SELF-RESILIENCE ANALYSIS OF PRODUCTION SYSTEM IN PRODUCT LIFECYCLE MANAGEMENT (PLM)

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Outline

1. Background – Warwick Digital Laboratory
2. Introduction
3. The changing paradigm
4. Self-resilience framework for PLM
   3.1 Challenges in complex manufacturing system
   3.2 Self-resilience in manufacturing
   3.3 Self-resilience in field/service
5. Summary
WMG – Scale

Over 450 staff including industrial secondees

£100 million annual programme, less than 10% funding from HEFCE

25% of University’s research activity

Effective relationships with over 500 global companies in all sectors – technology and process

4,000 individuals from industry on postgraduate and post experience education

Satellite operations in the Asia-Pacific Rim, China, India and South Africa
The Warwick Digital Laboratory

◆ A new £100 million Initiative

◆ Technology that is pervasive and core to all activities is digital

◆ Impacts all individuals, technologies, sectors and countries

◆ Currently no centralised interdisciplinary team of digital experts
The Warwick Digital Laboratory

◆ £13 million building completes June 2008
◆ Strategic new academic appointments
◆ Exploring, creating, exploiting transferring knowledge
◆ Multi-disciplinary science involving end users
◆ Research, knowledge transfer and education
◆ Impact on all sectors to create wealth
Multidisciplinary Research –, engineering, medicine, computer science, maths, psychology, physics, statistics, etc.
Motivation

Assembly Tooling
- Dedicated
- Flexible
- Reconfigurable
- Hybrid

Assembly process simulations:
Dimensional Analysis (Movies)

Assembly process simulations:
Process representation and Modeling
Distributed Sensing and Information Flow

- **End-of-line sensing vs. distributed sensing**

  (a) end-of-line sensing
  
  (b) distributed sensing

- **Information Flow**

  New!

  - multiple attributes
  - time history
  - station index
  - station 1, station 2, ..., station N

  New!

  - autocorrelation in terms of stations
  - cross-correlation among multiple attributes
  - autocorrelation in terms of time
2. The Changing Paradigm

Past

Deterministic

Now/Near Term

Automated Stochastic Model Predictions, RSM, Kriging, Virtual Experimental Design

Desired State

In Mfg Phase:
Root cause Identification

In Service Phase:
Field failures Identification

SELF Resilience in context of PLM?
Ability of the system to self-recover from changes in *design, manufacturing* and *field/service* phases of PLM.
2. The Changing Paradigm

Feedback to Design: (Heuristics–DOs & DON’ts)

Old!

Station 1  →  Station k  →  Station N

End-of-line sensing

distributed sensor

Service intervention

operator intervention

Warranty

Statistical Process Control

Field Failures

Physics of the Process (CAD and CAPP)

Statistics

Feedback to Design (Analytical)

New!

Root cause/Healing (Analytical)
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<td>Process in-control</td>
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<td></td>
<td>or out-of-control</td>
<td>Process adjustment</td>
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2. The Changing Paradigm: Trend in manufacturing
Self-Healing vs. Self-Resilience

**Self-Healing**

- Self-healing
  - Robustness
  - Diagnosability
  - Adjustmentability
- Intra-Loop Models: within a PLM phase
- Inter-loop Models: between PLM phases

**Self-Resilience**

- Self-resilience
  - Robustness
  - Diagnosability
  - Adjustmentability
  - Continuous faults: FT {0,1}
  - 6-sigma faults
- Intra-Loop Models: within a PLM phase
- Inter-loop Models: between PLM phases

### Fault Definition
- Discrete Fault: FT{0,1}
- Deviation from design nominal faults
- Continuous faults: FT {0,1}
- 6-sigma faults

### Interdependencies
- A single PLM phase
- A single product
- Multiple PLM phases: Dn, Mfg, Field
- Product family
3. Self-healing framework for PLM

State-of-Art / Challenges

Design
- Product / Process Design
- Digital Validation

Manufacturing
- Parts
- Station 1
- Station 2
- ... Station N

Service
- Warranty Data

Multistage Manufacturing Process

Objectives
- 1 and 3
- 2 and 4

Objectives
- Process adjustment and control
  - Out-of-tolerance Multi-product
- Field-based process adjustment and control
  - In-tolerance product failure

