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Web-based Polishing Process Planning Using Data-mining Techniques

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Abstract
A Web-based portal system (WBPS) is developed to implement process planning that aims to streamline polishing products and processes. This Web application system mixes its functions of providing intelligent decision support to polishing enterprises by facilitating the sharing of vast collective polishing knowledge, as well as addressing the hindrance problem of subjective human determination of knowledge discovery using data-mining techniques. WBPS will create an important knowledge base for parameter optimisation using fuzzy logic and genetic algorithms through laboratory experiments and field studies within collaborating companies. Another aim of developing WBPS is to cope with the vast collective polishing knowledge, information sharing across the companies and applicable case initialisation. Functionality of WBKP will be explained with provision of online interfaces, access integration to polishing expertise and values, and application embedment to serve as self-documenting activities.

2.1 Introduction

Polishing process is a mechanical finishing process regarded as a common practice to enhance product value [2.1][2.2] by removing a considerable amount of metal or non-metallic and to smooth a particular surface. Figure 2.1 illustrates a model to simply demonstrate how polishing generates additional value for products. It has been widely used as a finishing process for a wide variety of manufactured products, including kitchenware, watch belts, jewellery, automobile interiors and other souvenirs items.

In polishing industries, product designers and production engineers have developed a huge range of products for their customers or buyers, meeting diverse product requirements. They will also practice product customisation to design products for customer approval according to customers' specific requests and updated market trends. This kind of continuously renewed product knowledge can become a company's competitive advantage and further implement Customer

Relationship Management (CRM) well in developing their own marketing strategies. Polishing enterprises can make efficient use of their practicable past experiences in product development to swiftly generate polishing process plans after receiving customised feature specification from their customers.

Figure 2.1. Basic model of polishing process adding product value

An ideal practice is for polishing enterprises to store successful and useful projects on their database system after the projects are completed. Key polishing information such as product structure and operation process parameters can be referred to in the future, provided that production reordering is launched or products of similar kinds are exploited. However, it is not unusual to see polishing technicians and operators making their own judgments to determine which projects to retrieve for use upon receiving a new product specification request. There is a lack of systematic approaches to case matching by impersonal assessment of polishing projects. Also, polishing enterprises seem to be unable to store this valuable information and share among their departments. These pieces of polishing experience are only focused in a small group of experienced polishing masters, which may encounter a possibility to be lost or to gradually vanish after these masters retire. Polishing enterprises seem to have no system for keeping track of this vital polishing information [2.2], storing key process parameters and interacting between parties and providing decision support [2.3][2.4]. Furthermore, another significance of process planning is to support the sharing of polishing operation knowledge and experience. However, the current situation is that it is not easy to extract this polishing knowledge because the processes are still operated on the basis of traditional subjective human determination, even if most polishing industries make use of automatic machinery nowadays. The quality of polished products can not be guaranteed.

In an attempt to relieve the information-sharing, case-retrieval and knowledge-extraction problem, our project is to develop a Web-based portal system aimed to propose a total solution to streamline the polishing product and process and to facilitate communication across the polishing enterprise. The system is supported by development of a knowledge base for optimisation of polishing process parameters. Up to now, the mechanism of polishing processes is still under investigation. It could be regarded as a black box by outsiders. Fuzzy modelling is one of the techniques currently used for extraction of knowledge of nonlinear, uncertain, and complex systems [2.5][2.6] and it has been applied successfully in many cases [2.7], especially in control engineering. Park *et al.* [2.8] showed that the introduction of genetic algorithms could improve the performance of fuzzy control systems. The introduction of genetic algorithms into fuzzy systems, which is known as genetic-fuzzy systems, was successfully applied to different areas [2.9][2.10]. However, it has not been applied in the polishing of stainless steel.

This chapter is organised as follows. A literature review is presented in Section 2.2. Then the concept of process planning for polishing is described in Section 2.3. Section 2.4 illustrates the framework of a Web-based portal system for polishing. Section 2.5 describes the methodologies of knowledge-base development. The results and discussion of the knowledge-base development are delivered in Section 2.6. Finally, conclusions are presented in Section 2.7.

2.2 Literature Review

2.2.1 Research Works in Polishing

In the study of polishing, research efforts have been focused on the polishing mechanism and modelling of the polishing process. In abrasive polishing, Samuel [2.11] stated that several researchers tried to explain the interactions between the abrasive and the substrate in the 19th century. However, it has recently been established that the concept is false. The polishing mechanism seems to be not fully understood and there are still many uncertainties. Currently, major polishing guidelines are provided. Davis [2.12] stated qualitative procedures to achieve different grades of finishes. Dickman [2.13] suggested wheel speeds for hand buffing for different materials and production techniques for achieving satin finishing, cutdown buffing and colour buffing for some materials. Reyers [2.14] recommended the work pressure and wheel speed for different applications. It seems to be too general to apply these features in specific materials.

2.2.2 Web Application for Knowledge-based Planning

Knowledge application and knowledge creation are at the core of any organisation's existence. Without knowledge, companies cannot survive. The relevance of various knowledge differs between organisations and changes over time. A professional organisation, that is, an organisation of so-called "knowledge workers" [2.15][2.16], leans more heavily on its intellectual assets than the average production firm.

Knowledge management is the management of corporate knowledge that can improve a range of organisational performance characteristics by enabling an enterprise to be more "intelligent acting". It is not a new movement *per se*, as the organisations have been trying to harness their internal processes and resources that have resulted in various movements over the years, such as total quality management, expert systems, business processes re-engineering, the learning organisation, core competencies, and strategy focus.

Most organisations already have a vast reservoir of knowledge in a wide variety of organisational processes. However, these organisations could not fully utilise their valuable recorded knowledge to further their business. Up to 2001, it did not seem evident that managerial users could focus on developing business applications that provide them with predefined planning reports giving them the information they need for decision-making purposes [2.17]. Even if the concept of a management information system (MIS) started to be developed by 1970, such systems are still not adequate to meet many of the decision-making needs of management [2.17]. This knowledge is quite diffused and mostly unrecognised. Often, organisational culture itself prevents people from sharing and disseminating their know-how in an effort to hold onto their individual powerbase and viability. Determining who knows what in an organisation itself could be a time-consuming and daunting task. This, in itself, justifies the need for a system to manage important knowledge assets for the organisations to allow them to identify and access workers' skills and expertise.

A Web-based portal system is a knowledge-based system developed with artificial intelligence that has many applications in the cognitive science area [2.17]. It enables e-business by provision of a unified application access, information and knowledge management within enterprises, and between enterprises and their trading partners, channel partner and customers. Users can add a knowledge base and some reasonable capability to the information system. A portal system is regarded as a key technical application to create an interface that presents polishing information to users and a gate to users to access the required data sources and knowledge acquisition [2.3][2.18]. Significant and invaluable polishing knowledge is collected and kept track of for future use [2.2], providing a way to shorten the product development time in later process planning and to smooth the knowledge management. It can be viewed as a way to access disseminated information within a company since information chunks can be stored in various systems using different formats. One of the major differences between a traditional Web site and a portal resides in the fact that the portal is usually tailored according to users' need. A portal is, consequently, a single point of access to Internet resources, an integration platform focusing on unification oriented towards the business processes of the companies. Therefore, portals synchronise knowledge and applications, creating a single view into the organisation's intellectual capital. The best example in this category is Yahoo. Today, the term "portal" is widely used to describe many different modules with corresponding interfaces for different purposes.

An enterprise portal can be defined as a single point of access (SPOA) for the pooling, organising, interacting, and distributing of organisational knowledge [2.19][2.20]. While it is true that enterprise portals are useful because this technology can bring about cost reduction, organised and structured information, and reduced access time, their competitive advantages are inherent in their abilities to filter, target, and categorise information so that users will get only what they need [2.21]. My Yahoo!, which was developed in 1998, was the first personalised Internet enterprise portal. Campus portals were pioneered by UCLA in 1999 [2.22]. Enterprise portals have fairly complex structures and features. However, their basic functions and elements are relatively easy to define. First, from an operational perspective, the strength of corporate portals lies in their ability to provide Web-based access to enterprise information, applications and processes. Second, in a functional view, they leverage existing information systems, data stores, networks, workstations, servers and applications as well as other knowledge bases to give each employee in every corporate site immediate access to invaluable sets of corporate data anytime and anywhere [2.20][2.23]. These capabilities are made possible because the generic framework is essentially focused on delivering information to the users from disparate databases.

