Computers in Industry 59 (2008) 777–785

Contents lists available at ScienceDirect

Computers in Industry

journal homepage: www.elsevier.com/locate/compind

Web-based quotation system for stereolithography parts

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ARTICLE INFO

Article history:
Received 16 October 2007
Received in revised form 8 March 2008
Accepted 14 March 2008
Available online 15 May 2008

Keywords:
On-line quotation system
Stereolithography parts
Rapid prototype
E-commerce

ABSTRACT

RP service bureaus or providers constantly face urgent requirements for price and delivery quotations on complicated RP parts. They are challenged to respond quickly and accurately with bids that are tailored to each customer's specifications. In order to satisfy the current quotation requirements of RP service bureaus and providers, this paper investigates and develops a web-based automated quotation system which can provide instant price quotations for stereolithography (SL) parts. Two quoting approaches which include the rough quotation based on weight and precise quotation based on build-time were proposed to determine the price quotation for SL parts. Furthermore, a Java-enabled solution together with web techniques was employed to develop the on-line price quotation system. Implementation of precise quotation method, as a typical module, was used to demonstrate the development of the system. The system offers a new choice for RP customers to allow them to quote instantly and compare multiple rapid prototyping processes.

1. Introduction

In today's competitive market, quick and accurate price quotation for RP parts plays an important role in the RP service process, is also a fundamental premise to win an order, gain a potential client and keep company competitiveness. Furthermore, it is especially critical to determine what price and due date to quote when a potential customer requests a bid. The quotation process, from the receipt of quotation requisition to the dispatch of the complete bid, is quite complex and time-consuming. The price quotation usually needs close cooperation by various departments including finance, sales, design and manufacturing, and a number of factors need to be considered. Currently, there are many ways to deliver the price quotation for product to customer which mainly include telephone, fax, email, letter, etc. However, such methods may take too much time, leave lots of room for error, and are often more trouble than they are worth, which cannot meet the current requirements of RP&M service. Web-based price quotation that is a new emerging quoting method taking full advantage of the quickly evolving computer network and information technology can provide instant price quotation for remote customers, quickly obtain feedback from customers, and show a number of advantages: easy to use and update, simple operation, high interactivity with customer, user-friendly interface [1–9]. RP service bureaus or providers are constantly presented with complex, multiple requests for price and delivery quotations, and are challenged to respond quickly and accurately with bids that are tailored to each customer's specifications. The current major practice in the RP industry for quoting prices for building an RP part is either by experience or by comparison with a similar product. In order to satisfy the current quotation needs of RP service bureaus and providers, several web-based automated quotation systems have been developed. The "Quickparts.com" (and its software "QuickQuote") and "3T RPD" are now the main commercial on-line price quotation system for RP parts. Quickparts.com, which is a privately held manufacturing services company dedicated to providing customers with an on-line E-commerce system to procure low-volume and high-volume custom manufactured parts, has developed a QuickQuote system. QuickQuote is the proprietary geometric analysis and instant quoting engine behind Quickparts. With Quickparts' patent-pending QuickQuote technology, users simply upload their 3D CAD data (STL files), define their project specifications, and a custom, binding quote is presented instantly. The new version instant quoting software, MyQuote 3.0 does not require the upload of your CAD files. Geometry analysis is performed right on your desktop within the Quote software. To get an instant Quote, users select a process, select CAD files for quote, select material, finish, and quantity, and then click on "Create Quote". The unique, binding quote is instantly calculated and presented to users. The system provides an instant price quote for SLA, SLS, FDM, and Cast Urethanes/RTV Molding. Users can also compare these processes

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doi:10.1016/j.compind.2008.03.006

based on materials available, applications, and lead-time. The principle of quotation for QuickQuote is based on the geometric analysis of the model (model and define Specs) [10]. 3T RPD developed an automatic quoting system that can be accessed around the clock. Working from key data precludes the need for uploading sensitive information to a central server. The system can respond instantly with prices, as well as e-mailing an official quotation. The quotation principle of 3T RPD is also based on the data model and product details (e.g., product quantity, material, finishing/colouring, desired delivery date, etc.). The system seems to upload several data models. The best way to send the data is recommend by e-mail [11]. Unfortunately, may be due to reasons of commercial know-how (or secrets), neither of these describe and report the internal mechanism of quotation, application effect and development process. In order to meet the on-line quote requirements from RP bureaus (or providers) and other users, this paper investigates and develops a web-based automated quotation system which can provide instant price quotations for stereolithography (SL) parts, so that the realistic lead-time, due date and price can be achieved as quoted to customer.

