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Automatic Visual Inspection Reconfigurable Model of Piston Assembly Based on Extentics

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Abstract

As a visual inspection system can't meet all the testing demands of various types of piston assembly, a visual inspection reconfigurable model for piston assembly was designed. A five-layer gray box model was established based on analyzing the process of visual inspection, and expressed by extension element; On this basis, a foundation scheme library was made using extension transform and generation strategy; The optical scheme was evaluated and chose by Analytic Hierarchy Process (AHP). This model can realize reconfigurable visual inspection automatically, improve the adaptability of visual inspection, solve the contradictions between custom requirements and existing condition, time and production cost.

Keywords*: extentics, piston assembly, visual inspection, reconfigurable model, analytic hierarchy process*

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1. Introduction

The piston assembly is an important process of automatic engine assembly. To reduce production cost and improve the equipment utilization, sometimes it is necessary to undertake a variety of types of piston assembly in the same production line for the user's individual requirements. However, the specification of various pistons such as quality and performance is inconsistent, if the piston is installed wrong or neglected it will lead to decrease the whole engine performance or cause serious consequences, so it is necessary to be inspected in the assembly process.

Visual inspection is applied more in detection system for the advantages of real time, efficient and non-contact [1-3]. However, each visual detection algorithms and systems have a certain scope of application. A same visual inspection system can not meet all the detect requirements of various pistons assembly with different dimensions and parameters. Such contradictions can be attributed to the following four cases:

(1) The indicators such as the detection accuracy and test speed of detection system need to be further improved but the original detection system can not meet the requirements;

(2) New test items need to be added but the original detection system can not meet the requirements;

(3) The detection objects are changed but the original detection system can not meet the requirements;

(4)The detection environment is changed but the original detection system can not meet the requirements.

The existing detection systems (condition L) can not meet new requirements (target G) result in the emergence of the four cases above, that is to say there exist contradictions. Extenics [4, 5] studies rules and methods to solve the contradictions from the view of qualitative and quantitative using a formalized tool, which has been widely applied in engineering project [6-7].

Reconfigurable design [8-10] is a variable design method to quickly adjust product function, structure and production capacity by reconfiguring, re-using and updating the system configuration or subsystem.

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In allusion to above problems, an automatic visual inspection reconfigurable model is proposed in this paper based on extenics for various types of piston assembly, which is to solve the contradiction of visual inspection for piston assembly of multi-mode in the same production line.

2. The Extentics Model of Visual Inspection for Piston Assembly
2.1. Five Layer Grey-box Model for Visual Inspection

In the piston automatic assembly process, the pistons is sent to the installation location by the transmission system, and then it is installed in the cylinder hole by assembly robot, the whole process is done automatically. The visual inspection system for piston assembly is shown in Figure 1.

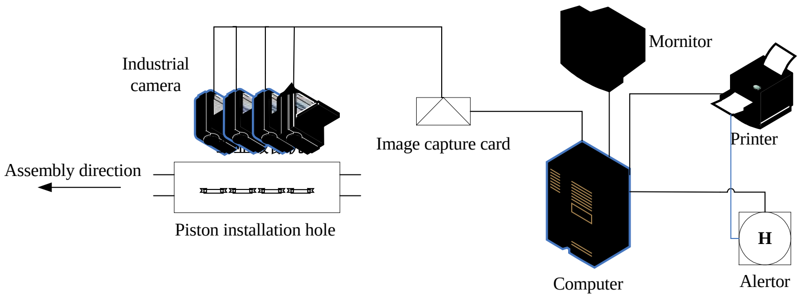

Figure 1. Visual Inspection System of Piston Assembly

As shown in Figure 1, the input in the visual detection system of piston assembly is the piston assembly image and the output is the mechanical movements. The visual detection system of piston assembly can be come down to a five layer grey-box model considering external factors and the conduction effects of relationship in the systems. As shown in Figure 2, data flows from bottom up, and the amount reduces gradually in this model.