2.2.3 Case-based Reasoning

Case-based reasoning stands for adapting the past solutions to resolve new problems or requests. It involves utilisation of precedent-applicable cases as paradigms to explain the new case. Sometimes, these selected existing cases even undergo revision in an attempt to match a new case's problem. A reasoning mechanism of case-based reasoning should be a learning system so that it has the capability to conduct evolution by itself, with the use of its own knowledge, to generate more feasible and consistent solutions to problem cases.

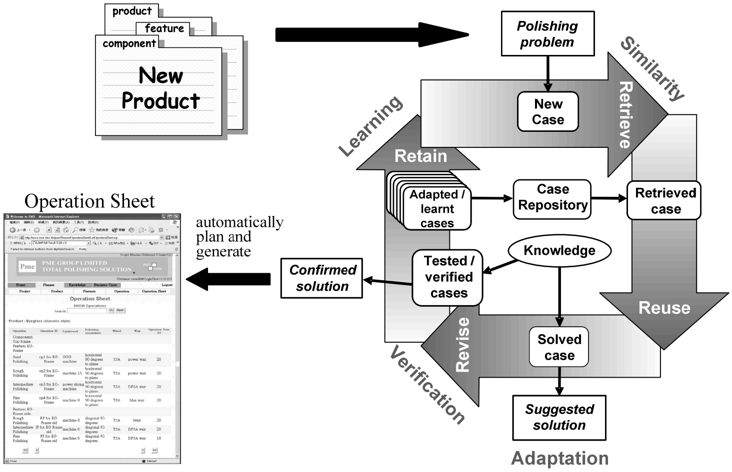

Figure 2.2. Artificial process planning with CBR to polishing problem

With adoption of the concept of case-based reasoning developed by Aamodt and Plaza [2.24], a polishing problem is studied to be resolved by optimal solutions derived from artificial process planning of WBPS, as demonstrated in Figure 2.2.

1. Case retrieval: The objective of this step is to retrieve the old cases stored in case libraries.
2. Case reuse: In case-based process planning, the selected old solution case is used as an inspirited candidate solution to solve the new problem case.
3. Case revise: Since a new problem case may not exactly match the old ones, the old knowledge may often need to be revised to generate a proposed solution case to fit the problem. The proposed solution will be verified as to whether it can solve the problem.
4. Case retain: Provided the new problem is solved, it is stored in case libraries for future use.

2.2.4 Fuzzy Modelling

Conventional approaches to system modelling mainly relied on mathematical functions for a precise description of a physical system [2.25]. One of the disadvantages of using conventional approaches is that the parameters obtained may not be easy to be interpreted by human beings. In addition, the approximation may not be good enough if a system that is to be modelled is highly nonlinear [2.26]. It was hard for users to extract knowledge if the mechanism of a system was unknown or highly nonlinear.

Fuzzy modelling is one of the techniques for nonlinear, complex systems. The underlying principle of this technique is based on fuzzy set theory, which was developed by Zadeh [2.27]. Details of the important concepts of fuzzy set theory were defined by [2.28]. Fuzzy set theory was the foundations of fuzzy logic (FL) systems, and the most important area of applications is fuzzy rule-based system (FRBs) [2.26].

In FRBs, fuzzy rules are presented in "IF-THEN" form. An "IF" part and a "THEN" part correspond to an antecedent part and a consequent part, respectively. Linguistic variables and their linguistic values are used in fuzzy rule representation and their meanings are defined by membership functions [2.29]. Mamdani and Takagi–Sugeno–Kang are two types of FRBs currently used for dealing with engineering problems. Mamdani-type FRB was the first FRB, developed by Mamdani in 1974, and is known as a fuzzy logic controller (FLC).

A FLC contains four major blocks. The FLC knowledge base consisted of two components: a database (DB) and a rule base (RB). The DB contains the membership functions and the RB contains a collection of fuzzy control rules. The operations of FLCs are well described by [2.26].

2.2.5 Genetic Algorithms

The formulation of genetic algorithms was started in the early 1950s for the simulation of biological system, and the work was done in the late 1960s and early 1970s by John Holland [2.30]. The operating principle is based on natural selection and natural genetics. It is summarised as follows: each chromosome represents a potential solution to a problem. Genetic algorithms start with chromosome initialisation. The fitness of each chromosome is evaluated by a user-defined fitness function. Chromosomes with higher fitness will have a higher chance to survive and *vice versa*. Crossover and mutation will be conducted so that a new search space can be exploited. The above processes are repeated until user-defined termination criteria such as the number of generations and fitness values are reached. After reaching the termination criteria, the best chromosome will be decoded into a real solution to the problem. Details of the mechanism can be found in [2.30][2.31].

The advantage of using genetic algorithms is that they are very effective in performing global searches. In addition, they can handle different kinds of objective functions and constraints [2.31].

2.2.6 GA-Fuzzy Systems

Park *et al*. [2.8] pointed out that the completeness of the fuzzy rule base, the subjective definition of a fuzzy subset and the choice of fuzzy implication operators are the challenging problems in the application of fuzzy modelling, and stated that the selection of membership functions have a significant effect on the output. The definition of fuzzy rules and the membership functions is one of the key questions in designing the FLCs. Genetic algorithms had been employed by many researchers to generate fuzzy rules and membership functions [2.32]. GA has demonstrated its power by producing promising results through different applications [2.10]. The approach is called a *genetic fuzzy system* [2.33]. The advantages of applying genetic algorithms into fuzzy models over other methods are stated in [2.8].

The automatic generation of fuzzy rules and membership functions using genetic algorithms has been investigated recently and had been categorised into four types [2.34]:

Type 1: learning fuzzy membership functions with fixed fuzzy rules
Type 2: learning fuzzy rules with fixed membership functions
Type 3: learning fuzzy rules and membership functions in stages
Type 4: learning fuzzy rules and membership functions simultaneously

Experiments have been conducted to compare the performance of DC motors using type 1, type 2 and type 4 approaches, and showed that the performance of fuzzy models was the best using type 4 [2.8].

In this chapter, type 4 is used to generate an optimal knowledge base for the polishing process of SS304 stainless steel.

2.3 Polishing Process Planning

Process planning can be defined as a systematic selection, determination and generation of detailed methods by which requested products or parts are manufactured from an initial form to a final form. For a polishing enterprise to proceed the polishing operations for products that meet the customers' appearance specification, the polishing processes of each feature part of the product must be thoroughly planned. Customers' requirements on polished products basically come from their satisfaction of products with respect to their appearance quality, aesthetics, reliability and durability. On the other hand, only guaranteeing that the products can meet the polishing quality specification is not enough. Like many other manufacturing processes, polishing processes of the products must be cost effective. In other words, the products must be polished to maximise the added value within the agreed processing time and production cost.

2.3.1 Purpose of Polishing Process Planning

Precision surface finishing makes remarkable finishing progress to complete the final product manufacturing. Precision finishing is mainly accomplished by lapping, grinding and polishing, according to Heiche and Spengler [2.36]. On the other hand, they mentioned that polishing can be considered the best finishing methods among the three, in the context of yielding the best precision and finish. Therefore, a scrupulous planning of the polishing process is a crucial stage of product manufacturing and requires defining the selection and proceeding of processes and operations to achieve the requested products. The main objective of polishing process planning is to identify the main tasks and corresponding detailed work instructions implemented to generate a well-designed polishing process plan.