Knowledge Mesh Model

Proposed Research

Research Challenges
- 1
- 2
- 3
- 4

Objectives
- Feedback to Design
- Field-based Feedback to design
- Field-based process adjustment and control
- Process adjustment and control

Self-Healing

Feedback to Design
- Design for diagnosibility and healability (adjustability)

Feedback to Manufacturing
- Feedback to Manufacturing/Design
- Feedback to Manufacturing Single Product (SOVA)
- Feedback to Manufacturing/Design DO's & DON'Ts for Multiple Products

Warranty Data

Self-healing framework for PLM
Example I: Self-resilience in Field/Service
3.3 Self-healing in service

Motivation for failure diagnosis and monitoring

- Service and Warranty are critical in the Product Life Cycle
  - 6% of all US products are returned (Lee et al. (2002))

- Warranty faults are caused by interactions between product and process parameters in field → difficult to model in design, causing failure region within design tolerances (In-tolerance failures)

- Current technology allows for the traceability of field information to manufacturing measurements

- The proposed methodology incorporates in-tolerance fault region(s) to determine optimum process adjustment and capability
Agenda

• Introduction

• Warranty failure diagnosis and monitoring

  • Out-of-tolerance vs. In-tolerance Product failures
    \rightarrow Fault Region Localization (FRL) Methodology

  • Process Capability Analysis vs. Functional Capability Analysis
    \rightarrow Functional Capability Space (FCp-space)-based warranty monitoring

• Industrial case study: Motorola cell phone manufacturing

• Conclusions and future work
(I) Traditional Step Function for Quality assessment
(II) Taguchi loss function
(III) Taguchi loss function with product failure in in-tolerance zone
Warranty Failure Diagnosis and Monitoring

- Fault Region Localization (FRL): To Identify In-tolerance fault region(s)
- $FC_p$-space: To determine optimum process adjustment and process capability
Functional $C_p$-space based warranty monitoring

Extension to $\mathbb{R}^3$ and $\mathbb{R}^m$

- Consider both non-normal distribution and in-spec failure regions
- $FCp$-Space: Determine region in tolerance space for process mean which ensures minimum overlap of process distribution with failure regions
Case study – Motorola IDEN manufacturing

Boundary Region (BND)

Warranty Fault Region (WFR)

Normal Region (NR)

Measurement 1 Tolerance

Design Nominal

Plant 1

Plant 2

Measurement 2 Tolerance
Functional Capability-space based warranty monitoring

Multivariate normal process

Process adjusted to nominal

Failure Region

Tolerance of PV

Process adjusted to reduce failures

Failure Region

Tolerance of PV

Multivariate non-normal process

Failure Region

Tolerance of PV

Failure Region

Tolerance of PV
Example II: Self-Resilience in Manufacturing
Self-resilience in Manufacturing - Framework

- Layer 1
- Layer h
- Layer m
- End-of-line sensing

**Self-resilience**
- Feedback to Design (Resilience)
- Feedback to Design (Robustness)

**Root Causes**

**Distributed Sensing**

**Diagnosis**
- Fault Identification
- Fault Localization
- Fault Isolation

**SOVA Model**
- Engineering Knowledge (CAD/CAM)
- Statistical Analysis
Adaptive Production System Configuration Tooling Selection
Self-resilience in manufacturing is needed for:

- Process adjustment and control of manufacturing system
- For decision models for system optimization
- Negotiation model in-case of problem can be corrected by multi-variable.
Adjustment based on Model 1

Adjustment based system variation

Adjustment based on Model 2
Self-resilience in Manufacturing - Framework

Layer 1 → Layer h → Layer m → End-of-line sensing

Self-resilience

Feedback to Design (Resilience)
Feedback to Design (Robustness)

Self resilience
Root Causes

Distributed Sensing

Diagnosis

Fault Identification
Fault Localization
Fault Isolation

SOVA Model
Engineering Knowledge (CAD/CAM)
Statistical Analysis
Summary

- Self-resilience framework is developed to address the issue related to diagnosability and adjustability in Product Lifecycle Management.
- Methodology developed for process adjustment and control based manufacturing and service data.
- The self-resilience framework has potential to be applied to various manufacturing industries such as automotive, semi-conductor, Rapid manufacturing and others.
• BACKUP SLIDES
Self-Healing mechanism for Multi-product assembly line

Multi-product assembly line

Product 1
Assembly

Product 2
Assembly

... 

