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Machine Learning for Intelligent Industrial Design

Philippe Fournier-Viger[1] [0000−0002−7680−9899], M. Saqib Nawaz[1] [0000−0001−9856−2885], Wei Song[2] [0000−0003−0649−8850], and Wensheng Gan[3] [0000−0002−5781−8116]

[1] Harbin Institute of Technology (Shenzhen), Shenzhen, China
{philfv, msaqibnawaz}@hit.edu.cn
[2] North China University of Technology, Beijing, China
songwei@ncut.edu.cn
[3] Jinan University, Guangzhou, China
wsgan@jnu.edu.cn

17th September 2021

Introduction

- **Industrial design:** process of designing products that are mass-produced in factories (e.g. cars, smartphones)
- Sometimes called **product design** or **new product development**
- Design is important
  - Well-designed products may be acclaimed and generate a large amount of profit
  - Ill-designed products may receive poor reviews, have poor sales, etc.
- **Design** is not easy. **Many constraints**: user satisfaction, how parts are assembled, stored, transported and recycled, profitability, …

Contribution

- **Industrial design has several steps** such as: analyzing potential customers wants and needs, planning, prototype design, and user evaluation.
- During **each of these steps**, **data** can be collected as documents such as product specifications and feedback forms, or by other means such as using sensors.
- **Opportunity**: analyze data generated or used during product design using ML techniques, and to build **intelligent design software**.
- **Contribution**: up-to-date review about opportunities for using ML techniques to **build intelligent software for industrial design**.

Product development

According to Do et al [17], there are five steps:

1. **Product planning**: Learning about the needs of users to write requirements for the design of a novel product.
2. **System design**: Producing a general design of a product as a set of modules, which may correspond to existing product parts.
3. **Detail design**: Producing a detailed design of the product modules by designing its parts, product structure, and creating engineering documents.
4. **Prototyping**: Creating a working prototype of the product based on the detailed design (which may result in redesigning the product).
5. **Preparing the production**: This includes planning required material and resource planning for production.

Product design: Steps 2 and 3

Product development: Steps 1 to 5

The lifetime of a product

Product development is a phase in the **lifetime of a product**:

- **beginning of life** : product design and production.
  - finding out what customers want (marketing research)
  - create a product that meets the desired functions.
  - choosing suppliers (procurement),
  - monitoring product quality in manufacturing,
  - managing the manufacturing equipment to ensure efficiency
- **middle of life**:
  - logistics (inventory, ordering process, product transportation, etc.),
  - customer service,
  - product support,
  - maintenance (preventive and corrective).
- **end of life:**
  - product recovery and recycling.

Lifetime of a product

- The lifetime of a product (from design to recycling) should be considered for product development since they are interrelated [44].
- For example:
  - which supplier or machine will provide/produce the material?
  - how will the product be manufactured, assembled, stored, transported, used, recycled?
  - how much will the product cost?
  - how much profit will it yield?
  - how the product will be marketed? Ignoring these questions during the design phase can cause serious problems
- It is important to fix design problem early to reduce costs!

Product evaluation

- **Product evaluation** is very important.
- Products should be evaluated **as early as possible** in the product development process.
- **Some evaluation techniques**:
  - marketing research to know what the potential customers want,
  - use surveys (or other methods) to evaluate user satisfaction for a prototype or final product
  - Chan [12] proposed an idea screening module to filter bad ideas before starting to design

Methodology

- A systematic literature review (SLR) [9] was conducted.
- **Time span:** Publications from 2006 to 2021
- **Source**: Scopus, Web of Science, DBLP, journals and conferences
- **Keywords**: machine learning, data mining, industrial design, product design, customer satisfaction and parametric design + synonyms
- 150 papers， then reduced to 42
- **Countries**: USA > China/Italy > UK
- **Top 3 venues:** Manufacturing & Service Operations, Expert Systems with Applications and Computers in Industry

ML in Industrial Design - **Data**

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Many **data types** can be collected analyzed during development or any stage of product life [25, 28, 45]:

- data about customer demands (e.g. product function, configuration, quality, cost, brand)
- data about customers (e.g. age, education, travel behavior)
- characteristics of a product and competitor products (e.g. size, weight, color, user manual)
- information related to production (e.g. how parts are assembled, a production plan)
- information related to logistics (e.g. inventory information, how the product will be stored and transported)
- information related to product support (e.g. spare part list, service instructions, customer support data)
- customer feedback about a product (e.g. feedback forms, physiological data, audio, video, location)
- information about how a product is used (e.g. usage environment, usage condition, usage time, failure data)
- information about the manufacturing process (e.g. how machines are used and scheduled to produce product units).
- information about orders, customer transactions, and customer support
- supplier financial data
- sustainability and green practices data
- product inspection results, data about product recycling