Examples of the tasks include selection of polishing operations, equipments, tooling, wheels and compounds used. In some special requirements, selection of quality levels is also involved by determining the process parameters. It can also be used to avoid the costly changes due to manufacturability problems, one of which is the quality levels of products determined by factors such as product components, features and process parameters. Therefore, process planning becomes important in stipulating the polishing activities to provide the best products to customers. Several contexts of process planning are described as:

- identify the product and components;
- identify the polishing features corresponding to the products;
- identify the main operations undertaken during process planning;
- specify and describe process parameters of each operation;
- specify assets and resources required for each operation;
- identify the main process planning documentation;
- identify the main data libraries used to store key polishing information.

These tasks in polishing process planning are implemented for domain specification in processing a successful case with appropriate adoption of equipments, wheels, compounds, and other expected resources for a total polishing solution.

2.3.2 Design of Polishing Process Planning

As polishing process planning aims to meet the production need, which in turn determines the final product quality in the whole operation management, the input parameters of the process planning play an important role in minimal reachable quality control, such as the product's feature specification, sequencing and optimisation and so on. This can be determined through the identification of the product item and consultation of those customers. Figure 2.3 shows the stages of polishing process planning adopted in polishing enterprises.

Within the flow chart, identification of the product item is constantly referred to during process planning. It formally states the customer's quality requirement, as this requirement plays a pivotal role in settling the quantitative stages of the process plan afterwards. Process planning is constructed by selection and sequencing of polishing processes and operations to produce finished products and components from initial materials. It is a way to prepare detailed work instructions including selection of polishing equipments, resources such as wheels and compounds, polishing time and so on. Another essential procedure is to specify polishing process parameters whose values regulate the product quality. In the polishing industry, polished products, for example, stainless steel cooker, glasses, are complex in shape and structure. They involve many components that are composed of various kinds of polishing features. These product hierarchical structures raise the complexity of polishing processes. This is the most apparent issue for the enterprise when considering the appearance-polishing process to products.

As illustrated in Figure 2.4, polished products form a hierarchical structure to components, features, polishing operations with reference to each feature and process parameters to generate the polishing operation sheet. In general, this operation sheet is the output of polishing process planning. According to this figure, we can see that when the complexity level of a product's design structure increases, required efforts to make an appropriate process plan on a larger number of components, features of each component and the product assembly will improve correspondingly.

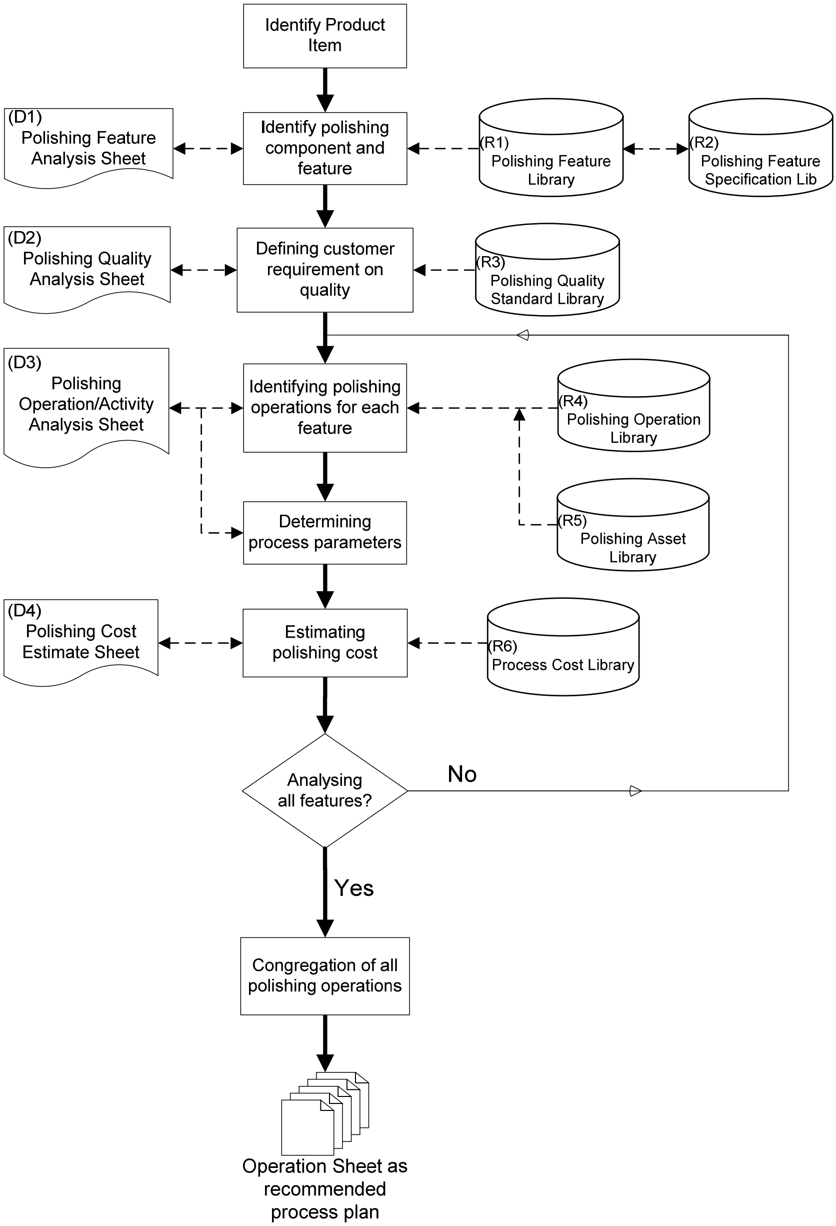

Figure 2.3. Flowchart of polishing process planning

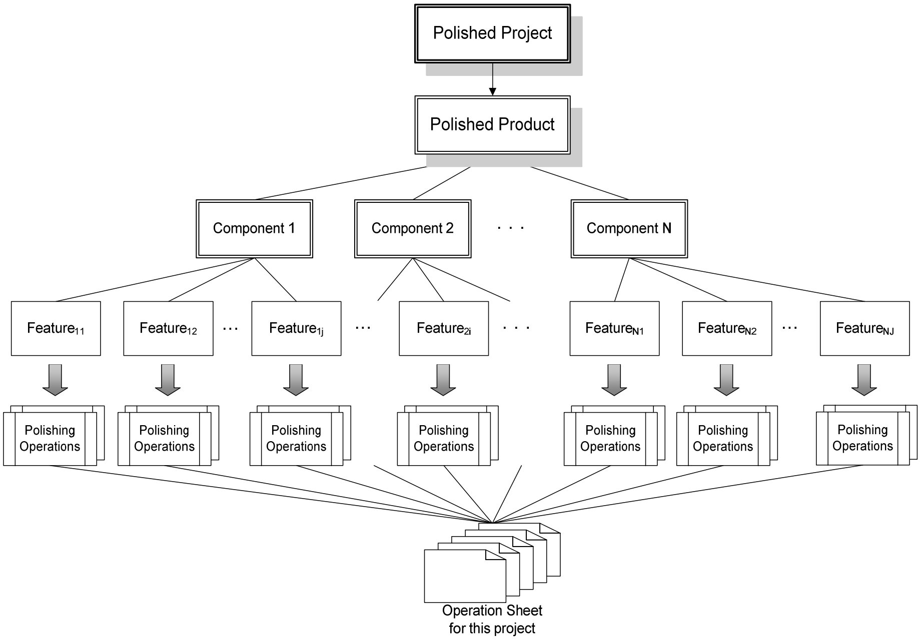

Figure 2.4. Hierarchical structure of polished product

2.4 Web-based Portal System for Polishing

This section presents an online system to streamline polishing products and processes through development of a Web-based portal system (WBPS). It is also used to communicate with users across the enterprise and even the whole industry. WBPS is a key technical application to create an interface that presents polishing information to users and a gate to users to access the required data sources and knowledge acquisition [2.3][2.18]. It can keep track of vital polishing information [2.2] by storing key process parameters, interacting between collaborating data and making decisions [2.3][2.4], and provides a benchmarking tool to smooth the knowledge management work by users, including disciplines of business intelligence management, information system resources [2.37]. Without adopting a knowledge-management approach, polishing enterprises might find it quite difficult to capture the key manufacturing knowledge and to retain recordable polishing information. Therefore, developing WBPS can benefit the polishing enterprises via important polishing knowledge integration and application, as well as its simpler circulation among departments and workers [2.4][2.37], which is expected to be shared in a multi-functional environment quickly and easily [2.38][2.39].

