DATA-DRIVEN DESIGN

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INDUSTRY 4.0 BRIEFLY

- Myriad of cyber-physical technologies are combined to digitally transform industrial activities.
- Result of I4.0 is to create a highly flexible, intelligent, distributed production and service network.
- The end goal: pave the way to reach the concept of a smart factory characterized by:
  - Adaptability, flexibility and efficiency
  - Whilst improving the value delivered to targeted customers.

SOURCE: S.Zindy, University of Manchester.
Research Aim
- Strategically collect and analyse large volumes of data from sensors embedded in products

Outcomes
- Understanding the practical implications of opening up the factory floor by investigating new data security requirements (GDPR) and the risks of converging Information Technology (IT) with Operational Technology (OT) on the factory floor.
- Investigating novel computational intelligence and mathematical methods to reduce noise in product sensor data to identify ‘useful’ data.

Contributions
- Identification of patterns within the IoT dataset using unsupervised Machine learning methods
  - Visualising the identified clusters
- Research on risk assessment methods for Converged IoT and SCADA systems. (Exploring the risk of introducing IoT into the factory)
  - Development of a security architecture

Benefits
- Challenging the assumptions of designers and engineers by analysing data using AI so as to provoke previously unasked questions about products.
  - Enable confidence in secure data flows.
- Scalable infrastructure to handle the volume, reduce storage needs and enable data to be annotated and reused on demand.
PRODUCT ETHNOGRAPHY

Research Aim
• Enable product ethnographers to interact with consumers to conduct data-driven research into why and how these artefacts occurred, gaining insights into how the product could be better designed to fit its use.

Outcomes
• Add on-device processing that can make sense of data as it comes in, reducing the amount of data that is shared. This will allow data to be collected in more places, and shared more easily.
• Develop ways to make use of data in the design process, allowing product designers to quickly and efficiently respond.

Contributions
• Continuous digital ethnography to understand product use at scale.
  • Reduce data at source, and make data collection less invasive.
  • Relate data to use supporting a dynamic, use-driven design process.

Benefits
Combination of live data, machine learning algorithms, and communication with consumers will enable designers and researchers to understand the motivations and issues around product use.
Research Aim
• The investigation of new interface techniques and visualisation methods that will better facilitate data-driven design.

Outcomes
• Streamline design and manufacturing processes to save time and money.
• Enhance product innovation and sustainability.
  • Develop new digital roles that fuse creative design with engineering skills

Contributions
• Allow product designers to exploit new streams of product usage data to become more creative, agile and efficient in their working methods.

Benefits
• Informed design to help product designers exploit new streams of live product usage data and enhance products with new workflows.
HUMAN MACHINE PEDOGOGY

Research Aim
• Current HRI/CHI is limited in that it considers the humans and robots as separate and autonomous entities. Exopedagogy seeks to look critically at this to challenge current working methods and improve them.

Outcomes
• The research will transform basic/abstract theoretical ideas about human-machine pedagogy and post-human forms of learning into a practical typography and applied toolkit.

Contributions
• Mapping how assumptions about human learning derive value in organizations, and using this to suggest practical interventions.

Benefits
• Current limitations may impact on a broad range of values important to businesses, such as: profit; efficiency; quality; creativity; innovation; integrity; teamwork and environmental sustainability. This work will seek to address this and provide an applied toolkit to move forward successfully.
Current Manufacturing

- Resource heavy with limited flexibility
- Does not make best use of individual element skills
  - Human worker dexterity, intelligence and adaptability
  - Strength, accuracy & optimized repeatability of a robot
DYNAMIC MANUFACTURING

Intelligent Task Planning

Design, Data and Regulatory Requirements

Adaptive Assembly Reconfiguration

Total Resource Allocation

Investigative Production Information

Production Indicators

Dynamic Reskilling

Learning Teaching

Production

Product
Future production looks at making better use of the strengths and weaknesses of each element in environments they can work together:

- Adaptability and intelligence of human workers
- Precision and tolerance of repetitive tasks of robot workers

Particularly useful in High Value Manufacture:

- Individualization
- Healthcare
- Biomaterials

Not limited to industrial uses:

- Healthcare, service, home, etc. all require the same technologies in different packages
- With, on or next to a human qualifies
• With continually changing products, how do we ensure the manufacturing process can adjust fast enough?

• Current task planning methods limit the effectiveness of teams by either:

  • Planning entire tasks offline through worker models that limit the ability to react to unexpected behaviour/performance

  • Assigning tasks online on a task by task basis using data from the manufacturing environment that limits optimisation of the task as a whole
Intelligent task planning framework is proposed to manage a human robot team executing a manufacturing task using a semi-online method.

