Survey about Smart Manufacturing

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- Introduction to Smart Manufacturing
- Human-Robot Collaboration in SM
- Applications in SM
- Open Questions in SM
- Commonsense Reasoning in SM

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Introduction to Smart Manufacturing

- Top ten intelligent algorithms towards smart manufacturing

smart manufacturing is a fully digitalized, connected, integrated, interoperable and collaborative system driven by advanced sensors and big data, showing advantages such as **rapid responsiveness**, **enhanced productivity**, and **optimized energy efficiency**.

new information technologies (e.g. advanced sensors, big data, intelligent systems),
the abilities by virtue of the technologies (e.g. interconnection, integration, interoperability, collaboration),
and the superior production performance (e.g. rapid responses, improved productivity and energy efficiency).

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Capabilities in Smart Manufacturing

- Perceive environments
- Uncover knowledge
- Take wise actions
- Enhance intelligence in manufacturing process

Performance Improvements

- shop-floor scheduling
- equipment prognosis
- product defect detection
- manufacturing service composition

Different Levels

- Shop-Floor Level: Production workers, machines, materials, environment
- Enterprise Level: Resource planning, inter-departmental coordination
- Supply Chain Level: Enterprise interaction and collaboration

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- **Key Processes in Smart Manufacturing**
- Detection
  - Collecting data
  - Monitoring events
- Analysis
  - Understanding negative information
  - Data-driven causality insights
- Prediction
  - Forecasting based on key information
- Decision-Making
  - Making choices based on multiple variables

	Detection →	Analysis →	Prediction →	Decision-making
Supply-chain level	• Risk detection • Anomaly detection • Process event detection • Transportation monitoring • Supplier disruption detection	• Cost evaluation • Supplier evaluation • Vulnerability analysis • Pricing strategy analysis • Service correlation analysis • Environmental performance evaluation	• Cost prediction • Demands prediction • Resilience prediction • Delivery time prediction • Supplier disruption prediction • Collaborative innovative capability prediction	• Supplier selection • Service scheduling • Resource allocation • Enterprise collaboration • Service recommendation • Transportation optimization • Supply-demand optimization • Service selection and composition
Enterprise level	• Inventory monitoring • Staff states monitoring • Energy load identification • Task progress and states monitoring • Product use activity recognition • Security detection of cyber spaces	• Risk assessment • Cost evaluation • Customer discovery • Sustainability evaluation • Competitiveness analysis • Customer demands analysis • Customer satisfaction analysis	• Risk prediction • Order prediction • Default prediction • Inventory prediction • Investment prediction • Customer demand prediction • Enterprise capability prediction • Corporate bankruptcy prediction	• Cost reduction • Factory design • Material selection • Energy conversation • Resource optimization • Inventory optimization • Order acceptance decision
Shop-floor level	• Operation inspection • Bottleneck detection • Material identification • Production monitoring • Product defect detection • Worker/tool/part detection • Equipment failure detection • Energy consumption detection	• Bottleneck analysis • Equipment diagnosis • Defect pattern extraction • Energy consumption analysis • Equipment performance analysis • Rules extraction for process design • Manufacturing failure mode analysis	• Quality prediction • Lead time prediction • Tool wear prediction • Workload prediction • Equipment prognosis • Parts arrival rates prediction • Material removal prediction • Production line states prediction • Energy consumption prediction • Production capability prediction • Remaining useful life prediction • Machine utilization prediction	• Tool allocation • Tool path planning • Equipment selection • Shop-floor scheduling • Assembly optimization • Logistics optimization • Production line balancing • Production process control • Production process planning • Sensor network optimization • Human-machine collaboration • Energy consumption optimization

Fig. 1. An overview of common manufacturing problems.