Figure 2.5 illustrates an overview of polishing knowledge sharing through the Web portal. An understanding of WBPS is dedicated to express its capability to locate and organise together the relevant polishing information involving a series of continuous processes through accessing structured datasets [2.4][2.37][2.40].

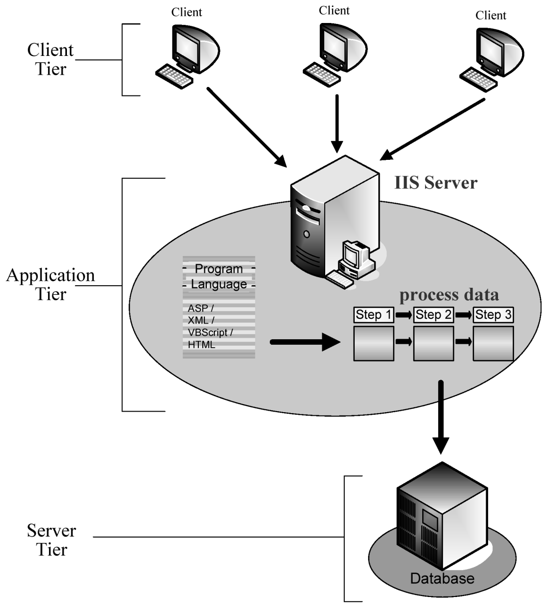

Figure 2.5. Knowledge integration in multi-functional environment by WBPS

2.4.1 Problem Definition

Current polishing practices are merely paper-based manual approaches, which are most likely unreliable and subject to human personal variations. WBPS has a purpose to develop an online portal system to streamline the polishing processes and products analysis (PPPA) such that a more scientific decision making can be generated with unambiguous expression of an innovative framework, and to build up a Web system to fulfil polishing product development analysis. Most often, users can even generate a higher value of polished products [2.1][2.2] through WBPS as intellectual and knowledge-based assets.

2.4.2 Objectives

The core points of introducing this system are the fixation of knowledge acquisition of parameters information in polishing processes and enabling that the key data of superior polishing features can be enrolled in recordable form [2.1]. While the portal system is attempting to build up a systematic knowledge-based support for polishing processes, it aims to achieve four main technological objectives:

- To identify and record polishing-incurring features of polished products and define quality requirements.
- To recognise relationships between polishing-process parameters and their corresponding quality levels through substantiated knowledge discovery.
- To collect information of polishing operations and specific quality levels they

could give rise to, and to prepare for building up of a discovery algorithm for optimisation of polishing-process parameters.

- To furnish a decision-support mechanism for polishing industries by WBPS's optimisation mechanism to produce appropriate and cost-effective polishing quality levels.

2.4.3 Design of Web-based Portal System

The framework of the portal system, its design and structure, as well as the organisational system are introduced as a tool to provide a platform to manage polishing information. Table 2.1 shows how knowledge application is conducted through WBPS.

Table 2.1. Knowledge application through WBPS

Activity	Selection criteria	System function
• Knowledge acquisition	Recognition procedure	Knowledge store and retrieval
• Recommendation	Algorithm procedure	Optimization analysis
• Product development	Product build-up	Case application

The Web-based portal system makes an important contribution to enable users to obtain efficient access to various types of structure and unstructured datasets (like features or operations) to streamline polishing process. The system also facilitates perspective-based combination and integration of information retrieval. Basically, WBPS is composed of 4 modules: Manual Planner, Repository, Business Cases and AutoPlanner. Figure 2.6 shows a graph to demonstrate the 4 architectural modules of the WBPS for polishing information sharing and how the process planning of polishing products and processes is accomplished.

2.4.3.1 Manual Planner

Planner is a starting user interface to allow them to process polishing projects. They either receive the enquiries or make stratified or "layer-to-layer" selection on project particularities. This kind of item-selection style provides a short time to give rise to a recommended polishing solution. It is designed to focus only on the work expected to be done by users planning to work out polished products structures and required operation sheets accordingly.

- Planner mainly builds a polishing project list for identification, management and accomplishment of product-oriented worksheets in Web page format.
- It helps look up the requested project, product, corresponding components and features, and operation processes quickly.
- It enables users to build up, delete or edit project or product details upon specific requirement of polishing process parameters.
- Mapping of product hierarchy helps manage its corresponding product structures and related process classes in a collaborative secured way.

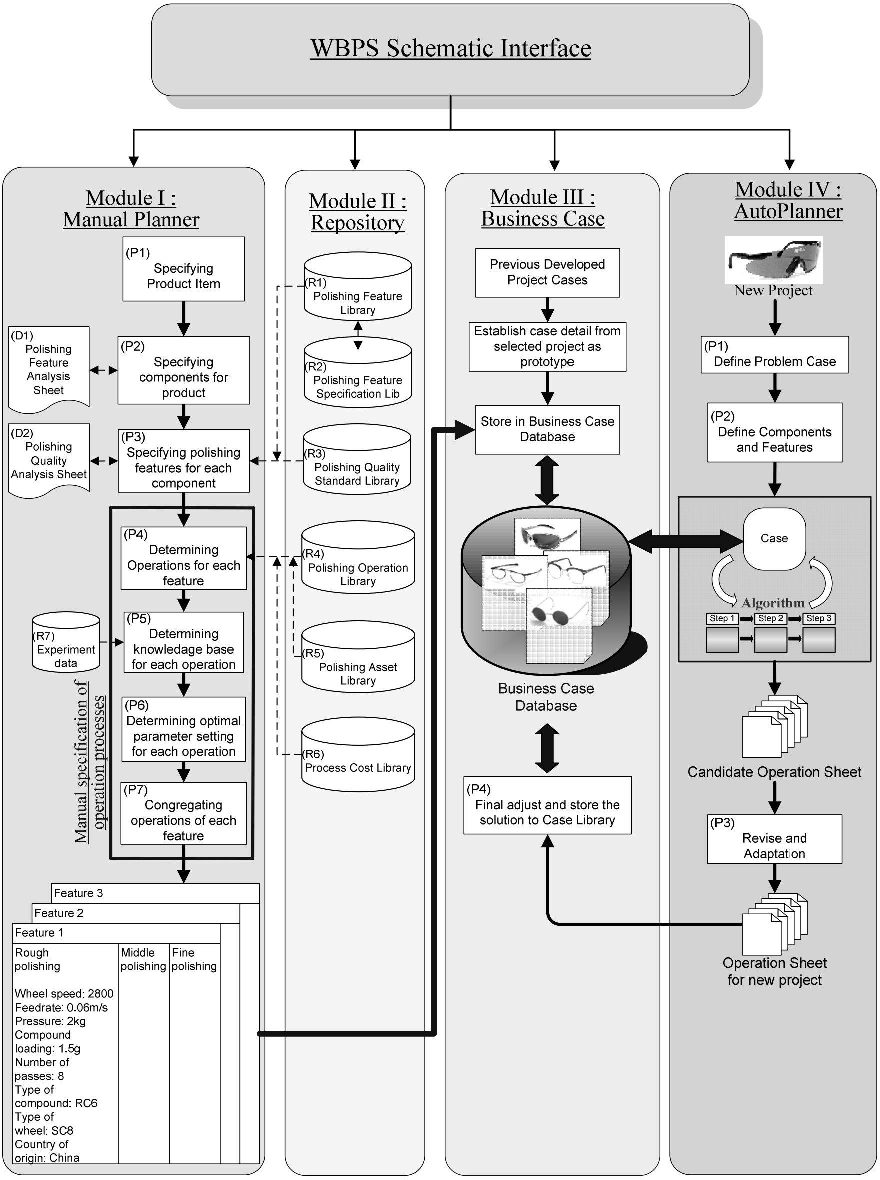

Figure 2.6. Conceptual framework of Web-based portal system

2.4.3.2 Repository

Repository consists of libraries for storing polishing information, related to the polishing processes. These data are self-contained information that can be used independently or shared with other components to satisfy the Planner requirement. Elementary data in the Repository module need to be customised in order to allow

Planner to handle the project planning specific to a new request of a conceptual product.

