Automated High-Accuracy Hybrid Measurement for Distributed Embedded Systems

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Introduction

The challenge: timing measurements of distributed real-time systems

• Requirements:
  • high accuracy
  • common ("global") time base
  • using embedded systems: limited facilities

• Additional requirements for this study:
  • record single events
  • end-to-end delays of communication events
  • large number of measurement runs ⇒ unattended operation

• Practical approach preferred, matching goals with minimum effort

Overview

• Introduction
• Hybrid Approach
• Modified Approach
• Approaches Compared
• Automated Measurement System
• Summary

Initial decisions derived:

• End-to-end delay ⇒ local clock timestamps not sufficient
• Dedicated clock source provides global time at observer
• Events are best generated locally
  • timestamp is determined by observer recording the event
  ⇒ hybrid approach

• Limited scope of "global" time as assumed here:
  • nodes within the experiment
  • time span covering the experiment

• Experiment conduction and analysis should be automated
**Hybrid Approach**

Combining local / centralised timestamp recording / processing

- **Determining the occurrence of an event**
  - event is determined locally
  - thus: close integration of event generation code and its context
  - events are exposed to an observer instance (device)
  - here: dedicated event signalling connections at hardware level

- **Mapping of events to timestamps**
  - exposed events are recorded by a central device
  - a high-accuracy clock source within the recording device is used to timestamp every event within a common time base ("global clock")
  - event context information (also exposed at event generation) is recorded with the timestamp for subsequent event identification/correlation

**Implementation Strategy**

- Instrumentation of application code provides event signaling and counter value on PC parallel port
- Logic analyser records events with timestamps and counter value (context)
  - Customized logic analyser recording state machine allows
    - long-term and high resolution time stamp acquisition
    - single event recording with multiple event sources
    - true end-to-end latency measurement (common time base)

**Correlation of send/receive event pairs based on counter values**

Characteristics:
- 10 ns logic analyser resolution
- 17µs latency for event occurrence → logic analyser capture
  - mostly through I/O driver for parallel port access
  - 0.1 µs mean probable error

**Modified Approach**

- **Motivation:** greater number of nodes, more context data
  - capabilities of original implementation are exceeded

- **Local clocks are used to capture timestamps**
  - common time base is initially lost

- For each measured node, establish a reference timestamp on the central timing device
  - reference timestamps are taken at beginning / end of measurement
  - procedure equals "original approach"

- **Regain "global time" by mapping of local timestamps to logic analyser time**
  - mapping is performed off-line after the measurement
  - timestamp data may remain distributed
Modified Approach

Mapping of local timestamps

- Assumed: merely linear clock drift within each node
- For reference timestamps $T_{LA1,2}$, local timestamps $T_{PC1,2}$ have been recorded

$\Rightarrow$ Local timestamps $T_{PC}$ can be mapped to "global" timestamps $T_{LA}$:

$$t_{LA} = (t_{PC} - T_{PC1}) \times \frac{T_{LA2} - T_{LA1}}{T_{PC2} - T_{PC1}} + T_{LA1}$$

Approaches Compared

Limitations using local clocks

- Non-linear drift is not regarded
  $\Rightarrow$ not suitable for variable processor clock speed and/or significant thermal changes affecting the clock speed
- Resolution and accuracy of the local clock must be sufficient

Benefits using local clocks

- Reduced overhead for taking timestamps
- No I/O access for event signalling: jitter is reduced
- Allows greater number of measurement nodes
- Context data can be more complex because it is kept locally

Automated Measurement System

Motivation for automated measurement, from study experiment:
- all permutations of parameter settings should be measured
  $\Rightarrow$ 400 measurements * 400 samples = 160,000 samples
- experiment conduction / sample management and analysis likely to become tedious and error-prone

Solution: Measurement control application on operator PC
- experiment setup
- variation of experiment parameters
- control of experiment run/stop and data acquisition
- sample data management
- send/receive event correlation
- automated statistical analysis and diagram generation

Automated Measurement System

- Operator PC runs control application as Excel VBA module
- NT 3 is connected to logic analyser, vendor provided control application is wrapped by custom OLE Automation server
- Experiment schedule UI for parameter preparation / execution
- Remote control of NT1 / NT2 through UDP communication
- Finally: automated sample import into Excel + analysis
Example Diagrams Showing Single Event Data

- Only possible using single event recording
- Singular exceptions visible (here: packets violating QoS)
- Appearance of artifacts, resulting from secondary effects

Summary

- Two aspects combined, forming a versatile measurement system
  - hybrid high-accuracy measurement
  - automated experiment conduction and analysis
- Single event recording preserving singular phenomena
- Automated operation: saving time, reducing errors
- Early judgements supported by analysis generation
- Usability and accuracy have been verified
  - accompanying application study
- Measurement system has been reused in several research projects
- Future extensions and enhancements planned