2. Price quotation method

There are various approaches estimating the price of a product. In general, these methods can be broadly classified as the intuitive method, the analogical method, the parametric method, and the analytical method [12,13]. The intuitive method is based on the experience of the estimator. The result is always dependents on the estimator's knowledge. The analogical method attempts to evaluate the price of a set or a system from similar sets or systems. The parametric method seeks to evaluate the price of a product from parameters characterizing the product but without describing it completely. The main principle of this method is to develop a statistical relationship between the attributes and price of previous products in order to predict the price of a new product. Parametric methods use the knowledge of a certain number of physical characteristics or parameters such as the mass, the volume, and the number of inputs and outputs. Thus, these parametric methods allow us to proceed from technical values characterizing the product and possessed by the engineer, to economic data. They are typically employed at the early stages of product development. The analytical method allows evaluation of the price of a product from a decomposition of the work required into elementary tasks. In practice, the use of one method alone is not sufficient, it is a better solution that various methods are employed synthetically [14]. According to the specific characteristics of the SL process, two quoting approaches, namely, the rough quotation (the parametric method) and precise quotation (the analytical method), are proposed in this paper. The former approach is based on the weight of the RP part and the latter is based on build-time (or man-hours).

2.1. Rough quotation method

For the rough quotation, the price of building an SL part is simply a mathematical function of some attributes of the part. The weight of the SL part is used to estimate its rough cost. This method has been widely used by many companies because it provides the price quotation in a simple and prompt manner. The price of an SL part (Q) can be estimated by the following equation

$$Q = KVPR \tag{1}$$

where K is an adjusting coefficient that may vary from 0.9 to 1.1, which can slightly adjust the price quotation according to the requirements of the current market and features of SL parts; P represents the mean density of resin used, which is equal to 1.25 kg/m^3; R denotes the cost/unit weight for building a SL part; V is the volume of a SL part which can be worked our by the STL model [15].

2.2. Precise quotation methods

When determining the price quotation of an SL part based on the machine-hour method, the production cost (C) will be a function of time, i.e., $C = c(T)$, where T denotes the manufacturing time involved. In previous literatures [16,17], the equation to estimate the production costs of an SL part has been established. By mapping between cost and price, the price quotation (Q) can be expressed as a function of cost (C), i.e, $Q = q(C)$. Hence, the price quotation can be directly expressed in term of time as follows:

$$Q = q(C) = q(c(T)) = f(T) \tag{2}$$

where f denotes the function of price quotation and time, and is a linear function.

As stated earlier, among the three stages of an SL part's life (the pre-build preparation, build, and post-processing), the build phase is usually the most time-consuming and costly. For the SL process, the machine depreciation expenditure is the most significant cost item, particularly the laser depreciation. The gas or solid laser used in the SL apparatus is rather expensive, and, its effective working life may be rather short. For example, the price of the He–Cd laser (solid) used in the LPS 600 RP machine is about US$ 50,000. Its working life is about 2500 h. Thus, the build-time of a SL part has the most important effect on the total product cost.

A model of build-time estimation has been established by the authors [17]. The precise quotation is based on the man-hour method to estimate the price of an SL part. To implement the precise quotation, a new algorithm of predicting build-time of an SL part, which utilizes geometrical properties (the volume and surface area) calculated from the part's STL model and the statistical value of support structures, has been developed after a detailed study of the laser scan mechanism of SL machines. The conventional methods of predicting build-time are based on the detailed scan and recoating information from the actual build file after slicing and adding supports. The new algorithm incorporates the geometry information drawn from the STL file (e.g., volume, surface, etc.) and the value of support structures which are determined by a statistical method. The new algorithm of predicting build-time of SL parts which incorporates the geometric features drawn from the part's STL model and the value of support structures determined by a statistical method have been used to implement the precise quotation. The build-time of an SL part can be expressed as follows:

$$\begin{aligned} T &= \frac{T_c + T_h + T_r + T_{ba}}{1 - \tilde{U}} \\ &= \frac{(S - S_H/D_z v_c) + (KV_p/D_z h_s v_h) + n t_r + T_{ba}}{1 - \tilde{U}} \end{aligned} \tag{3}$$

where S is the surface of an STL model of a part; S_H represents the horizontal projection area in X–Y plane; D_z denotes the layer thickness; v_h represents the hatching velocity; v_c represents the velocity of scanning contour; t_r is recoating time of a layer; h_s is the hatching space (distance between neighboring scanning vectors); n is the total number of layers; K is the scan coefficient; $\tilde{U}$ denotes the statistical value of build-time for support structures; T_{ba} is the statistical value of build-time for the base support.