- Repository is managed to acquire the key polishing knowledge in the form of documentary, libraries, information record.
- It is referring to a quantified presentation of abstract polishing parameters in recordable form to users, so they can specify suitable and workable values to these parameters for streamlining the polishing processes and products.
- Definition of the content of polishing information can be supported by this package to store the key values. Products, components, polishing features, quality levels and operation process parameters can be generated for a standard meta database.
- Libraries are utilised to share polishing information categories for internal departments such as Project Team, Product Development Department, Operation Department and Quality Department, and for outside parties like customers or vendors. With a system to implement this strategy, every party can share significant information in order to achieve a better polishing product and process.

2.4.3.3 Business Cases

The Business Case module is another knowledge storage in WBPS. The Repository module contains libraries to record polishing process data. The Business Case module, on the other hand, is evolved to register the whole polishing projects in the format of cases. Each case consists of all elements of the polishing projects, such as products, hierarchical structures of products' components and features, polishing operations to make the qualities and corresponding process parameters. All the aspects are captured in Business Case databases to enable search, categorisation or other tasks in support of AutoPlanner, the fourth module of WBPS.

In terms of implementation, project cases can be built up from the Manual Planner module, in which the Operation Sheets for polished products are manually created and stored in databases as a practical case to achieve working memories. Another derivation of cases in Business Case is the adaptation of applicable cases from the AutoPlanner module. It involves many abstract case concepts and underlying product structures to mandate the knowledge-based mechanism. The bilateral case sharing between Business Case and AutoPlanner is shown in Figure 2.6, where it is clear that AutoPlanner searches and retrieves case records from the Business Case database for algorithm analysis. While the expected-to-be suitable case is extracted, it can be revised to solve the problems and for adaptation, then assembled to the database in the Business Case module.

2.4.3.4 AutoPlanner

AutoPlanner undertakes an essential contribution to develop an automatic processing algorithm to search for existing solutions, to revise the retrieved cases and to delve into applicable new solutions to the problem cases. It provides users with Operation Sheets of project solutions best resolving the new product prototype. This module will also help the users save valuable time in launching projects of similar products, so that a better time-to-market and quick return on its knowledge investment can be made.

- AutoPlanner provides a platform for users to define new product design and desired quality levels. Projects of similar product specifications or prototype styles can be looked up from the database of the Business Case module to search for existing solutions, where advantageous polishing features and process parameters can be traced and revised to new solutions.
- Polishing product and process are defined dynamically. New product structure and operation specification can be built on the basis of elite selected existing projects, followed by customisation of product details. This approach allows for a mapping of learning style to any successful product development.
- It is capable of building new projects from existing projects and implementing modifications. This facilitates product development improvement by driving knowledge exchange and brainstorming procedures across parties. It integrates the development of new products from past successful cases and advanced technical skills for products.
- AutoPlanner analyses the function gaps of existing products in terms of what functions the products can perform, what key features need to be developed and the cost. This can be managed and responded to through this module.

2.4.4 Implementation of Web-based Portal System

Implementation of the WBPS will be discussed in this section. Polishing process planning is detailed to show how a knowledge-based system is deployed through the Web application to conduct process planning for the Operation Sheet of problem cases. It is utilised as an identification to specialise every polishing project based on stating its key polishing properties or relevant product attributes. Figure 2.7 and Figure 2.8 show a simplified diagram to demonstrate how the Web application supports the streamlining procedures of polishing process planning and libraries management under different modules.

2.5 Knowledge-base Development Methodology

2.5.1 General Framework

A general framework of knowledge-base development is shown in Figure 2.9. The encoded chromosomes consist of fuzzy rule sets and membership functions. The internal structure of chromosomes is shown in Figure 2.10.

The generic format of fuzzy rule, R_i, is expressed in the following format.

R_i : IF x_1 is A_1 and x_2 is A_2 and … and x_n is A_n
THEN y_1 is B_1 and … y_m is B_m

where

$x_1, x_2, \ldots x_n$ = input variables
$y_1, y_2, \ldots y_m$ = output variables

