Systems Engineering for Intelligent Industrial Processes

Jan van Deventer
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Outline

• Definitions,
• Systems Engineering standards & documentation,
• System lifecycle management,
• Model Based Systems Engineering,
• SOA Framework to promote “Intelligence”.
my Background

Why System Engineering?
IIP

- Processes,
- Industrial Processes,
- Intelligent Industrial Processes.
Paper Production Process

Ultrasonic measurements and modelling of attenuation and phase velocity in pulp suspensions

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Abstract
— In the manufacturing process of paper the mass fraction and material properties of the fibres in the pulp suspension are important for the quality of the finished product. This study presents two different methods of pulp characterisation. The first is based on phase velocity, which we use to investigate the composition of the pulp. Here a method is presented where the optimal number of circular shifts within the sampling window of the signal is determined which gives, in a weakly dispersive medium, a continuous phase spectrum and minimizes the likelihood of discontinuities within the bandwidth. Hence, the ambiguity in phase unwrapping is avoided. The results from phase velocity measurements show that the phase velocity weakly increases with increasing amount of fines in the suspension. The dispersion is caused by the fibres and it correlates with fibre mass fraction. The second method is based on attenuation and is used to characterise the wood fibres. The results of the attenuation experiments show that it is possible to inversely calculate wood fibre properties by fitting the model to the experimental data, if the fibre diameter distribution is known. However, the accuracy of these calculations is difficult to determine and more work in this area is required.

I. INTRODUCTION

In the manufacturing process of paper the mass fraction and material properties of the fibres in the pulp suspension are important for the quality of the finished product. When using recycled paper, fibres with unknown and varying material properties enter the process. Therefore, there is an increasing demand for methods of on-line characterisation of the pulp suspension as well as the fibres in suspension.

This study presents two different methods of pulp characterisation. The first is based on phase velocity, which we use to investigate the composition of the pulp. The second is based on attenuation and is used to characterise the wood fibres.

In the first method, we investigate how the phase velocity changes with different mass fractions of fibres and fines. To determine the phase velocity, a method is proposed based on the method by [1], where each circularly shifted optimal number of samples.

In the second method, to be able to characterise the wood fibres, we use an analytical model which relates the material properties of saturated fibres to the attenuation. We then aim to solve the inverse problem of identifying which values result in the best fit of the model to the attenuation values calculated from experiments.

II. PHASE VELOCITY

A. Theory and experiments

When determining the phase velocity from pulse-echo measurements, one encounters the problem of performing a correct phase unwrapping. The problem is well known and has been addressed in earlier investigations, for instance [2]. The problem arises when the phase velocity is calculated from the phase spectra of a the Fourier transform of each of the two echoes. In this study, we propose a method, termed Minimum Phase Angle (MPA), that determines an optimal number of circular shifts to the windowed signal which results in a continuous phase spectrum and minimizes the likelihood of discontinuities within the bandwidth. Therefore the ambiguity in the phase unwrapping is avoided. To experimentally test the method experiments were performed in pulp fibre suspensions, which are weakly dispersive. The experiments were carried out using the pulse-echo technique in a custom designed test cell. The schematic view of the measurement cell is shown in Fig. 1.

The echoes from the interfaces depend on the initial pulse pressure amplitude $p_0(t)$ emitted from the transducer and the reflection and transmission coefficients of the different interfaces. For simplicity, we omit the reflection and transmission coefficients and the attenuation. With these assumptions, the echoes from the interfaces between the buffer rod/suspension are:

The diagram in Fig. 1. Lattice diagram of the pulse-echo measurement system used this study.
Steel Pellet Production Processes
Zooming in: Flotation Process

Flotation process map

- Raw ore
- Vibrating Feeder
- Jaw Crusher
- Hydraulic Cone Crusher
- Spiral Classifier
- Ball Mill
- Pendulum Type Feeder
- Small Storage bin
- Vibrating Screen
- Agitator
- Flotation Machine
- Flotation Machine
- Flotation Machine
- Finally Products
- Tailings
District Heating Process

- Biomass transported to district heating plant
- District heating plant
- Waste heat
- Cooled water: The cooled water returns to the district heating plant to be reheated
- Heated water: The hot water is directed from the district heating plant to houses via a closed piping system
- Households
- Industries
- Commercial properties
Increasing the complexity to improve “things”
What “Intelligence” are we seeking?