The volume, surface and horizontal projection area in the X–Y plane of an SL part based on the STL model should be determined before estimating the build-time of the part using Eq. (3).

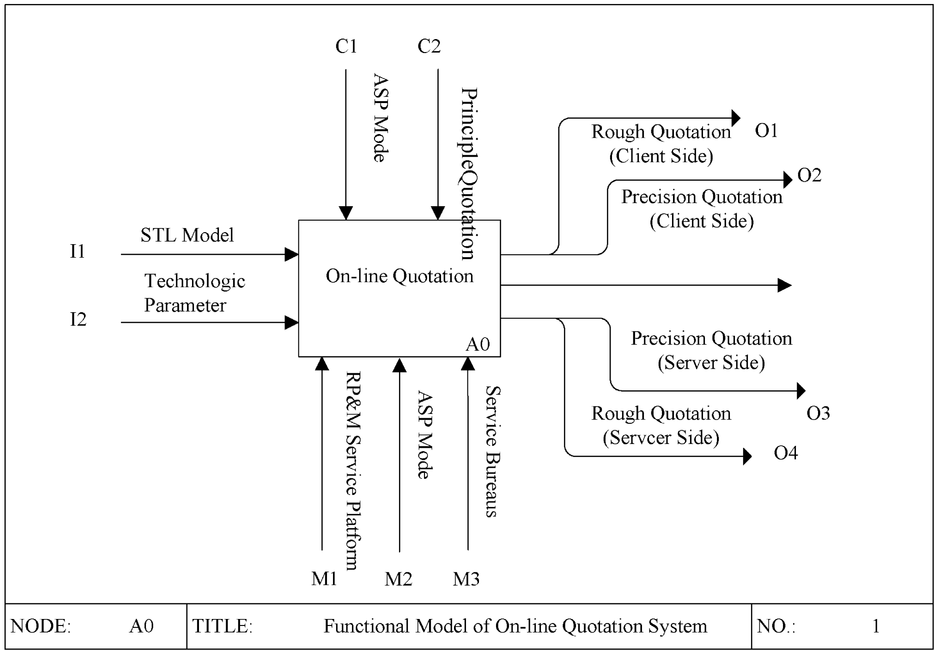


Fig. 1. The functional model of the quotation system.

3. Implementation of the web-based quotation system

Based on the proposed method, a web-based automated quotation system that can provide instant and accurate price quotation for SL parts to support effectively the RP&M service has been developed by the authors. The system can provide the two quotation methods mentioned above and two use modes (Server-side and Client-side) according to the requirements from different users. The system utilizes two quotation methods proposed above, namely, the rough quotation method and the precise quotation method based on the build-time. For usage modes, users can upload their STL file or download and install the application of Active X control with functions for using the STL file, calculating volume and surface area, estimating build-time on the desktop, by which users can get an instant price quotation. The functional model of the on-line quotation system for SL parts is shown in Fig. 1.

3.1. Difference between Server-side and Client-side

When developing a web application, we first need to determine the implementing methods, whether Server-side or Client-side? Client-side scripting means all calculations are done by the computer of the visitor. Most of the time the script is interpreted by their Internet browser (Javascript) or a specific browser plugin (Flash action script or Active X control). Server-side scripting means all calculations are done by the Server your website is hosted on. The script is interpreted by the supported language parser, like Java Server Pages (JSP), Person Home Pages (PHP) or Active Server Pages (ASP). Many factors like security issues have led to restrictions in both Server-side and Client-side possibilities. Both types have advantages and disadvantages, but the better solution is to attempt to combine both. According to the actual requirements of the web-based quotation system, both Server-side and Client-side web analytics programs are adopted. Table 1 shows the comparison of Server-side and Client-side for the on-line quotation system. For a user, he/she can select a suitable service mode based on the actual requirements. Compared with the precise quotation method, the rough quotation is relatively simple. Therefore, implementation of the precise quotation method based on the build-time, as a typical module, demonstrates the development of the whole system.

3.2. Program development of the precise quotation in Server-side

The process flow of the precise quotation method based on the build-time can be described as follows:

Step 1: Upload the STL file of an SL part by a user. Calculate the volume (V_p) and surface area (S) of the part based on the STL model.
Step 2: Determine the suitable build orientation, and compute the horizontal projection area (S_H) in X–Y plane of the part.
Step 3: Select the technological parameters (users can also adopt the default values of these technological parameters).
Step 4: Calculate the build-time of the part through Eq. (3) based on the data above.
Step 5: Obtain the price by using function (2).
Step 6: Display or return the price quotation to users.

The detailed process flow of the precise quotation is described in Fig. 2.

