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DIGITAL TWINS FOR COMPLEX SYSTEMS

Prof Anton Basson

Rand Water Chair in Mechanical Engineering Mechatronics, Automation and Design Research Group Department of Mechanical and Mechatronic Engineering May 2024

Overview



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- Mechatronics, Automation and Design Research Group
- The Challenge
- Digital Twins for Complex Systems
- Applications
- Opportunities



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Mechatronics, Automation and Design Research Group

Mechatronics, Automation and Design Research Group



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The challenge

Digital Twins for Complex Systems

Applications

Opportunities



Prof Anton Basson Professor in Mechanical Engineering Rand Water Chair in Mechanical Engineering PhD in Aerospace Engineering, Penn State Univ

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System engineering, digital twins for complex systems, predictive maintenance

Collaborators

Co-leaders

Prof Karel Kruger Extraordinary Associate Professor, Stellenbosch Univ

Associate Professor, Univ of Cambridge

PhD in Mechatronic Engineering, Stellenbosch Univ



Dr Nicole Taylor Lecturer in Mechanical Engineering

PhD in Mechatronic Engineering, Stellenbosch Univ

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Human-system integration, human-cyberphysical systems, human comfort

Prof Herman Vermaak

Extraordinary Professor, Stellenbosch Univ

Stadio: Head of School: Architecture and Engineering

PhD in Mechanical Engineering, Univ of Twente

Mechatronics, Automation and Design **Research Group**



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Applications

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PhD



Dylan Eksteen MEng (II)

Sa'eed Fataar MEng (II)



Dauda Sheni MEng (II)

Heinrich Swanepoel MEng (II)



Rvno Visser MEng (II)









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Digital Twins for Complex Systems



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The Challenge

Digital Twins for Complex Systems

Applications

Digital Twins for Complex Systems

Opportunities

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The challenge

The challenge

- Information not accessible and systems not interoperable
 - Data ≠ Value!
 - Data silos and solution silos
 - Paywalls & restrictions on commercial solutions





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Addressing the challenge



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Applications

Opportunities

• Smart **digital representations** of role-players

- Highly **modular**, **distributed** approach
- **Reconfigurable** platforms with incremental functionality





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Digital Twins for Complex Systems

What is a Digital Twin? Our view



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Applications

Opportunities

• DT to have a primary goal: **reflect reality**

• DT should not be locked into a single end-use





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"a virtual representation of a physical entity, which facilitates and

organises the *integration* of data, technologies and digital

services, to achieve the Industry 4.0 vision."



1

Digital Twins for Data-Led Decision Making

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Applications

Opportunities

Integrated, structured data

- From different data sources
 - Existing or new
 - Existing digital repositories
- Enhanced accessibility through the cloud
- Maximize value of IoT technologies



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Long-Term Repositories

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Services.

Emulation, Simulation and

Control

SLADT

six-layer architecture for digital twins 1

Digital Twins for Data-Led Decision Making

Data sources from multiple

Serve multiple stakeholde

sources, stakeholders

Reflect reality

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Applications

Opportunities

Federated digital twins





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Digital Twins for Data-Led Decision Making

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Applications

Opportunities

2 Services

- Modelling, simulation, prediction
 - Machine learning operations
 - Physics-based
 - Heuristics-based
 - Monitoring
 - Emulation
 - Anomaly detection
- Design and implementation
 - Software pipeline provisioning
- Stakeholder-specific perspectives
 - Data privacy and separation of concerns





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Applications

Opportunities

2 Services examples

- Sustainability analyses
 - Carbon, energy footprint
- Maintenance
 - Life cycle costing
 - Granularity from fleet to component
 - Predictive maintenance
- Machine learning
 - Tactical aggregation and disaggregation
 - Integrate with machine learning operations (MLOps)
 - Ambient intelligence





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| The challenge | 3 E |
| Digital Twins for Complex Systems | |
| Applications | |
| Opportunities | |

- 1 Integrated, structured data
- 2 Services
 - Enhanced presentation and visualization



Digital Twins for Data-Led Decision Making

1 Integrated, structured data

- 2 Services
- 3 Enhanced presentation and visualization
 - User-specific dashboards & reports
 - Historical, real-time and forecast data
 - Virtual, augmented reality
 - Remote assist





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Digital Twin Applications

Application Domains



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Applications

Opportunities

• Monitoring and fault detection for a manufacturing system

• Complex DT built up from component/subsystem DTs

• Operation monitored in near real-time

 Intelligence embedded in DT to detect deviations from normal operations



Data integration for facility management



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- Applications

Opportunities

- Stellenbosch University main campus
- Electricity and water usage measured by 3rd parties
- Data ingested, integrated and servitized in DT system
- Graphical and geographic presentation in VR environment



Data Servitization for the Circular Economy

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Applications

Opportunities

 Circular economy requires functions throughout a product's lifecycle

- Data acquisition
- Modelling
- Analysis
- Decision making
- Decisions are influenced by product data and external data
- Involves many and diverse stakeholders

| Hisponsha | Strategy | Description |
|-----------|---------------|---|
| Hierarchy | Strategy | Description |
| Circular | Refuse | Make products redundant by abandoning their |
| Economy | | functionality or by offering the same functions |
| | | with radically different products. |
| | Rethink | Make product use more intensive. |
| | Reduce | Increase efficiency in product manufacture or |
| | | use, by consuming fewer natural resources and |
| | | materials. |
| | Reuse | Reuse of discarded products which are still in |
| | | good condition and fulfils their original function. |
| | Repair | Repair and maintenance of defective products so |
| | 1 | they can be used for their original functions. |
| | Refurbish | Restoration of old products to bring them up to |
| | | date, so they fulfil their original functions. |
| | Remanufacture | Use parts of discarded products in new products |
| | | with the same functions. |
| | Repurpose | Use discarded products or their parts in new |
| | | products with different functions. |
| | Recycle | Reprocessing of waste materials into products, |
| | - | materials, or substances. |
| | Recover | Use waste to serve a useful purpose, which |
| | | would otherwise be fulfilled by other material |
| | | (e.g., incineration of material for energy |
| | | recovery). |
| | Dispose | Disposing waste material in a non-regenerative |
| | | way (e.g., landfills, non-regenerative |
| | | incineration, permanent storage, release of |
| | | substances into natural environments). |



Supporting effective AI deployment

The challenge

Digital Twins for Complex Systems

Applications

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Opportunities

• Al can be deployed in DTs to

Enrich DT data

• Perform DT functions

• Provide DT services

• DT can provide infrastructure **Digital Twin** required to put AI into production

Cyber-Physical Interaction

Physical Twin

Digital Services



AI

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Applications

Opportunities

Complex Systems

Decision Support for Railway Maintenance

- Maintenance challenges due to:
 - Unintegrated data sources
 - Isolated subsystems
 - Interactions and effects
 - Various stakeholders

• DT system to integrate data and provide services that offer various perspectives.





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Opportunities

Industry Collaboration



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Applications

Opportunities

- DT as **integration** mechanism
- \rightarrow DT as **collaboration** mechanism
- Explore and implement the encapsulation of expert domain knowledge in DTs
- Leverage DTs to develop value-adding digital services



Industry Collaboration



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Applications

Opportunities

• Complex facilities and operations

• Various stakeholders and functions

• Looking for opportunities to change data into insight into value

• Looking to reuse and servitize expert knowledge (models, analyses,...)



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Conclusions

Conclusion



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Applications

Opportunities

• Digital Twin: key enabler for Industry 4.0

- We have developed DT applications that serve various purposes
- We have applied the research in various domains
- Many opportunities for collaboration and application in various sectors



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Thank you

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