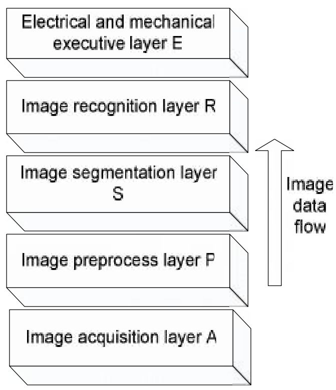

Figure 2. Five-layer Grey-box Model of Inspection System

2.2. The Extentics Model of Piston Visual Inspection System

Extenics expresses the relationship of substance between quality and quantity by matter-element. Given an object N, with the value of characteristic c is v, an ordered triple $R=(N,c,v)$ is used to describe the basic element.

For the five layer grey-box model of automatic visual inspection of the piston assembly showed in Figure 2, the extension matter-element model is established as follows:

$$M_{\mathrm{T}} = (O_T, C_T, V_T) = \begin{bmatrix} O_{\mathrm{T}}, & c_{TA}, & v_{TA} \\ & c_{TP}, & v_{TP} \\ & c_{TS}, & v_{TS} \\ & c_{TR}, & v_{TR} \\ & c_{TE}, & v_{TE} \end{bmatrix} \quad (1)$$

Here, O_{T} represents the detection system, C_T represents operations and V_T represents methods.

2.3. Extension Transformation

The method of extension transformation is a process to put an object into another object or break up into several objects, which is the basic technology of the generation strategy. It can be formalized by affair-elements:

$$T = \begin{bmatrix} O_{T'}, & c_{T1}, & v_{T1} \\ & c_{T2}, & v_{T2} \\ & c_{T3}, & v_{T3} \\ & c_{T4}, & v_{T4} \\ & c_{T5}, & v_{T5} \\ & c_{T6}, & v_{T6} \\ & c_{T7}, & v_{T7} \\ & \cdots & \cdots \end{bmatrix} = \begin{bmatrix} Transformation, & Control\ objects, & v_{T1} \\ & Accept\ objects, & v_{T2} \\ & Transformation\ results, & v_{T3} \\ & Agent\ objects, & v_{T4} \\ & method, & v_{T5} \\ & tools, & v_{T6} \\ & time, & v_{T7} \\ & \cdots & \cdots \end{bmatrix} \quad (2)$$

$O_{T'}$ ——the transformation implemented, the transformation commonly used is as follows:

$$O_{T'} = \{replacement, decomposition, add, delete, expand, shrink, \cdots\}$$

3. The Reconfiguration of Piston Assembly Visual Inspection

3.1. The Architecture of Reconfiguration System

A piston assembly visual inspection system can not meet the detection requirements of various types of piston assembly which had been mentioned in the previous analysis. Aiming at the contradiction, a visual inspection system for piston assembly can be established using the extension model and extension strategy mentioned above. The architecture of the detection system is shown as Figure 3.

The scheme mainly includes three parts: scheme generation, scheme transformation, and scheme evaluation. First, the goals and conditions of piston assembly visual inspection were analyzed, the extension model was established, information was extracted on this basis, and the primitive database was established. And then elements involved in were expanded according the extension reasoning rules. The range of possibilities was obtained and put into the question library by the expansion rules according to the domain of discourse, association rules and elements that the issue involved; A variety of strategies were generated by using the extension transformation and transmission rules, and stored in the strategies library; Strategies were evaluated and screened according to goodness evaluation rules, what's more, it was sorted based on the goodness, the strategy with highest goodness was selected as a reference for decision maker.

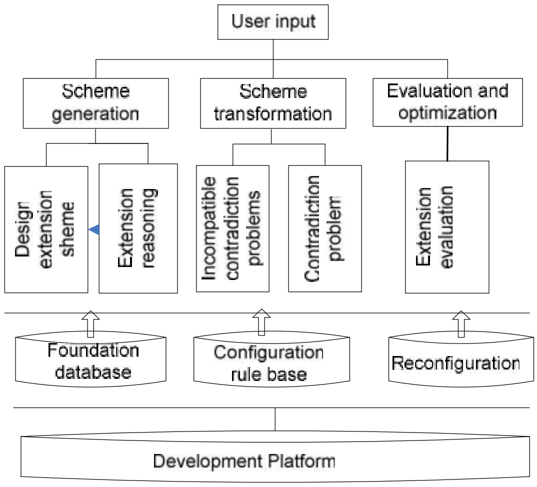

Figure 3. Architecture for Reconfigurable Inspection System

3.2. The Reconfiguration for Visual Inspection System

Suppose L is the existing condition of the visual inspection for piston assembly, G is a new target of the system, it can be expressed as follows:

$$P = G * L \tag{3}$$

Here $L=\{L_A, L_P, L_S, L_R, L_E\}$ are the conditions and methods commonly used in the system. L_A represents the process of image acquisition with hardware of Daheng acquisition card or digital camera, etc.. L_P represents the process of image preprocessing with methods of gray transformation (such as image complementation, contrast stretch, etc.) or histogram modification (such as equalization, specification, etc.), and so on. L_S represents the process of image segmentation with ways of Roberts, Sobel, Canny, etc. L_R represents the process of image recognition with approaches of feature extraction and classification. L_E represents the process of execution with modes of automatic control and mechanical execute.

Taken the existing inspection system T_A suited for piston A as condition L, the target is to design an inspection system T_B suited for piston B.The extension model of the problem can be shown as follows:

$$\begin{aligned} P &= G * L \\ &= \begin{bmatrix} detection & control\ object, & piston\ B \\ & agent\ object & T_B \end{bmatrix} * \\ &\begin{bmatrix} tool & methords & T_A \\ & suitable\ object & single \end{bmatrix} \end{aligned} \tag{4}$$

To convert the detection system T_A into detection system T_B, it can be obtained by the transformation of the condition matter-element L_A, L_P, L_S, L_R.

The element model of the existed detection system T_A is established as Equation (5):

$$
\begin{aligned}
T_A &= L_{A1} \oplus L_{P1} \oplus L_{S1} \oplus L_{R1} \oplus L_{E1} \\
&\text{==Z=}\left(O_{A1}, acquisition \quad image\ acquisition\ card\right) \oplus \\
&\begin{bmatrix} O_{P1}, & gray\ transformation & complementation \\ & histogram\ modification & equalization \\ & filtering & mean\ \ filtering \end{bmatrix} \oplus \\
&\left(O_{S1}, segmentation \quad Robert\right) \oplus \\
&\begin{bmatrix} O_{R1}, & feature\ extraction & boundary\ characteristic \\ & recognition & discrimination\ \ function \end{bmatrix} \oplus \\
&\begin{bmatrix} O_{E1}, & automatic\ control & computer\ \ control \\ & mechanical\ executing & pneumati\ cactuator \end{bmatrix}
\end{aligned}
\quad (5)
$$

L_{S2} is obtained using extension transformation shown in equation (2) to transform the matter element L_{S1} by extension transformation d_{S1}, the detection system T_A is transformed into T_B. The matter-element model of detection system T_B is shown as Equation (6) below:

$$
\begin{aligned}
T_B &= L_{A1} \oplus L_{P1} \oplus d_{S1} L_{S1} \oplus L_{R1} \oplus L_{E1} \\
&= L_{A1} \oplus L_{P1} \oplus L_{S2} \oplus L_{R1} \oplus L_{E1} \\
&\text{==Z=}\left(O_{A1}, acquisition \quad image\ acquisition\ card\right) \oplus \\
&\begin{bmatrix} O_{P1}, & gray\ transformation & complementation \\ & histogram\ modification & equalization \\ & filtering & mean\ \ filtering \end{bmatrix} \oplus \\
&\left(O_{S2}, segmentation \quad Sobel\right) \oplus \\
&\begin{bmatrix} O_{R1}, & feature\ extraction & boundary\ characteristic \\ & recognition & discrimination\ \ function \end{bmatrix} \oplus \\
&\begin{bmatrix} O_{E1}, & automatic\ control & computer\ \ control \\ & mechanical\ executing & pneumati\ cactuator \end{bmatrix}
\end{aligned}
\quad (6)
$$

The piston vision solutions database is established as shown in Figure 4 using the above extension transformation and generation strategy, which carries out the piston assembly visual inspection system reconstruction.