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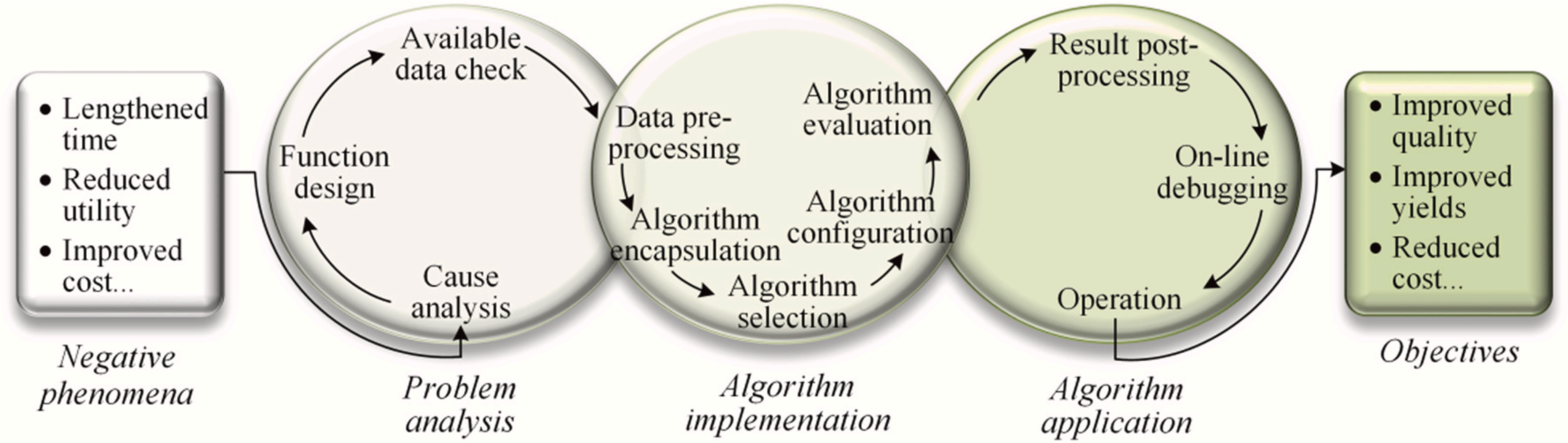

Fig. 10. Application framework of the ten algorithms.

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Human-Robot Collaboration in SM

- An Overview of Human-Robot Collaboration in Smart Manufacturing

• Humans:	• Robots:
• Human experience	• Strength
• Decision-Making	• Repeatability
• Critical Thinking	• Accuracy

Human-Robot Collaboration in SM

- An Overview of Human-Robot Collaboration in Smart Manufacturing

- **Goal**:
  - Create a flexible, efficient, collaborative, consistent, and sustainable manufacturing process.

- **Specifically**:
  - Humans provide decision-making, while machines handle repetitive, hazardous, and high-precision tasks.
  - Even non-specialists can easily communicate and collaborate with machines.
  - Gestures, voice commands, and blinking offer intuitive alternatives to traditional interactions.

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Applications in SM

- Robot learning towards smart robotic manufacturing: A review

Table 7
Typical industrial applications on robot le

Year	Task
2021	Safe interaction [25]
2021	Dynamic and stochastic planning [153]
2021	Collaborative cuboid assembly [154]
2020	Optimization in a tripolar production line [155]
2015	Subtask allocation in collaborative assembly [156]
2016	Lifting, transportation and assembly [157]
2020	Collaborative toy car assembly [158]
2018	Cylinder assembly [159]
2021	Hand-over collaboration [160]
2021	Path generation [161]
2020	Collaborative assembly [162]
2021	Collaborative assembly [163]
2022	Collaborative assembly [164]

- Ensure robot movement avoids collisions for safety (25).
- Address human's dynamic and unpredictable nature in HRC (153).
- Robots adapt to varying proficiency levels among human operators (154).
- Improve robot-human interactive adaptability (155).
- Adjust robot speed to enhance human trust in robot interactions (156).
- Physical contact tasks: teach robots collaboration through demonstrations (157).
- Collaborative toy car assembly (158).
- Solve complex robot programming; adapt to sudden situations in overlapping workspaces with humans (159).
- Part hand-over: robot learns human preferences (160).
- Enable cobots to perform various complex manufacturing tasks through pick-and-place experiments (161).
- Long-term path planning for efficiency improvement (162).
- Address long-range issues via chess-piece-like game movements (163).
- High precision assembly tasks (164).

Applications in SM

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- Robotic grasping

Task
Pick and transport [43]
Separate entangled workpieces [111]
Pick and move [112]
Real-time hand-eye coordinated grasping [113]
Pick and place [114]
Grasp for assembly [115]
Pick by vacuum [116]

- Robotic assembly and disassembly

Task
Steam cooker assembly [117]
Torque converter assembly [118]
Peg-in-hole assembly [119]
Peg-in-hole assembly [120]
Cranfield assembly benchmark [121]
Toy car assembly [122]
Valve body assembly [123]
Square peg-in-hole assembly [124]
Pick-and-place / assembly [125]
Case assembly [126]
Circuit breaker assembly [127]
Peg-in-hole insertion [128]
Gear assembly [129]
Computer assembly [130]
Peg-in-hole assembly [131]
E-waste unscrewing disassembly [132]