• When things go wrong (or could be improved) and

  • there is potential information pointing to the symptoms.

  • Information that is available

  • Information that could be available

  • have an intelligent system that saves or improves the situation.
The fundamental question is: “How do we make *Intelligence* happen?”

- How do we connect sensors, controllers, actuators together?
- How do we develop “intelligent” controllers?
- How do we describe the processes and their improvements?
- How much will it cost? How long will it take? How do we introduce the new solutions in an existing infrastructure? How do we maintain the systems? How do we retire the systems?
A System

• A combination of interacting elements organized to achieve one or more stated purposes, an integrated set of elements, subsystems, or assemblies that accomplish a defined objective.

• These elements include products (hardware, software, firmware), processes, people, information, techniques, facilities, services, and other support elements.
Systems Engineering

• Systems Engineering (SE) is an interdisciplinary approach and means to enable the realization of successful systems.

• It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, and then proceeding with design synthesis and system validation while considering the complete problem: operations, cost and schedule, performance, training and support, test, manufacturing, and disposal.

• SE considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs.

Stakeholders’ views

How the customer explained what they wanted.

How the project leader understood the concept.

How the funding application described the product.

How the designer implemented the system.

How the demonstration system was built.

How the system was documented beyond publications.

How the system was supported after the project.

What the customer really needed.
There is nothing new under the sun.

System Engineering is not new

Common example is the Apollo missions although the term can be found in the 1940’s at Bell Labs.

LTU has no education or research in Systems Engineering.
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A Successful System

Figure 6-3. Concept Description Sheet Example

External Command Guidance System

Missile

Steering Commands

Radio

Computer

Missile Tracking Radar

Target Tracking Radar

Target
System Engineering Process

Figure 3-1. The Systems Engineering Process

Process Input
- Customer Needs/Objectives/Requirements
- Missions
- Measures of Effectiveness
- Environments
- Constraints
- Technology Base
- Output Requirements from Prior Development Effort
- Program Decision Requirements
- Requirements Applied Through Specifications and Standards

Related Terms:
- Customer = Organizations responsible for Primary Functions
- Primary Functions = Development, Production/Construction, Verification, Deployment, Operations, Support, Training, Disposal
- Systems Elements = Hardware, Software, Personnel, Facilities, Data, Material, Services, Techniques

Process Output
- Development Level Dependent
  - Decision Database
  - System/Configuration Item Architecture
  - Specifications and Baselines

Requirements Loop
- Analyze Missions and Environments
- Identify Functional Requirements
- Define/Refine Performance and Design Constraint Requirements

Design Loop
- Transform Architectures (Functional to Physical)
- Define Alternative System Concepts, Configuration Items and System Elements
- Select Preferred Product and Process Solutions
- Define/Refine Physical Interfaces (Internal/External)

Verification
- Trade-Off Studies
- Effectiveness Analyses
- Risk Management
- Configuration Management
- Interface Management
- Data Management
- Performance Measurement
  - SEMS
  - TPM
  - Technical Reviews

Synthesis
- Transform Architectures (Functional to Physical)
- Define Alternative System Concepts, Configuration Items and System Elements
- Select Preferred Product and Process Solutions
- Define/Refine Physical Interfaces (Internal/External)

Functional Analysis/Allocation
- Decompose to Lower-Level Functions
- Allocate Performance and Other Limiting Requirements to All Functional Levels
- Define/Refine Functional Interfaces (Internal/External)

Requirements Analysis
- Analyze Missions and Environments
- Identify Functional Requirements
- Define/Refine Performance and Design Constraint Requirements

System Analysis and Control (Balance)
Objects of stakeholders

Figure 1-4. Primary Life Cycle Functions

- Disposal
- Operation
- Development
- Deployment
- Training
- Verification
- Support
- Manufacturing/Production/Construction

8 Primary Life Cycle Functions

Operation is the user function and includes activities necessary to satisfy defined operational objectives and tasks in peacetime and wartime environments.