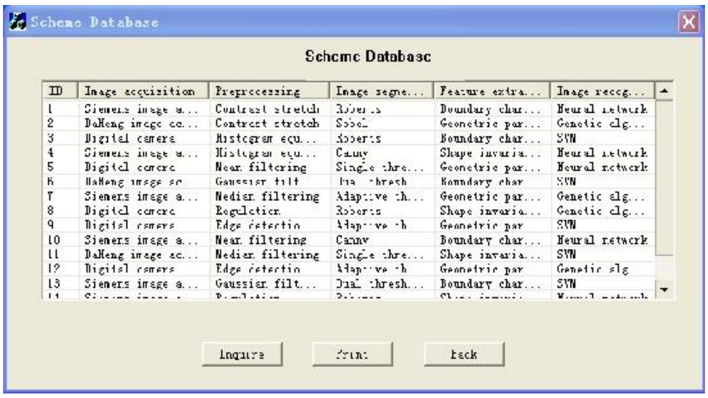

Figure 4. Scheme Library of Visual Inspection System

4. The Optimal Solution Selection

According to the composability of primitives, $m(m \leq n)$ elements are taken from the n expanded condition matter element as a group, and constitute one scheme then several detection systems can be reconstructed to meet the specific requirements. The number N of schemes for automatic visual inspection system reconstructed can be calculated as follows:

$$N = C(n,m) = \frac{A(n,m)}{m!} = \frac{n!}{(n-m)!m!} \tag{7}$$

The N visual detection schemes shown in Figure 4 are compared and the one with best performances is chosen to get the best reconfigurable system. The piston assembly visual inspection system is a complex system, as for evaluation of multi-level factor like this, AHP [12, 13] method is used to determine the weight of each factor.

4.1. Comprehensive Evaluation of the Hierarchical Model

In line with the comprehensive analysis of the process of piston automatic visual inspection, the hierarchical model of evaluation index can be built as shown in Figure 5. In this model, the target layer represents advantages and disadvantages of the scheme; criterion layer is five evaluation factors, such as image acquisition, image preprocessing, image segmentation, image recognition and electromechanical actuator; sub-criteria layer is specific targets contained for each factor (shown in Table 2).

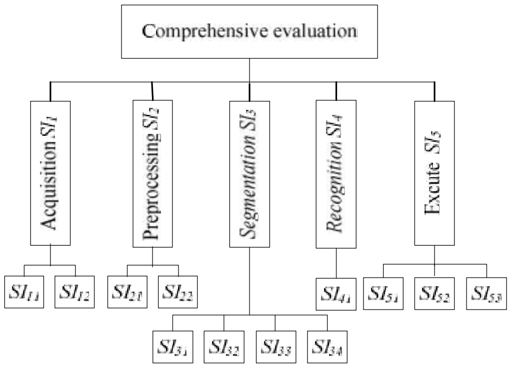

Figure 5. Evaluation Model of Inspection System

4.2 Weight and Correlation Functions

The hierarchy model shown in Figure 5 model is established, then the factors that each level contains compares with a factor on previous level as the comparison criteria. A pairwise comparison matrix is constructed with 1-9 grade scale proposed by Satty [14]:

$$A = \left(a_{ij}\right)_{n\times n}, a_{ij} > 0, a_{ji} = \frac{1}{a_{ij}} \tag{8}$$

a_{ij} ——value of 9 scale grade.

The eigenvalues are calculated by equation (9), the normalized w is taken as the sort weights with criterion SI_i for element SI_{ij}.

$$Aw = \text{a}_{\max} w \tag{9}$$

$\text{a}_{\max}$ ——the largest eigenvalue of A

Evaluation index weights for the visual inspection system calculated by Equation (8) and (9) are as shown in Table 1.

Table1. Evaluation Index and its Weights of Inspection System

sublayer	weights	evaluation index	weights
SI_1	0.41	SI_{11}	0.25
		SI_{12}	0.75
SI_2	0.04	SI_{21}	0.25
		SI_{22}	0.75
SI_3	0.14	SI_{31}	0.11
		SI_{32}	0.19
		SI_{33}	0.35
		SI_{34}	0.35
SI_4	0.19	SI_{41}	1
SI_5	0.19	SI_{51}	0.17
		SI_{52}	0.44
		SI_{53}	0.39

According to the actual requirements of the detection system, the correlation function is established as shown in Table 2.