Product M
Assembly

Diagnosis

Fault identification filter (EPLS)

Adjustment

Kalman Filter

Optimization of feedback

Where, $k = 1, 2, ..., m$

Where, $j = 1, 2, ..., m$

$X^l \rightarrow Y_1$

$w_1 \rightarrow e_1$

$X^2 \rightarrow Y_2$

$w_2 \rightarrow e_2$

$...$

$X^m \rightarrow Y_m$

$w_m \rightarrow e_m$

$P^k \rightarrow P^j$

$P^k \rightarrow P^j$
Motivation

Complex Product
Extensive manufacturing organisation
Structural Assembly
High number of parts
Various Assembly levels

Importance of Assembly Cost

Assembly 45%
Conversion 30%
Material 25%

Need to manage product’s assemblability
Motivation

- Dimensional and geometric variation management

Data-based methods: Six Sigma
Model-based methods: Stream-of-Variation (SOVA)
Application 2: Panel fitting in automotive

Product and process leading to panel fit variation

Hard to open close doors (QTS Survey)

6-sigma variation in panel fitting door flushness for side doors
Application 2: Development of self-resilience framework for rapid manufacturing (RM)

Framework for SOVA-RM
The Digital Laboratory

A new £50m Initiative

£13m building opens June 2008
Warwick Digital Lab - Images
Warwick Digital Lab - Images
APPLICATION DOMAINS

DIGITAL MANUFACTURING

DIGITAL

E-BUSINESS

E-SECURITY

E-LOCATION

LIFE-CYCLE ENGINEERING

INDUSTRIAL NEURO-IMAGING

EXPERIENTIAL ENGINEERING

VR / AR – (3D, haptics etc.)

VISUALISATION

SENSOR NETWORKS/CONTROL

MODELLING / SIMULATION

HEALTHCARE SCIENCES

Integrating Technologies (WDL USPs)

Multidisciplinary Research –, engineering, medicine, computer science, maths, psychology, physics, statistics, etc.
An International Benchmark

• “A future role model for German Universities”.
  • (German Government)

• “Singapore should look at WMG and clone it”.
  • (Chairman Economic Development Board)

• The Group is unique in having a sensitive understanding of political issues that affect a nation and helping to implement industrial policy in harmony
  • (Nelson Mandela)

• “WMG is an outstanding example of combining academic excellence with industrial relevance - a unique international contribution, which we are all proud of”
  • (Tony Blair)
1. Introduction:

SELF HEALING in context with PLM?

Ability of the system to self-recover from changes.
Motivation

Assembly process simulations:
Kinematics (Movies)
Variation causes

- part variation due to fabrication processes
- part positioning and clamping error in fixture
- part/subassembly spring back
- part/subassembly variation due to joining process
2. The Changing Paradigm: Research Roadmap
3.1 Challenges in complex manufacturing system

Challenges in modern Manufacturing systems:

- **Process adjustment and control for multi-product production on single line.** Most of the research related to process adjustment and control in manufacturing is carried out with assumption that only single product is produced on a single production line. In case of production of multi-products the problem becomes considerably more complex as the adjustment for one product may affect other products.
- **Process adjustment** for products with failure that occur when design parameters and process variables are *in-tolerance* using warranty/service data.
- **Process diagnosibility and adjustability** analysis in design phase for *multiple-product production*.
- **Process diagnosibility and adjustability** analysis in design phase based on *field (warranty/service) data*.
3.2 Self-healing in Manufacturing

Motivation for Process adjustment and control

- Development of flexible fixture system (FFS)

- 70-75% of root causes of product dimensional variations are due to fixture related problem.

- Current technology allows for the identification of fault failure for single product assembly line for orthogonal design

- The proposed methodology incorporates fault identification and process adjustment for assembly line producing multi-product.
Adaptive Production System Configuration Tooling Selection

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<tr>
<th>Current Methods</th>
<th>Proposed Method</th>
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<td>Fixture workspace for part family</td>
<td>Practice</td>
</tr>
<tr>
<td>Fixtures</td>
<td>Tooling Elements (TEs)</td>
</tr>
<tr>
<td>N/A</td>
<td>Fixture</td>
</tr>
<tr>
<td>DAF</td>
<td>Workspace Synthesis</td>
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<tr>
<td>Current family of parts</td>
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<td>FAF</td>
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<td>Current part family and future parts</td>
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<td>Proposed</td>
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