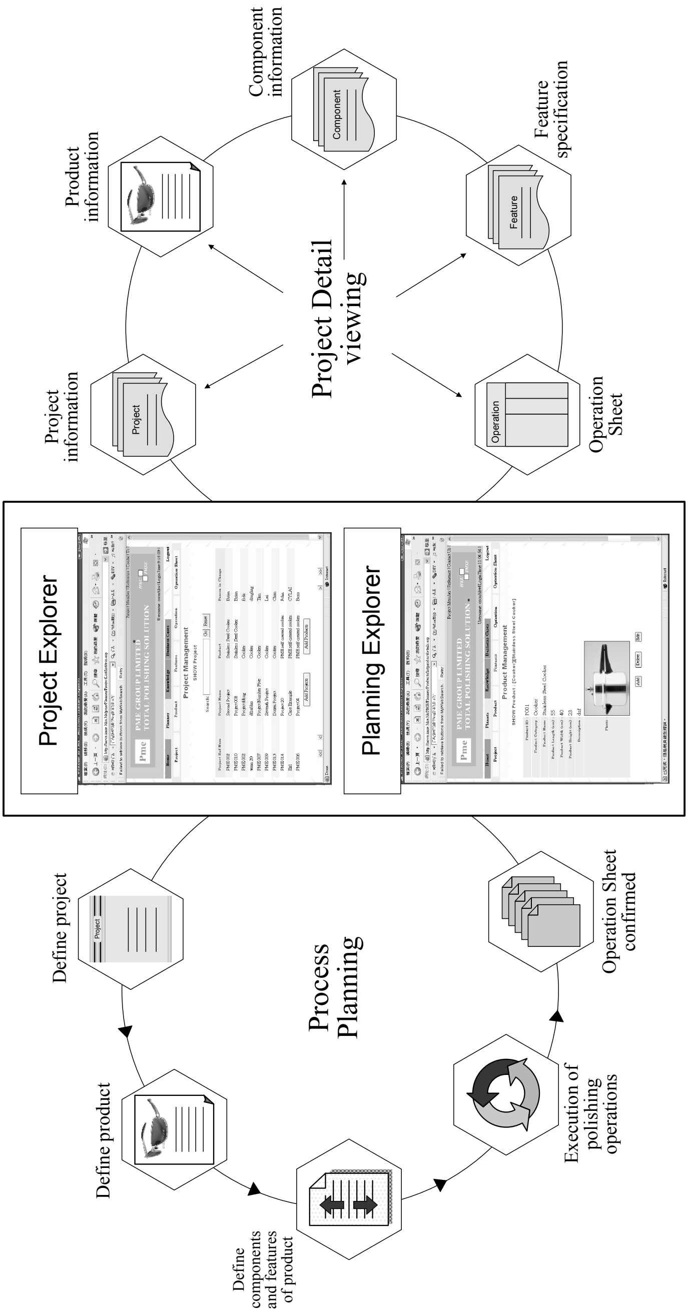

Figure 2.7. Process planning flow path of WBPS

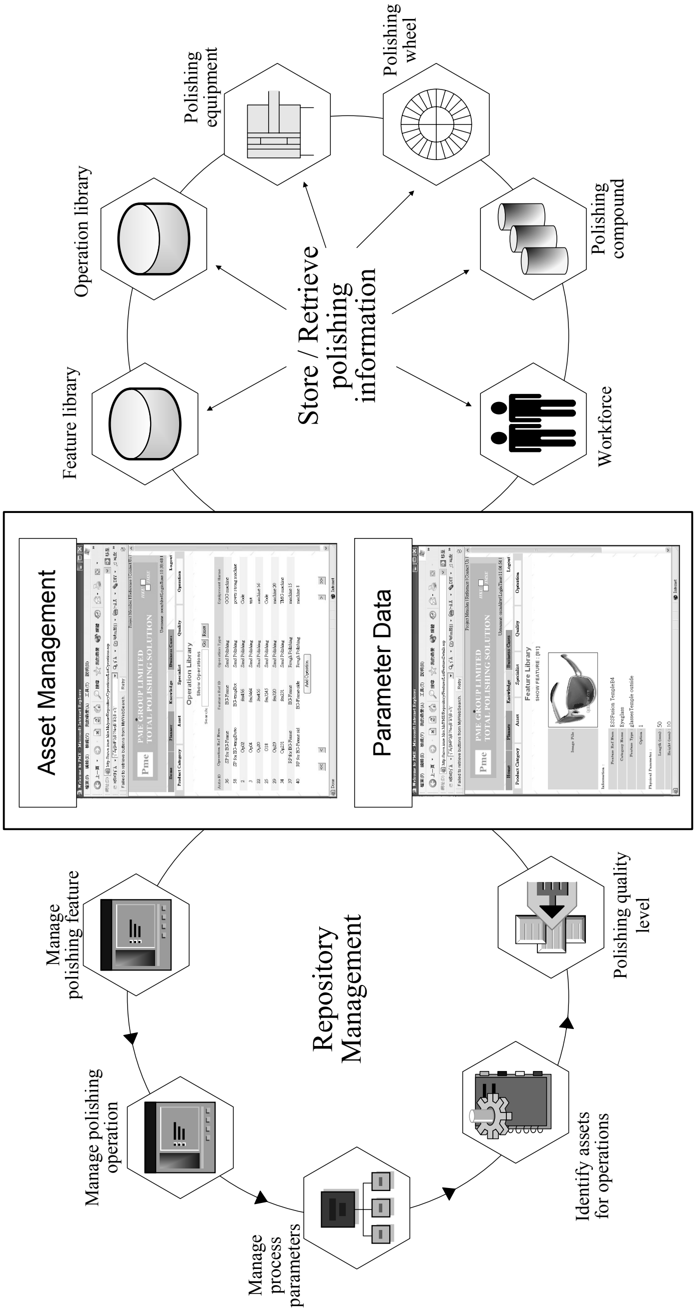

Figure 2.8. Repository information management of WBPS

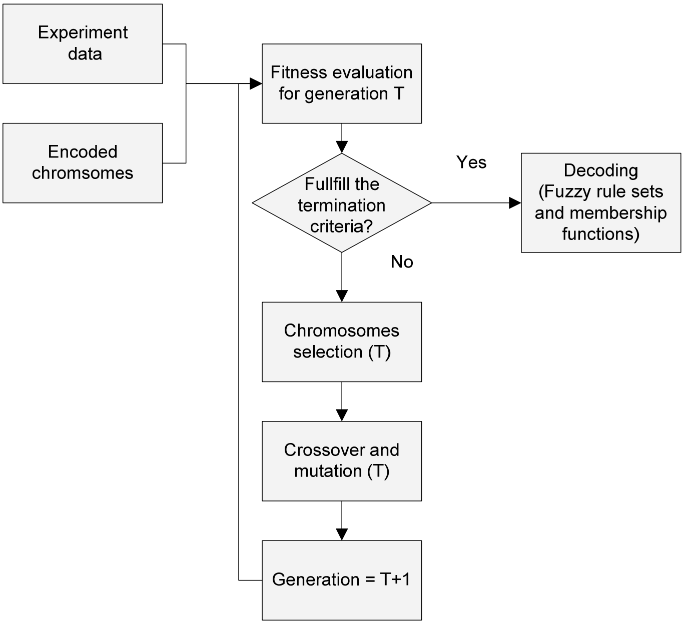

Figure 2.9. Framework of knowledge-base development

$A_1, A_2, \ldots A_n$ = fuzzy sets defined in the universe of discourse $U_1, U_2 \ldots U_n$
$B_1, B_2, \ldots B_m$ = fuzzy sets defined in the universe of discourse $U_1, U_2 \ldots U_m$

Parametric representation of a membership function of a fuzzy set A of a process parameter P is defined in the following.

$$MF_{PA} = (A_{(start)}, A_{(righttop)}, A_{(lefttop)}, A_{(finish)})$$

where

$A_{(start)}$ = the value on the left-hand side of the membership functions defined in the universe of discourse of fuzzy set A when $u(A_{(start)})$ is zero
$A_{(lefttop)}$ = the value on the left-hand side of the membership functions defined in the universe of discourse of fuzzy set A when $u(A_{(lefttop)})$ is one
$A_{(righttop)}$ = the value on the right-hand side of the membership functions defined in the universe of discourse of fuzzy set A when $u(A_{(righttop)})$ is one
$A_{(finish)}$ = the value on the right-hand side of the membership functions defined in the universe of discourse of fuzzy set A when $u(A_{(finish)})$ is zero

In fitness evaluation, the condition part of encoded chromosomes and past data will be compared to see whether they match or not. If their conditions match, the resultant parts will be compared. The fitness value will be assigned based on the proximity of the resultant part of chromosomes and past data. The higher the proximity of the resultant parts, the higher the fitness value of the chromosome. If the condition parts do not match, zero fitness values will be assigned. After fitness evaluation, chromosomes will be selected based on the fitness values for crossover and mutation to form a new population. The best chromosome, which contains the optimal fuzzy rule set and membership functions, will be selected and decoded after fulfilling the termination criteria. The decoded chromosome will be the optimal knowledge base for parameter optimisation.

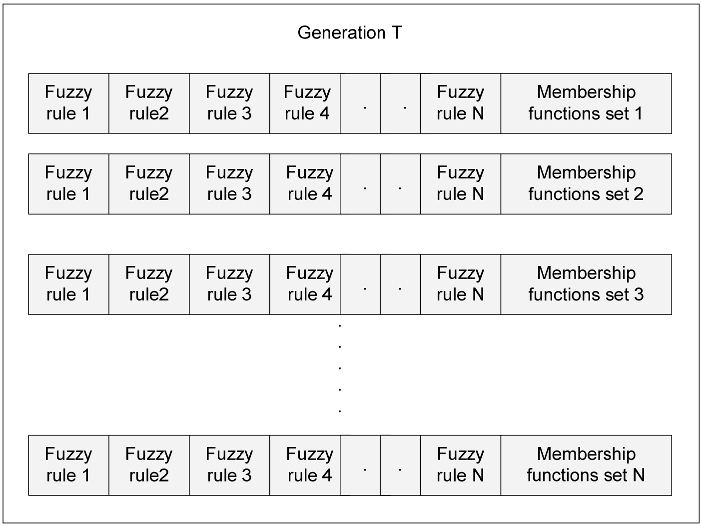

Figure 2.10. Internal structure of chromosomes in generation *T*

2.5.2 Case Study

2.5.2.1 Problem Description

The polishing process has been widely applied to different product categories. Products such as ornaments and jewels with polished surfaces could increase their attractiveness. A polished surface not only increases attractiveness, but also affects issues related to safety and health. However, the current practice is that the subjective judgement of polish masters determines polishing parameter settings. Parameter settings may be different from one to another and they are hard to express. Therefore, the quality of the surface finish could not be guaranteed. It is difficult to establish relationships between input parameters and the quality of the surface finish using the conventional approach as the polishing mechanism is not clear [2.35]. Fuzzy logic has been applied to model complex systems to determine outputs, which are known as fuzzy systems, since a knowledge base that consists of a fuzzy rules set and a membership function set affects the performance of the fuzzy system. The problem is to develop the best knowledge-base for the polishing process so that a proper surface finish quality would be determined with a given input. Intensive research efforts have been focused on the generation of knowledge bases using genetic algorithms. A number of papers have shown that a genetic algorithm is a powerful technique for selecting high performance FLC [2.10][2.41]. This has been applied in industrial processes [2.42], but not yet in the polishing industry.

The general framework proposed in Section 2.5.1 is used to generate the best knowledge base using fuzzy logic and genetic algorithms. The implementation of the proposed framework is described and the flow chart of the case study is shown in Figure 2.11.