Support includes the activities necessary to provide operations support, maintenance, logistics, and material management.

Disposal includes the activities necessary to ensure that the disposal of decommissioned, destroyed, or irreparable system components meets all applicable regulations and directives.

Training includes the activities necessary to achieve and maintain the knowledge and skill levels necessary to efficiently and effectively perform operations and support functions.

Verification includes the activities necessary to evaluate progress and effectiveness of evolving system products and processes, and to measure specification compliance.

Systems Engineering Considerations

Systems engineering is a standardized, disciplined management process for development of system solutions that provides a constant approach to system development in an environment of change and uncertainty. It also provides for simultaneous product and process development, as well as a common basis for communication.

Systems engineering ensures that the correct technical tasks get done during development through planning, tracking, and coordinating.

Responsibilities of systems engineers include:

- Development of a total system design solution that balances cost, schedule, performance, and risk,
- Development and tracking of technical information needed for decision making,
- Verification that technical solutions satisfy customer requirements,
- Ensuring that the correct technical tasks get done during development through planning, tracking, and coordinating.
Systems Lifecycle Management

• ISO/IEC 15288 Systems and software engineering — System life cycle processes (IEEE Std 15288-2008)

• This International Standard establishes a common process framework for describing the life cycle of man-made systems. It defines a set of processes and associated terminology for the full life cycle, including conception, development, production, utilization, support and retirement. This standard also supports the definition, control, assessment, and improvement of these processes. These processes can be applied concurrently, iteratively, and recursively to a system and its elements throughout the life cycle of a system.
The Event Schedule includes tasks for each event/exit criteria that must be performed to meet key system requirements, which are directly related to product metrics.

The Calendar (Detail) Schedule includes time frames established to meet those same product metric-related objectives (schedules).

Earned Value includes cost/schedule impacts of not meeting those objectives, and, when correlated with product metrics, can identify emerging program and technical risk.

14.3 PROCESS METRICS

Management process metrics are measurements taken to track the process of developing, building, and introducing the system. They include a wide range of potential factors and selection is program unique. They measure such factors as availability of resources, activity time rates, items completed, completion rates, and customer or team satisfaction.

Examples of these factors are: number of trained personnel onboard, average time to approve/disapprove ECPs, lines of code or drawings released, ECPs resolved per month, and team risk identification or feedback assessments. Selection of appropriate metrics should be done to track key management activities. Selection of these metrics is part of the systems engineering planning process.

How Much Metrics?

The choice of the amount and depth of metrics is a planning function that seeks a balance between risk and cost. It depends on many considerations, including system complexity, organizational complexity, reporting frequency, how many contractors, program office size and make up, contractor past performance, political visibility, and contract type.

14.4 SUMMARY POINTS

- Management of technical activities requires use of three basic types of metrics: product metrics that track the development of the product, earned value which tracks conformance to the product metrics, and cost/schedule impacts of not meeting objectives.