Operates on the principle of:

- Continuously quantifying worker capabilities based on production data collected during execution of the manufacturing task by human robot team (Online)
- Generating new sets of task assignments and task plans between iterations of manufacturing task at set intervals based on updated data (Offline)
INTELLIGENT TASK PLANNING

• **Dynamic Cost Function Generator** used to quantify the capabilities of a worker
  - **Continuous Variables** used for gradually changing factors across a work shift such as fatigue or completion times.
  - **Discrete Variables** used for sudden changes such as errors in completing tasks.
  - These variables are weighted to provide the cost to complete a given subtask

• **Dynamic Task Plan Generator** used to generate an optimal set of task assignments and plan using:
  - **Metaheuristic search algorithms (DGSA)** to quickly and intelligently find an optimal solution
  - **Dual Layer Implementation** searching task assignments in first layer and for each of these finding the optimal task plan in the second layer
INTELLIGENT TASK PLANNING

Benefits

- Task assignments and task plans for human robot teams are adapted to suit capabilities of individual human and robot workers as they change, utilising each worker in tasks most suited to them whilst optimising the whole task.

- Task assignments and task plans can be adapted to gradual continuous changes such as a worker becoming fatigued, or instantaneous changes such as an error in task execution.

- Metaheuristic search methods allow optimum task plans and task assignments to be found quickly and efficiently between task iterations despite changes in performance.

Red lines indicate task allocation shift from a human to a robot for a simulated subtask in an assembly.
With continually changing designs comes the need for continual adaption of skills to produce things.

How do we best train production elements?

- Intelligent knowledge transfer
- Both automated and human
- Ensure “right-first-time” production
DYNAMIC RESKILLING – PRINCIPLES

• Operates on the principle of:
  • Learning various expert knowledge which may not all agree on performing a task, but must have the same outcome
  • There is a correspondence issue between the expert teacher and robot that may result in movements not being optimal for given robot dynamics.  
    • Gives rise to optimization process to be carried out to obtain optimality in terms of energy, cost, etc.
  • Data from manufacturing elements are required to be collected online to obtain optimal task completions

Flowchart of sealing path as a sample task with continuous teaching and learning requirement
DYNAMIC RESKILLING – MAIN COMPONENTS

• **Objective Functions** are used to quantify the movement quality of a robot:
  • **Continuous Variables** the trajectory of robot movement.
  • **Discrete Variables** the place of robots, the order of performing task.
  • These can be updated online to reflect real production requirements and constrains

• **On-Demand Task Programming** is used to program robots optimally in accordance with objective functions using:
  • **Digital Twin** with manufacturing and design processes
  • **Metaheuristic search algorithms** (ACO/Fuzzy type-2/etc, depending on what is happening) to quickly and intelligently find the optimal solution for the objective function

• **Enhanced HR pedagogy** will be used to question the current state-of-the-art thinking for skill transfer, and investigate new possibilities
DYNAMIC RESKILLING - ACCOMMODATING EXPERT BEHAVIOURS

• Interval type-2 fuzzy systems use membership functions which are themselves fuzzy

• Can be used to accommodate motion behaviour of various non-necessarily agreeing experts

• Customized manufacturing products
• Achieves a more fluid evolution of products on the factory floor
• Traceable and ensures “right first time” production
• Accommodates different individuals working with a machine over time
• Enable human in-the-loop based on “digital twin” environment and exopedogogy
• Accommodating design changes whilst minimizing time
• Rapid skill transfer between humans and robots
Chatty Factories – A refined vision…

• New forms of agile engineering product development via “chatty” products through embedded sensors, IoT and data driven design tools.

• Enabling the manufacturing environment to dynamically respond to changes in terms of physical configuration and ethical reskilling of robots and humans.

• Confronting the challenges of data volume, privacy and cybersecurity to develop an access controlled manufacturing ecosystem

• Merging Operational Technology (OT) with Information Technology (IT) in the business.
Next Steps…

• A web-based tool with the capacity to visualise raw data, annotate and then push it to the digital design twin

• Demo of data driven dynamic design: a proof-of-concept demonstrator that allows us to model a change in design, take that through to a digital design twin where product use data can be shown and used to further influence design changes.

• Demo digital twin for manufacture: robot reskilling based on new design instructions, with learning time reduced using both machine learning and better human-robot teaching environments

• Demo of instructions obtained from design digital twin being tested in the manufacturing digital twin and validated before implementation
  • Detailed plans to accomplish integration of design twin with manufacturing twin

• A risk assessment and security architecture to address the risks in the Chatty Factories model, for validation by industrial stakeholders post
QUESTIONS?

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DYNAMIC MANUFACTURING

Research Aim
• To dynamically reskill production elements in response to continuous design changes with minimal retraining time
• Develop an efficient method for dynamically planning and assigning subtasks in manufacturing systems in response to changes in production

Outcomes
• Digital twin link with design to ensure right-first-time production
• Improved autonomous adaption to manufacturing changes
• Ability to accommodate differences in expert knowledge
• Dynamically generate optimal task assignments and plans based on worker capabilities and performance
• Continuously update task plans and assignments to reflect changes across a work shift

Contributions
• Enabling better artificial intelligence approaches to train robots
• Communication between manufacturing and design elements
• Use of metaheuristic search algorithms to dynamically generate optimal task plans based on changing costs

Benefits
• Accommodate design changes whilst minimizing manufacture time
• Rapid skill transfer between humans and robots