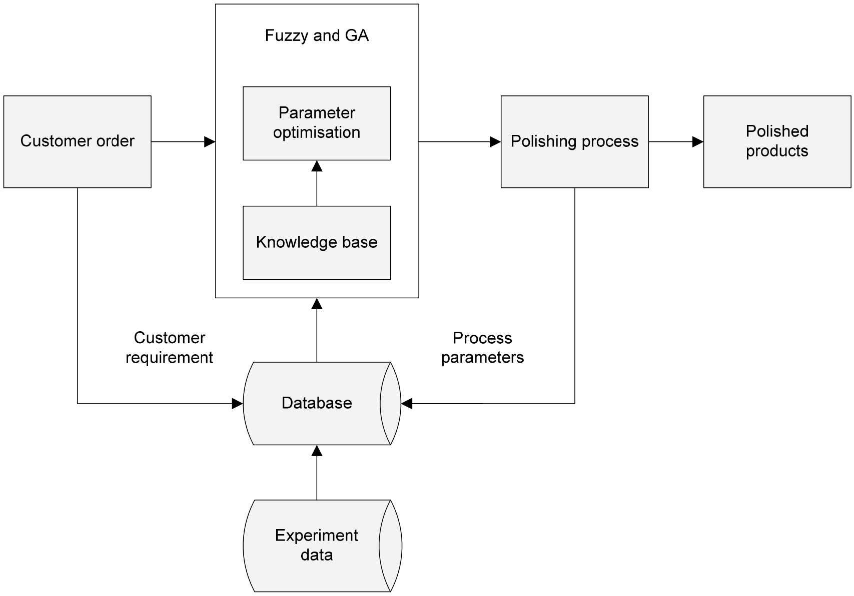

Figure 2.11. Flow chart of case study

2.5.2.2 Framework Implementation

Past data consists of three parts: customer requirement, process parameters and the output, which is shown in Table 2.2.

Table 2.2. Data structure

Process parameters	Values	
material	SS304	customer requirement
pressure	1 kg	process parameters
wheel speed	2100 rpm	
feed rate	0.06 m/s	
compound loading	1 g	
number of passes	10	
type of compound	RC6	
type of wheel	7X8	
country of origin	China	
roughness grade	6	surface roughness

Each chromosome consists of 10 fuzzy rules and membership functions. The genetic pattern of a chromosome is shown as follows:

Genetic pattern$_{chromosome}$ = FR1, FR2, … FR10, $MF_{wheelspeed}$, $MF_{pressure}$, $MF_{feedrate}$, $MF_{compoundloading}$, $MF_{numberofpasses}$, $MF_{RGrade6}$, $MF_{RGrade7}$

where

FR1	= fuzzy rule 1
FR2	= fuzzy rule 2
FR10	= fuzzy rule 10
$MF_{wheelspeed}$	= membership functions for wheel speed
$MF_{pressure}$	= membership functions for pressure
$MF_{feedrate}$	= membership functions for feed rate
$MF_{compoundloading}$	= membership functions for compound loading
$MF_{numberofpasses}$	= membership functions for number of passes
$MF_{RGrade6}$	= membership functions for roughness grade 6
$MF_{RGrade7}$	= membership functions for roughness grade 7

For the format of fuzzy rules, input variables are customer requirement and process parameters and the quality of surface finish for rough polishing, and the output variables are the fuzzy terms defined in Table 2.3.

Table 2.3. Fuzzy terms for rough polishing

Process parameters	Range			
material	SS304(1)	SS316(2)	SS420(3)	customer requirement
pressure	low(1)	medium(2)	high(3)	process parameters
wheel speed	low(1)	high(2)		
feed rate	low(1)	medium(2)	high(3)	
compound loading	low(1)	medium(2)	high(3)	
number of passes	low(1)	medium(2)	high(3)	
type of compound	RC6(1)	SC8(2)	SC33(3)	
type of wheel	6X8(1)	7X8(2)	10X8(3)	
country of origin	China(1)	Korea(2)	Japan(3)	
roughness grade	6(6)	7(7)		surface roughness

For the format of membership functions, since all membership functions are expressed in triangular form, the value of $A_{(lefttop)}$ and $A_{(righttop)}$ will be the same. In this case study, fuzzy sets for each membership function and the universe of discourse of each fuzzy set is defined in Table 2.4.

Since each chromosome consists of a fuzzy rule region and a membership function region, genes in the fuzzy rule region stores the encoded values of input variables and output variables defined in Table 2.5. The encoded values of genes stored in the membership functions region are the values of the universe of discourse defined in Table 2.4.

Table 2.4. Fuzzy sets for membership functions

Membership functions	Fuzzy sets	Universe of discourse
$MF_{wheelspeed}$	high	2100–2800 rpm
	low	2100–2800 rpm
$MF_{pressure}$	high	1.5–2 kg
	medium	1–2 kg
	low	1–1.5 kg
$MF_{feedrate}$	high	0.06–0.08 m/s
	medium	0.04–0.08 m/s
	low	0.04–0.06 m/s
$MF_{compoundloading}$	high	1–1.3 g
	medium	1–2 g
	low	1.5–2 g
$MF_{numberofpasses}$	high	10–12
	medium	8–12
	low	8–10
$MF_{RGrade6}$	Grade 6	0.04–0.07
$MF_{RGrade7}$	Grade 7	0.03–0.05

Table 2.5. Encoded values of input and output variables

Parameters	Actual value of data 1	Fuzzy terms	Encoded values
pressure	0.5	low	1
wheel speed	2800	high	3
feed rate	0.06	medium	2
compound loading	1	low	1
number of passes	8	medium	2
type of compound	RC6	RC6	1
type of wheel	6X8	6X8	1
country of origin	China	China	1
roughness	0.04	Grade 4	4

In this stage, data 1 and fuzzy rule 1 from chromosome 1 will be used to illustrate how the processing stage works.

Step 1: *Random Generation of Chromosomes*

The first generation of chromosomes are randomly generated within the range specified in Table 2.3 for fuzzy rules and Table 2.4 for membership functions.

The encoded format of a chromosome would be as follows:

= [1, 1, 1, 1, 1, 1, 1, 1, 1, 6, 1, 1, 1, 2, 2, 2, 2, 2, 1, 2, 7, 1, 1, 2, 1, 2, 2, 1, 3, 3, 1, 7, 1, 1, 1, 1, 3, 3, 3, 3, 3, 2, 6, 1, 1, 1, 2, 2, 1, 3, 3, 1, 3, 7, 1, 1, 3, 2, 1, 2, 3, 1, 3, 1, 7, 1, 1, 3, 2, 2, 1, 2, 1, 3, 2, 7, 1, 1, 3, 1, 3, 1, 1, 2, 3, 2, 7, 1, 1, 3, 1, 3, 1, 1, 2, 3, 3, 7, 1, 1, 3, 1, 2, 3, 3, 1, 2, 1, 7, 1, 2100.0, 2100.0, 2100.0, 2800.0, 2100.0, 2800.0, 2800.0, 2800.0, 100, 100, 100, 104, 100, 129, 129, 200, 199, 200, 200, 200, 4, 4, 4, 6, 4, 5, 5, 7, 7, 8, 8, 8, 70, 70, 70, 72, 70, 95, 95, 113, 116, 130, 130, 130, 8, 8, 8, 10, 8, 9, 9, 12, 11, 12, 12, 12, 0.04, 0.05, 0.05, 0.07, 0.03, 0.04, 0.04, 0.05]

Step 2: *Data Fuzzification and Encoding*

For each chromosome, data are converted into fuzzy terms through fuzzification using the random-generated membership functions stored in that chromosome and encoded based on Table 2.3. The result of Step 2 is shown in Table 2.4.

Step 3: *Comparison of the Fuzzified Data and Fuzzy Rules*

The objective of this step is to determine which fuzzy rules are valid through the comparison of the condition parts of the encoded data 1 determined in Step 1 with the "IF" part of fuzzy rule 1. The comparison is shown in Table 2.6. The result showed that fuzzy rule 1 matched with encoded data 1. Their output parts will be compared in the next step. Otherwise, the fitness value of fuzzy rule 1 will be zero and data 1 will be compared with the next fuzzy rules in chromosome 1.