ML in Industrial Design - **Data**

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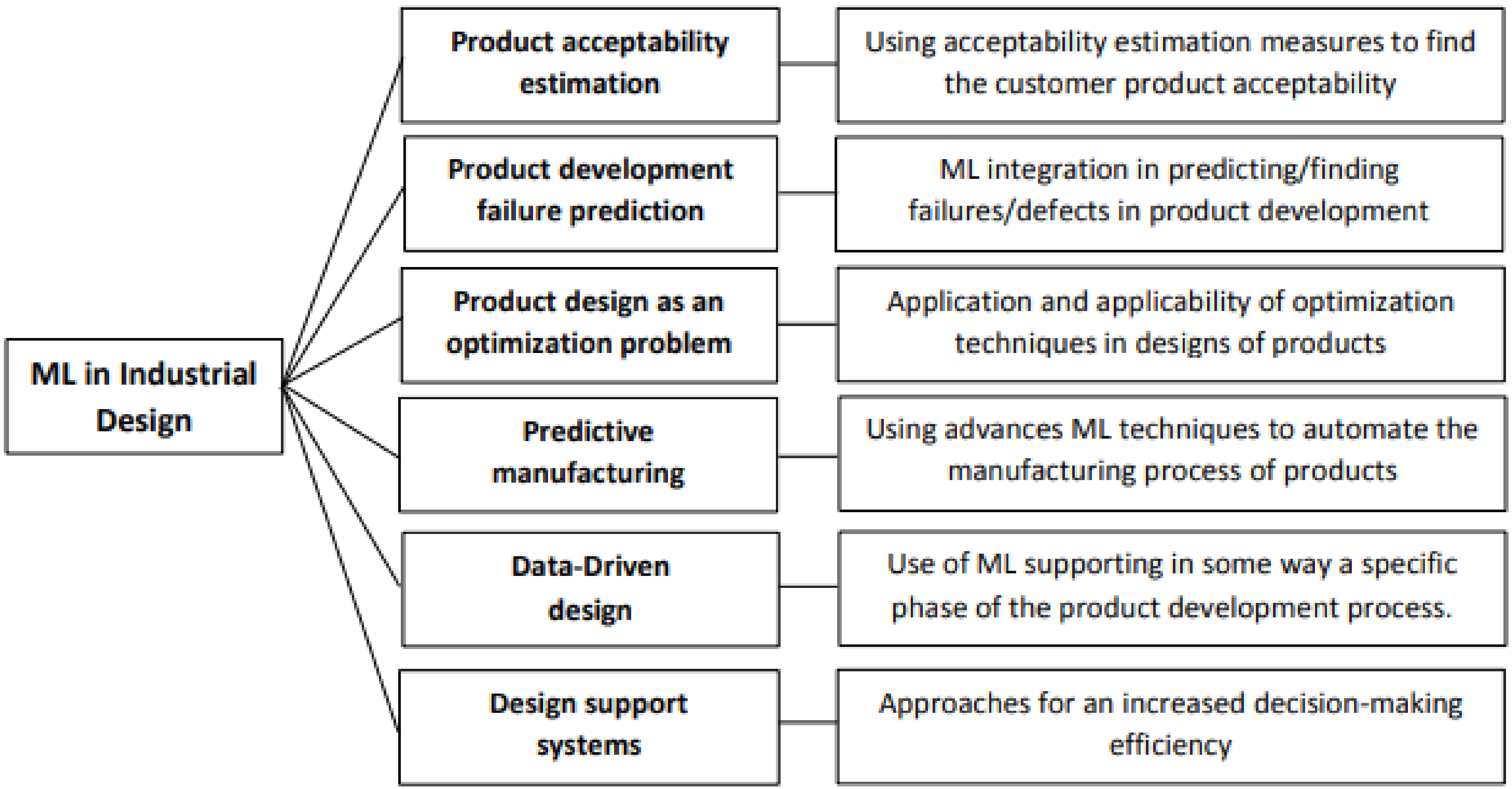
Where to get data?

Several public datasets:

- a **car design evaluation database** from the UCI repository for classification of acceptability of a car design. 1728 instances, and 6 attributes of car: buying, maint, doors, persons, boot, and safety.
  The target attribute for classification : very good, good, acceptable and unacceptable.
  a **dataset of Amazon customer review of products** with star ratings.
  reviews, title and description of products, which products have been purchased together.
  18 years of data, and products are categorized by category.
  Quite interesting and large dataset!
- a **customer spending dataset** obtained from a wholesale distributor which indicates how much money each customer spend on different categories of product each year.

Also possible to **get** or **buy data** from **businesses**… etc.

Recent studies – six clusters



Recent studies – six clusters

(1) Product acceptability estimation

- **Goal:** estimating the probability of success (or failure) of products.
- **Garces et al [19]** uses questionnaires and Bayesian network to predict acceptability of products based on its characteristics。
- **Tang et al. [39]** applied genetic algorithms to generate designs. Designs are then evaluated by a neural network trained based on feedback from users about characteristics of products (phone)
- **Luo et al [20]** model to predict acceptability of car designs.