Table 2. Correlation Functions of Index

Index	SI_{11}, SI_{21}	SI_{41}, SI_{53}
Correlation function	$k_{11}(x)=k_{21}(x) = \begin{cases} \frac{x}{3}, x \le 0, \\ \frac{3-x}{3}, x \ge 0, \\ k(1) = 0 \vee 1, x = 0, \end{cases}$	$k_{41}(x)=k_{53}(x) = \begin{cases} \frac{x-0.6}{0.4}, x \le 1, \\ \frac{1-x}{0.4}, x \ge 1, \\ k(1) = 0 \vee 1, x = 1, \end{cases}$
Index	SI_{12}, SI_{22}	$SI_{31}, SI_{32}, SI_{33}, SI_{34}, SI_{51}, SI_{52}$
Correlation function	$k_{12}(x)=k_{22}(x) = x-20$	$K_{31}(x)=K_{32}(x)=K_{33}(x) =K_{34}(x)=K_{51}(x)=K_{52}(x) = \begin{cases} 5, & x=A \\ 4, & x=B \\ 3, & x=C \\ 2, & x=D \\ 1, & x=E \end{cases}$

4.3 Goodness calculation

The goodness is calculated according to Equation (11) based on the relational degree calculated by Equation (10).

$$k_i = \sum_{k=1}^{m_i} \sim_{ik} k_{im_i} \tag{10}$$

$$C(Z_j) = \sim K(Z_j) = (\sim_1, \sim_2, \cdots, \sim_n)\begin{bmatrix} k_1 \\ k_2 \\ \vdots \\ k_n \end{bmatrix} = \sum_{i=1}^{n} \sim_i k_i \quad (11)$$

5. Experiments and Results

In line with the previous extension model about visual detection, three detection schemes Z_1 Z_2 and Z_3 are reconstructed on a certain piston assembly detection system, and the indicators shown in Table 3.

Table 3. Indexes of System Z_1, Z_2 and Z_3

	SI_{11}	SI_{12}	SI_{21}	SI_{22}	SI_{31}	SI_{32}	SI_{33}	SI_{34}	SI_{41}	SI_{51}	SI_{52}	SI_{53}
Z_1	0.8	45	0.2	40	B	C	B	A	75%	C	A	65%
Z_2	2	30	1.7	30	C	B	C	D	80%	C	B	80%
Z_3	2.5	20	2.8	28	D	C	D	C	85%	B	C	75

Then the corresponding correlation was obtained according to Equation (10):

$$k(Z_1) = \begin{bmatrix} 18.93 \\ 15.23 \\ 3.81 \\ 0.25 \\ 2.76 \end{bmatrix}, k(Z_2) = \begin{bmatrix} 7.58 \\ 7.61 \\ 2.84 \\ 0.5 \\ 2.47 \end{bmatrix}, k(Z_3) = \begin{bmatrix} 0.04 \\ 6.02 \\ 2.54 \\ 0.63 \\ 2.1 \end{bmatrix}$$

And the system goodness was obtained according to Equation (11):

$$C(Z_1) = 9.47 \quad C(Z_2) = 4.37 \quad C(Z_3) = 1.14$$

It's clear that $C(Z_1)$ is the maximum value, so Z_1 was chosen as the optimum system.

6. Conclusion

(1) A five gray-box model is proposed based on the analysis of visual inspection system for piston assembly, which vividly expresses the process and the amount of data decreasing of the automatic visual inspection system;

(2) An extension primitive model for visual inspection was established, and a basis visual inspection scheme library was built by extension transformation;

(3) The goodness of each layer was evaluated using analytic hierarchy process. A comprehensive assessment model of visual inspection was established, and the weight of each index and the correlation function in the model were determined, then the scheme with higher goodness was selected as a visual detection scheme for piston assembly.

The extentics model implements the detection of several types piston assembly in a same production line by restructuring detection scheme, solves the contradictions between customer's customization, production costs and time, what's more, it improves application efficiency of the visual detection system.

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