Table 2.6. Comparison of encoded data 1 with fuzzy rule 1

	Encoded data 1	Encoded fuzzy rule 1
pressure	1	1
wheel speed	3	3
feed rate	2	2
compound loading	1	1
number of passes	2	2
type of compound	1	1
type of wheel	1	1
country of origin	1	1

Step 4: *Comparison of the Output Part of the Fuzzy Rule and the Dataset*

The output part of the fuzzy rule 1 is then compared with the encoded data 1, which is shown in Table 2.7.

Table 2.7. Comparison of output parts

	Roughness grade
Fuzzified data 1	4
Fuzzy rule 1	5

Step 5: *Computation of the Accuracy of the Fuzzy Rule*

The accuracy of fuzzy rules, denoted by $\mathrm{A}(R_i)$, is shown as follows:

$$\mathrm{A}(R_i) = 1 - \frac{Dr}{13} \tag{2.1}$$

where $\mathrm{A}(R_i)$ is the accuracy of fuzzy rule i and Dr is the difference in roughness grade, *e.g.* the accuracy of the fuzzy rule 1 after the comparison in Step 3 is:

$$\mathrm{A}(R_1) = 1 - \frac{(5-4)}{13} = 0.9166$$

Step 3 and Step 4 are repeated for the other fuzzy rules.

Step 6: *Determination of the Amount of Data Covered by Chromosomes*

Valid fuzzy rules are summarised and the summarised rule is used to determine the amount of data covered by chromosomes. The percentage of coverage of the chromosomes, denoted by C_i is determined by the following formula:

$$C_i = \frac{\text{number of data matched with summarised rule by chromosome } i}{\text{number of data}} \tag{2.2}$$

Assume that the total number of data is 20 and the number of data matched with the summarised rule is 9 in chromosome 1. The percentage of coverage of chromosome 1 is:

$$C_1 = \frac{9}{20} \times 100\% = 45\%$$

Step 7: *Determining Fitness Values of Chromosomes*

Fuzzy accuracy and the data coverage are also taken into consideration in the design of fitness functions. Since the accuracy of rules affects the summarised rule, higher weight will be assigned in the fitness evaluation. The fitness function, denoted by $F(i)$, is defined in the following:

$$F(i) = (\text{average of accuracy of fuzzy rules}) \times 0.7 + (\text{data coverage}) \times 0.3 \tag{2.3}$$

Assume that the average accuracy of fuzzy rules in chromosome 1 is 70% and the data coverage of the chromosome 1 is 50%. Therefore, the fitness of chromosome 1 is shown in the following:

$$F(1) = 70 \times 0.7 + 50 \times 0.3 = 64$$

and the maximum fitness is 100.

Steps 3 to 7 are repeated for the fitness evaluation of the other chromosomes. Step 8 will be performed until all the fitness values of chromosomes are determined.

Step 8: *Checking the Termination Criteria*

Termination criteria are used to determine whether the evolution process should be terminated or not. In this case study, the number of generations is used as a termination criterion. If the current number of generations does not exceed the termination criterion, Step 9 will be needed. Otherwise, Step 10 will be performed to decode the best chromosome among the population.

Step 9: *Crossover and Mutation*

Chromosomes are selected for crossover and mutation based on the fitness values so that a new generation of chromosomes can be formed in this step. After Step 9, Steps 3 to 7 will be repeated for this generation.

Step 10: *Chromosome Decoding*

If the current number of generations equals the number specified in the termination criterion, the best chromosome will be selected among the population and decoded. The decoded chromosome represents the optimal fuzzy rules and membership functions.

2.6 Results and Discussions

The Jgap package, which is written in Java, has been used to develop the program based on the methodology. Since the number of generations affects the total computation time, the number of generations is set to 50, 100, 150, and 200. The graph of fitness values against total number of generations is plotted, which is shown in Figure 2.12.

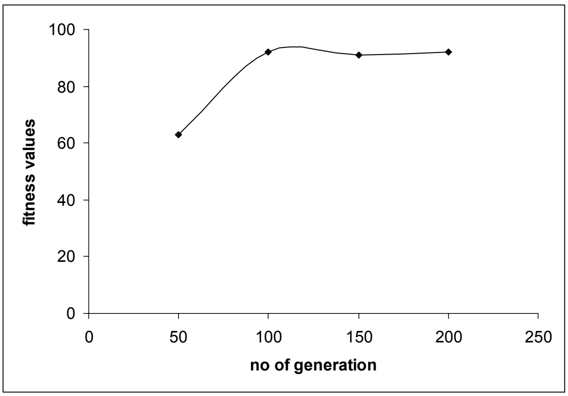

Figure 2.12. Fitness values versus the number of generations

According to Figure 2.12, fitness values for the generations after 100 are more or less the same. In the consideration of the computation time and accuracy, the termination criterion is 100. Two generalised rules were generated. They are verified through the comparison of the generalised rule and data. It was found that 78% of the data can be classified by the rules.

The performance of the system can be improved by two factors. The first factor is the amount of data. Since the number of variables involved in a rough polishing process is very large, generalised rules will be more concise and precise if the system can get more data. The second factor is the number of rules for each chromosome. There is a trade-off between the number of rules, the data coverage and the computation time. If the number of rules increases, the percentage of data coverage will be increased but computation time will be longer and *vice versa*. In the future development, it is necessary to design a methodology to determine the optimal number of rules for each chromosome. The optimal number of rules is the compromise between the data coverage and the computation time.

2.7 Conclusions

This chapter introduced a Web-based framework for provision of a collaborative system of polishing product and process analysis, and knowledge-base development. It is not unusual to see that there are many polishing companies following human-dependent work in many manufacturing activities, where the processes are actually based on personal knowledge and the experience of technicians. A Web-based portal system (WBPS) is developed to deliver a Web application system to conduct online polishing process planning, with a framework model to support knowledge sharing, retrieval, adaptation, and optimisation. The WBPS is constituted of four modules: Manual Planner, Repository, Business Case and AutoPlanner, these modules perform different planning and sharing functions to achieve product development and library construction. These special properties have been integrated and adopted in various complex systems for polishing problem solving. In particular, the optimisation mechanism of WBPS is such a sophisticated system that could potentially be used to design and represent polishing solutions as an applicable project paradigm when new projects are launched.

This research work aims at developing a Web-based generic system to provide effective instantaneous knowledge coordination in streamlining the polishing product and process, and in presenting the enterprises with a single point of access to their knowledge assets. WBPS is able to respond and behave adaptively in a dynamic environment to tackle polishing problems. Polishing enterprises can structure their precious polishing knowledge through effective and user-friendly Web system interfaces, and process the intellectual polishing solution accordingly. Enterprise management can easily target and acquire the correct polishing information where this information is stored in Repository. It allows users to share valuable information among individuals, project groups, departments, companies and even the whole industry on a real-time basis, depending on the necessity of manufacturing progress. Therefore, our Web-based portal system represents a generic distributed control framework, where the need for an optimal process planning can be truly fulfilled by the Intelligent Decision Support Mechanism of WBPS within a short period of time. All these are believed to award the companies using WBPS a competitive advantage. With implementation of this online polishing application system, not only the polishing enterprises can be benefited to facilitate a better utilisation of existing knowledge and new product development, but also it enables strong information-retrieval capabilities and key information exploration.

Regarding the knowledge-base development, a general framework for the construction of a knowledge base was developed and it has been implemented in the polishing process. Results showed that the classification result was satisfactory. With a proper knowledge base, it is expected that proper parameter settings could be extracted with given the required surface finishes. In addition, parameter settings could be kept permanently, they could be accessed at anytime and therefore the quality of surface finish would be consistent even though skillful polishing masters retire. Furthermore, through the Web-based system, technical opinions could also be delivered online to manufacturers quickly so that production lead-time could be shortened to increase competitiveness.

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