input

- Easy to calculate what to test against.





Inputting trapezoidal signals

- Tested negative pulse: returns NaN or incorrect.
- Tested some special signals: constant, the number of samples is 1 or 2, or there is only one transition, etc.
- For positive trapezoidal pulse, the IEEE parameters expressed in a simple closed form match those calculated by the code.

Findings

- To summarize, the code calculates what is supposed to under certain assumptions:
    - The number of samples is greater than 2,
    - The signal consists of two transition waveforms, where the first transition is positive-going, and second transition is negative-going.

Adding Noise

- If a noise is added to a signal, what happens to calculated parameters?
- The white Gaussian noise was added to sample signals provided.
- The noise with signal-to-noise ratio of 40dB was added using Matlab's function awgn.

Findings

- Even weak noise can make some parameters vary substantially.

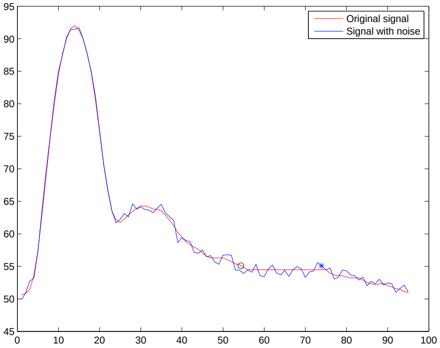


Figure: For one of the provided samples, the point corresponding to 10% reference level of the negative-going transition shifts from the one marked with a circle to the one marked with an asterisk.

What is Interval Analysis?

- Useful when uncertainties are present.
- Assume that value of a measured quantity is in interval **x**.
- Intervals are propagated through computations using interval arithmetics, e.g.:

$$\mathbf{x} \circ \mathbf{y} = \{x \circ y | x \in \mathbf{y}, y \in \mathbf{y}\}, \qquad \circ \in \{+, -, *, /\},$$
$$0 \notin \mathbf{y} \text{ for } \circ = /$$

- Allows for investigation of division by zero: if 0 is not in a calculated range for the divisor, it is a proof that the divisor cannot be 0.
- Tools: INTLAB, a Matlab toolbox.

Uncertainties

- Interval arithmetics can be used for noise robustness analysis.
- Assume that, for each sample at t_i, the interval for the magnitude of pulse at t_i is $\mathbf{p_i}$.
- Propagate interval computations to IEEE parameters.
- Find ranges for 10%, 50%, and 90% reference values, and ranges for corresponding instances.
- The analysis found the same noise sensitivity of some parameters as classical noise robustness analysis presented earlier.

Static Code Analysis

- No static analysis tools for Matlab (showing e.g., index out of bounds, null dereferencing, etc.).
- Converting to C did not work out.

Specification in Eiffel

- Contracts describe each component's expectations and guarantees.
- Assertions: preconditions, postconditions, and invariants.
- Rewrote the Matlab code in Eiffel in a straightforward manner.
- Signal validity conditions are given as preconditions, while postconditions and invariants are derived from IEEE 181.

Testing with Eiffel

- Assertions can be evaluated at run time.
- AutoTest, an automatic software testing tool for Eiffel.
- For one of the pulses provided by the industrial partner, a postcondition failed pointing to a problem:
    - According to IEEE 181 standard, if there are more than two instances corresponding to the 10% level, the one closest to the 50% should be chosen.
    - But, the code does not choose that one.

Ideas for Future Work

- Implement contracts and AutoTest-like tool for Matlab,
- Investigate theorem proving,
- Explore Simulink Design Verifier.