Limitations: acceptability is based on user perception, some models not evaluated by designers, …

Recent studies – six clusters

(2) Product development failure prediction

- **Do et al. [17]** applied a Naïve Bayes classifier to analyze logs to determine causes of product development failure for student projects.
- [**47] and [29]** detect product defects from social media data and online review, respectively. But cannot detect unknown defects.
- **[32]** can predict service-level failures a few weeks earlier and thus alerts the planners/designers.
- **[36]** for the detection of failures in surface mount devices during production
- **[22]** integrated statistical inference methods and ML techniques to build a framework for product warranty prediction during product development

Recent studies – six clusters

(3) Product design as an optimization problem

- **Shi et al. [34]** presented an optimization framework for product design.
- **[6], [10]** designed efficient methods were developed based on Lagrangian relaxation for the **product line design problems**.
- **Mosavi et al. [33]** considered the design of a product as a problem of finding a design that satisfies multiple objective (constraints), that may be contradictory
- **Tseng & Ganzoury [42]** presented a system to generate design ideas to help designers in the early stages of product design.
- …

Recent studies – six clusters

(4) Predictive manufacturing

- **[27]:** important to predict failure, plan maintenance to reduce costs by monitoring the performance and current condition of machines.
- **Han & Chi [21]** predicted the CNC tool wear compensation offset value by using the support vector regression + other methods
- **Susto et al. [38]** presented a multiple classifier ML methodology
- **Khan et al. [23]** recently proposed a manufacturing analytics model to predict failures in the production process in heterogeneous streams of data

Recent studies – six clusters

(5) Data-driven design

- **[8]** investigated the definitions, uses, and application of data-driven design (DDD) in the concept development process.
- **Fuge et al. [18]** applied machine learning algorithms in recommending design methods taken from the HCD Connect online community.
- **[11], [43]** provided conceptual frameworks to understand the design and innovation in the age of digitization, and their impact on the world of design

Recent studies – six clusters

(6) Design support system

- **[12]** proposed an integrated decision support system (iDSS) to support new product development and help companies in making reliable decisions on new product development.
- **Bedkowski et al. [4]** designed a mobile robot that can provide real-time help for spatial design.
- **[5]** extends the mobile robot [4] to perform qualitative reasoning in the security domain and for spatial design support.

Research opportunities

Analyzing how user think or react to products. This can be done using data collected through sensors, EEG signals, text, feedback forms, etc. A promising topic is to study the influence of emotions on customer satisfaction for products/designs, as well as other reactions such as confusion, motivation and why they occur.

Analyzing how users utilize a product. This can be studied using ML techniques, and by using cognitive models to explain customer behavior. For example, aspects related to spatial cognition such as spatial representations and spatial reasoning can be evaluated. This could be relevant for evaluating the behavior of users in virtual environments, or how user manipulate objects.

Analyzing the user wants and needs. ML can be used to analyze customer reviews from websites and other data. This can allows to analyze/ understand/ predict sale data of similar products or characteristics.

Research opportunities

Analyzing how persons behave as customers. Some interesting tasks are to predict the return on investment, predict which customer will buy a product, and modelling customer buying behavior.

Analyzing data to improve the manufacturing processes. Various data may be analyzed such as data from equipment management, fault detection, inspection data and quality monitoring.

Analyzing data about suppliers. Data about the performance of suppliers can be modelled as well as other aspects.

Discovering and analyzing customers interest from online data: Customers use social media platforms such as Facebook and Twitter to share their opinions. Moreover, companies now store the customers inquires, suggestions, feedbacks and complaints in a database. ML can be used on such online dataset to infer customers interest related to specific products.

Research opportunities

Automating Design practices. Most design practices depend on human decision-making and is a labor-intensive activity. ML techniques such as supervised, unsupervised and reinforcement learning can be used to automate design practices. Moreover, abstract design patterns can be identified with pattern mining that can be applied in the object generation process. Automatic creation and adaptation of design models can increase designers creativity through suggestions of appropriate object shapes. Automation of time-consuming routine tasks will also save time.

Handling specific product types and development processes. In this document the term "product" was used to denote any type of products. But for specific types of products, different research challenges are raised. For example, if we loosen the definition of product to consider a virtual environment or mobile phone application as a product, then techniques for evaluating these products may be different from those used for other products, and other challenges may be faced such as the importance of handling spatial designs. Different challenges may also arise by considering various development processes such as: assemble-to-order, make-to-order and store-to-order [25].

Intelligent design systems. Another interesting possibility for research is to use the product evaluation techniques to build intelligent design systems. In ML, data is analyzed for two purposes: understanding the past, and predicting the future. This can lead to some interesting research opportunities such as

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What kind of expertise is required?

- ML and Statistics,
- Design, Sentiment analysis,
- Opinion mining,
- Text mining,
- Planning/Scheduling,
- Cognitive modeling and User modeling (to better understand the user),
- Human Computer Interactions,
- Marketing,
- Manufacturing (inventory management, suppliers, delivery, cost and feasibility constraints, etc.),
- data collection

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Conclusion

- A detailed survey on the integration of ML in the process of industrial design,
- Six clusters were found
- Research opportunities have been discussed
- Astarting point for further investigation in this area and to suggest interesting research directions…