Figure 14-1. Earned Value Concept

Figure 14-1. Earned Value Concept from DOD’s SYSTEMS ENGINEERING FUNDAMENTALS
Model-based systems engineering (MBSE) is a systems engineering methodology that focuses on creating and exploiting domain models as the primary means of information exchange between engineers, rather than on document-based information exchange.
A Modeling Tool

With the hollow, triangular arrowheads mean. They're called generalizations. You read them as "is a type of" in the direction of the arrowhead. (I discuss generalizations in detail in Section 3.6, "Generalizations.") With this in mind, Figure 2.1 conveys quite a bit of information. Activity diagrams, sequence diagrams, state machine diagrams, and use case diagrams are types of behavior diagrams. Block definition diagrams, internal block diagrams, and package diagrams are types of structure diagrams. Parametric diagrams are a type of internal block diagram; therefore, a parametric diagram is transitively a type of structure diagram. Finally, requirements diagrams are in a category by themselves—but still a useful addition to this family of SysML diagrams.

Here's a brief summary of the purpose of each kind of diagram.

- The block definition diagram (BDD) is used to display elements such as blocks and value types (elements that define the types of things that can exist in an operational system) and the relationships between those elements. Common uses for a BDD include displaying system hierarchy trees and classification trees.

- The internal block diagram (IBD) is used to specify the internal structure of a single block. More precisely, an IBD shows the connections between the internal parts of a block and the interfaces between them.

Figure 2.1 SysML diagram taxonomy
Self Awareness

• For the sake of the discussion afterwards, please be aware of your current understanding of the list below (before the rest of the talk)

• District Heating

• The Arrowhead Framework

• Model Based System Engineering
District Heating Structure

Diagram showing the structure of a district heating system, including blocks for system coordination, data management, simulation, production, distribution, consumption, commercial buildings, apartment buildings, single family houses, insulated pipes, pressure sensor, flow meter, temperature, valve, pumps, fuel, burner, heat exchanger, electricity, and radiators.
Distribution System

```
<table>
<thead>
<tr>
<th>Value</th>
<th>Description</th>
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<tbody>
<tr>
<td>temperature</td>
<td>C</td>
</tr>
<tr>
<td>Sampling frequency</td>
<td>Hz</td>
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- Insulated pipes
- Leakage detection
- Pressure sensor
- Flow meter
- Temperature
- Valve
- Pumps
- Communication
- Pipes
- Insulation
- Distribution
Component Interactions

ibd [Block] District heating substation [ District heating substation ]

- Primary supply temperature
- Primary return temperature
- Primary flow meter
- Outdoor temperature
- Radiator supply temperature

: Heatmeter

: Controller

Communication

Valve position

Outdoor temperature

Radiation supply temperature

Energy

Graph: Heatmeter vs Valve position
Service Oriented District Heating Components

Outdoors temperature service provider

Valve service provider

Flow service provider

Heat meter service provider
Orchestration out of problems (or Intelligence)

- The outdoor sensor is offline (e.g., out of battery),

- You could use the neighbor’s outside sensor via the Gate Keeper,

- but the Internet is dead!

- You could use an indoor temperature sensor to control the indoor temperature....
I would like to get the outdoor temperature. Do you have a service provider?

No, we don't. But we have an indoor temperature sensor. It's address is 130:240:20:15. You are authorized to talk with it.

What about one from the neighbor's house?

Do you have an indoor temperature sensor?

Yes

What's its address?

130:240:20:15

Thank you.
More can be done in this configuration...

- Estimation of thermal insulation and thermal capacitance of the building in real time,
- Better control control of heating control strategy in Demand Response applications,
- System Prognostic and Diagnostics, e.g., damaged pipe insulation,
- Tamper proof, information to stakeholders,
- System phase in and out, Scalability.
System Engineering in IIP

- Increase stakeholder communication to understand their paradigms or views on the same issue,
- Manage the lifecycle of the systems and subsystems,
- With MBSE, zoom in and out within the systems,
- Develop “Intelligence” through Use Cases.
Do we know what we really want?

- The technology is here.
- The Arrowhead Framework is here.
- How does one make an Industrial Process Intelligent?
Which is the right problem?

• Successful problem solving requires finding the right solution to the right problem. We fail more often because we solve the wrong problem than because we get the wrong solution to the right problem.

Russell L. Ackoff, Redesigning the future, 1974, p. 8.