Extension Intelligence for Process Manufacturing

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Abstract. Artificial Intelligence (AI) is supporting much innovation in intelligent manufacturing in the ubiquitous network information environment, while there are still many problems such as production quality vs costs to produce, and new intelligent theory and method is needed. Based on Extenics, we put forward the concept of Extension Intelligence and analyse the characteristics of extension intelligence, then present its implementation path and steps for the application. Multi-dimensional information and knowledge will be extended from the industrial big data of manufacturing system and the Internet to build the basic-element model in order to deal with engineering problems by extension and transformation algorithms. The application proves the validity of Extension Intelligence.

1. Introduction
The burgeoning new era of big data and ‘Internet plus AI’ is influencing the process industries tremendously, providing unprecedented opportunities to achieve smart manufacturing, and providing unprecedented opportunities to achieve intelligent manufacturing, which is triggering a great change in the models, means, and ecosystems of the manufacturing industry, as well as in the development of AI[1-2]. General key technologies such as the Internet of Things (IoT), cyber-physical systems (CPSs), cloud computing, big data analytics (BDA), and information and communications technology (ICT) are used to enable intelligent manufacturing [3], and Ensemble Sparse Supervised Model is employed to improve the degree of automation [4]. A machining database with data evaluation model is set up to ensure integrity and online monitoring in CNC machining process based on IoT and multi-sensors [5].

The use of big data with predictive models and solution-finding algorithms promotes the data quality and plays an important role in intelligent manufacturing. Along with recent advances in data analytics and machine learning applied to the monitoring, control, and optimization of industrial processes, there is a strong need for more demonstration of model-based tools on realistic problems in order to demonstrate their benefits and highlight any systemic weaknesses [6]. However, there are still some problems in the process manufacturing. For example, (1) when data collection is difficult, data is not sufficient or data quality is poor, it is difficult for us to apply machine learning, data mining and other technologies to acquire knowledge for problem solving and decision-making; (2) restricted by produce capacity, demand, time and space or other factors, many problems such as urgent delivery time but limited capacity, high quality but low price are still difficult to solve even we have sufficient data. In most cases, we can only rely on inspiration and experience to get compromise solutions.

The intelligent human-computer interaction will be the key research direction in the future. Academician Zhang pointed out that human beings have innate knowledge driven ability in problem
solving especially dealing with uncertain problems. The current machine learning has data driven ability and high-speed computing ability in data analysis and processing, and the combination of the two is the development trend of information processing in the future [7]. According to the top-down AI view, it is impossible to build intelligent machines that can solve contradictory problems. These machines only look intelligent, but do not really have intelligence or have autonomous consciousness. One of the main reasons is the lack of mechanisms for extension and transformation. For this reason, this paper puts forward an Extension Intelligence model based on Extenics [8-12] to solve the contradiction problem in manufacturing.

2. The Concept of Extension Intelligence

2.1 The theoretical basis of Extension Intelligence---Extenics

Extenics was founded by Cai Wen[8]. It is applied to study the extension and transformation of things in formalized models and obtain systematic creatives to solve contradictory problems intelligently [13-17]. In recent years, Extenics has been applied in many fields of engineering such as mechanical, information, control, management, designing and other fields [18-20]. Extension data mining method is explored to improve the product manufacturing quality and product qualification rate [21-22]. the achievements in mechanical engineering have shown a good application prospect of Extenics as a novel methodology in intelligent manufacturing.

2.2 Extension Intelligence

Extension Intelligence is a new kind of AI which can deal with contradictions intelligently by extending and transforming information and knowledge based on the theory and methods of Extenics especially extension set. It can intelligently extend the relevant information from the initial conditions and objectives by the multi-dimensional extension and transformation methods in order to build comprehensive base of elements for problem solving. Furthermore, based on the massive data, the rule knowledge of the transformation is obtained by the algorithms such as extension data mining.

Strong artificial intelligence (bottom-up AI) holds that it is possible to produce real reasoning and problem solving. Human like AI, that is, machine thinking and reasoning are just like human thinking. Non-human like AI, that is, machines produce completely different perception and consciousness from human beings [23-24]. As a new method that combines Extenics with AI to deal with contradiction problems and generate systematic strategies intelligently, Extension intelligence is expected to become a bridge from weak AI to strong AI.

2.3 The comparison between extension intelligence and current artificial intelligence

The comparison between extension intelligence and current artificial intelligence from six directions is shown in table 1.

| NO. | Content                  | Current artificial intelligence                                                                 | Extension intelligent                                                                 |
|-----|--------------------------|--------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------|
| 1   | Research objects         | Explicit data and information                                                                   | Explicit and latent data, information and knowledge                                     |
| 2   | Theoretical basis        | Computer science, Cantor set of mathematics, psychology, philosophy and linguistics           | Extesion Set in Extenics, System science, complexity science, philosophy                |
| 3   | Implementation methods   | 1)Programming, such as expert system; 2)Modeling approach, such as generic algorithm and artificial neural network, etc | 1) Institutionalism, process oriented systematic approach, such as strategy generation system; 2) Modeling approach, such as basic-element |
The modelling approach mimics the same or similar approach used by human or biological organisms, by designing an intelligent module for each character, which at first knows nothing, like a newborn baby, but it can learn, can gradually adapt to the environment and cope with various complicated situations.