Applications in SM

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- Robotic process control

- injection,
- scanning,
- obstacle avoidance,
- fabric manipulation,
- pouring,
- and path-tracking

Task
Brine injection [133]
Quality inspection [134]
Obstacle avoidance [135]
Fabric manipulation [136]
Scheduling in robotic manufacturing cell [137]
Pick and Place without vision [138]
Mobile robot navigation [139]
Path planning for mobile robot [140]
Robot training in cloud manufacturing [141]
Teleoperation [142]
Visual path-following in welding [143]
Pouring [144]
Soft fabric shoe tongues automation [145]
Mobile manipulation [146]
Contour tracking [147]
3D motion imitation [148]
Learn stiffness regulation strategies from humans [149]
Robotic ultrasound scanning [150]
Cooperative handling [152]
Cooperative handling [151]

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Open Questions in SM

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- manufacturing data
- Imbalanced data distribution
- Variety of data formats
- Data missing
- Data uncertainty
- manufacturing problems
- Problem complexity
- Problem uncertainty
- Problem uniqueness
- manufacturing implementation
- Uncertainty in algorithm implementation
- Engineers lack of professional background
- Engineers differentiated experiences

Open Questions in SM

- Robot learning towards smart robotic manufacturing: A review

- Visuomotor Control & Planning
  - Handling high-dimensional images in real-time.
- **Stochastic and unstructured Industrial Scenarios**
  - How to estimate uncertainties and identify unknowns
- Dimension of Observation
  - Varied dimensions for different tasks.
- **Training Systems & Benchmarks**
  - Don’t have universal training systems and benchmarks, like Atari Games.
- Sim-to-real Gap
  - Solution: Digital twins for 1:1 simulation.
- **Multi-agent multi-task robot learning**
  - Inspiration: Game AI techniques.
- **Transfer Learning & Knowledge Sharing**
  - Solution: Cloud robotics and knowledge frameworks.
- **Reward Shaping & Inverse RL**
  - Focus: Establishing effective reward functions.
- Hardware & System Integration
  - Goal: Implement in drones, autonomous vehicles, etc.
- Manufacturing Application
  - Aim: Moving from labs to industries with standards.

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Commonsense Reasoning in SM

- Human-Robot Collaboration With Commonsense Reasoning in Smart Manufacturing Contexts

HRC + CSK（commonsense knowledge）

- This paper presents a novel system on human-robot collaboration guided by commonsense reasoning for automation in manufacturing tasks.

Commonsense knowledge (CSK):

- understanding objects,
- their properties,
- and how they relate to and interact with each other.

Commonsense Reasoning in SM

- Human-Robot Collaboration With Commonsense Reasoning in Smart Manufacturing Contexts

- The four main premises for commonsense knowledge based reasoning are:
- 1. Humans prefer carrying lighter and closer parts due to ease and comfort.
- 2. Humans will carry heavy parts more slowly than light parts.
- 3. Humans should handle less stable parts in order to avoid damaging them.
- 4. Humans should not handle dangerous parts as human safety is imperative.

$$W_a(s_p) = (min_a(s_p) + mean_a(s_p) + max_a(s_p))/3 \quad (1)$$

$$O_1(p) = \sum_{a=1}^{t} r(a_{min}) \times W_a(s_p)/(a(p)) \quad (2)$$

$$O_2(p) = \sum_{a=1}^{t} r(a_{max}) \times (a(p)/W_a(s_p)) \quad (3)$$

$$O(p) = O_1(p) + O_2(p) \quad (4)$$

attribute options	distance	weight	stability	danger	time
cskoriginal	531.8	43.7	24.8	18.9	35.6
cskv3	551.4	39.2	25.8	19	34.8
blank	566.4	49.2	24.9	26.1	37
closest	501.6	49.3	25.6	25.8	37.8
norobot	508.1	52.7	28.1	28.4	36.7
combinations	523.7	40.6	26.1	20.5	35.4
combinationsv3	528.3	40.5	25.5	21.2	35.5
thesis	514.4	44.1	26.6	19.4	35.8

Commonsense Reasoning in SM

- Commonsense-enhanced Natural Language Generation for Human-Robot Interaction

- **Open Challenges**

- Unknown objects and entities
- Reasoning about object utility - beyond visual descriptions
- Inference of objects that are not visible

Discussion