3. The basic implement directions of Extension Intelligence

3.1. Intelligent extending methods to solve contradiction problems in the situation of insufficient information

When there is no solution to the problem, people not only hope to get the answer of "yes" or "no", but also hope that the machine can analyze the unsatisfied factors or conditions according to the relationship between conditions and goals, provide the knowledge to solve the problem automatically or semi automatically, which is a kind of knowledge-based intelligent manufacturing service. By the way of full path traversal, we can find out the hidden, obscure and fuzzy knowledge to recognize the whole system and internal relevance of the objectives, and often solve the previously seems unsolvable problems. The main steps are as follows:

1) By using the basic-element theory of Extenics and the method of contradiction analysis, the extension model of the problem is established as: \( P = L \ast G \), \( L \) is the current conditions, \( G \) is the goal; the explicit information involved in conditions and objectives are described by matter element, affair element and relation element respectively. The description formula is as follows:

\[
B = (O, C, V) = \begin{bmatrix}
O & c_1 & v_1 \\
& c_2 & v_2 \\
& \vdots & \vdots \\
& c_n & v_n
\end{bmatrix}
\]  

2) From internal data, Internet and multi-source big data, objects, characteristics and values are extracted to build domain basic-element base; then methodology base including extension, transformation and evaluation are established to support intelligent extension based on Extenics.

3) Carry out extended analysis on the goal, such as implication, correlation, decomposition and combination chain and divergence analysis, identify the real final target, and supplement or replace the

![Figure 1. Intelligent extending methods to obtain systematic information for problem solving](image-url)
original goal. In the process of extension, the basic-element base can be further updated and supplemented.

4) According to the extension set theory, the core problem that the existing conditions cannot achieve the goal is analyzed and expanded from the elements, criteria and domains.

5) The conditions are analyzed in terms of correlation, implication, divergence, decomposition and combination chain to supplement new conditions. In the process of extension, the basic-element base can be further supplemented.

6) Judge whether the extended conditions can achieve the new goals, if not, return to step 3 to extend again, until the problem is solved or redefined.

3.2. Extension transformation methods under the conditions of completed data to realize the transformation of the state of products in processing

It is useful to predict the forthcoming result by classification algorithm or other data mining method, but it is not enough for us to change the bad result. As the results come from several steps and the data is collected by sensors or the MIS software, we can do more to find the rules of how to transfer bad to good during the processing procedures based on Extenics and data mining. The main steps are shown in figure 2 as follows:

1) Prepare necessary data. Including three types of data as following. T1, basic data in static, such as product type, raw material, operator, equipment information, etc.; T2, process data, such as equipment parameters, environmental temperature, humidity, accuracy level, pressure, temperature, etc.; T3, final result data, such as the label of qualified, unqualified after product inspection, etc.

2) The above data are integrated and connected into a large table, including basic information, process information and result labels.
3) After the accuracy of test set data classification reaches more than setting degree, for example 75%, the main features of the category are extracted by using decision tree and other methods to supplement the dynamic information of the basic-element base.

4) Using the extension data mining method to obtain the rule knowledge of transformation from bad to good, for example, in a certain state, adjusting the processing temperature of equipment \( H \) can increase the qualification rate by 2%, support=23%, confidence= 69%.

5) The transformation rule knowledge obtained by extension data mining is applied to the process manufacturing. For example, when it is predicted that a WIP is about to become a non-conforming product in the \( K^{th} \) process, the conversion rule suggests to improve the processing accuracy by one level in the \( K+4^{th} \) process, then the WIP will finally become a qualified product with 73.9% probability.

4. Case study

For many years, enterprise \( A \) in the suburb and enterprise \( B \) in the urban area have maintained the cooperation that \( A \) machining product parts for \( B \). Last year, due to the improvement of environmental protection requirements, \( A \) invested in the transformation of the production line, and with the increase of employees' wages, the cost of processing increased. In the renewal of the contract with \( B \), it was proposed that the cost of single processing increased by RMB 30, while company \( B \) could only increase by RMB 10 at most. The negotiation of processing price was in a deadlock.

It's difficult to reach an agreement just on price. By extension analysis we found that: in the previous cooperation, enterprise \( A \) was responsible for fetching and delivering the parts to be processed to and from enterprise \( B \). On the other hand, the freight car of enterprise \( B \) often returns empty after delivering the goods to the transfer destination, and the return route will pass through enterprise \( A \). Thus, a new cooperation scheme is obtained: enterprise \( B \) uses the spare capacity of vehicles to transport the parts to be processed and is responsible for transporting the processed parts back to enterprise \( B \); furthermore, \( B \) introduced a consultant engineer to analysed the producing data by extension data mining and gave a lots of suggestions to improve the quality but no much cost added. So, enterprise \( A \) saves the cost of producing and car rental for transportation and keeps unchanged the price of processing for enterprise \( B \). They get a win-win solution from deadlock.

5. Conclusions and future research directions

From the perspective of the integration of Extenics and artificial intelligence, this paper studies the new model of extension intelligence to obtain the transformation knowledge by means of man-computer collaboration with the methods of modelling, extension, transformation and extension data mining, so as to solve the contradiction problems in manufacturing. The extension intelligence is a new direction of intelligent engineering problem solving. From the view of artificial intelligence, it is an inverse operation algorithm of most existing artificial intelligence which can extend information and knowledge based on uncertain small data. The main contradictions that will be solved by extension intelligence in the field of process manufacturing may as following:(1) The contradiction among cost, quality and efficiency; (2) The contradiction between demand individuation and industrial production; (3) The contradiction between work simplification and standardization; (4) The contradiction between automation and human centred management.

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