The Server-side program was written in JSP/Servlets. Java Server Pages is a better solution generating dynamic web pages in

Table 1
Comparison of Server-side and Client-side for the on-line quotation system

Operating mode	Transferring file capability	Real-time performance	Requirements of Client-side software	Security performance	Load of Server-side	Operation transparence
Server-side	Small	Poor	Low	Low	High	Normal
Client-side	Minor	Good	High	High	Low	High

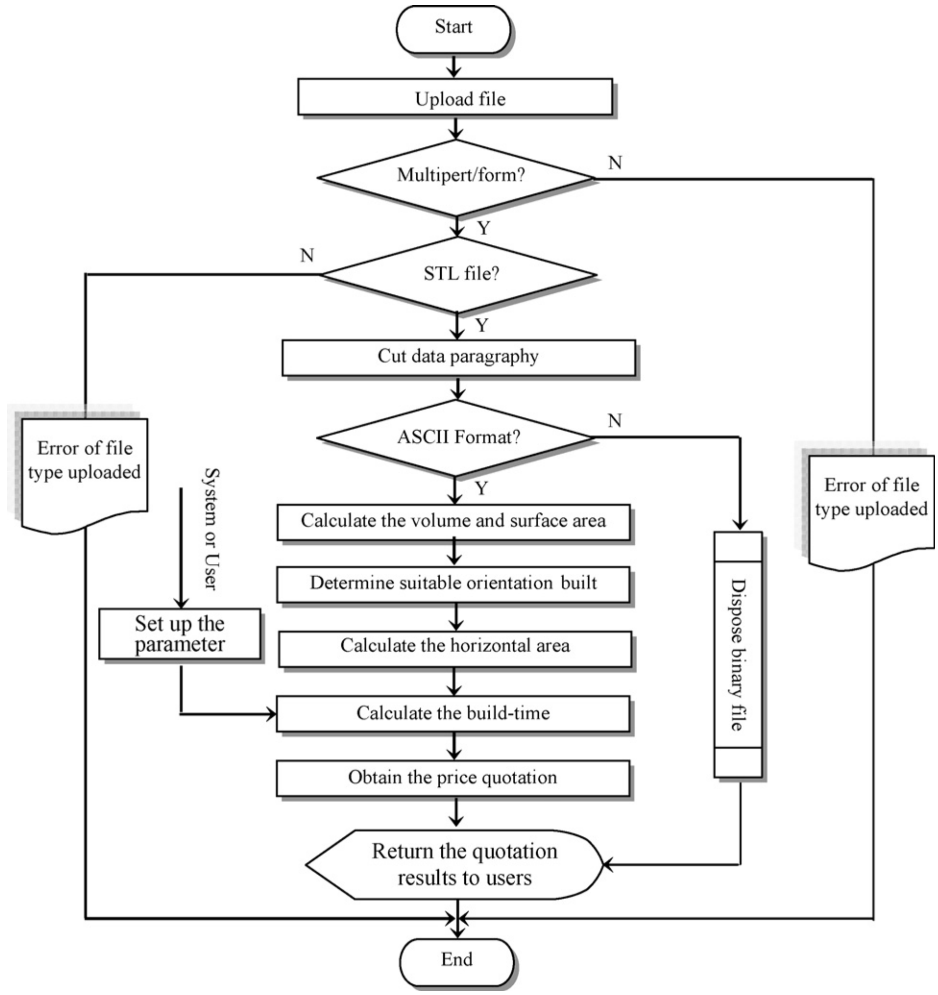


Fig. 2. Process flow of the precise quotation in Server-side.

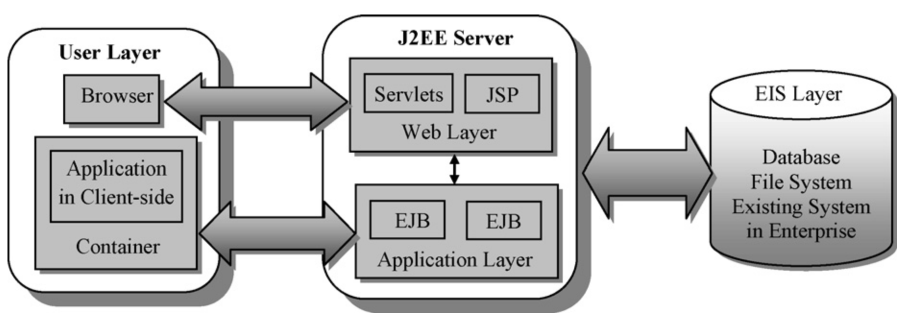


Fig. 3. Architecture of development platform based on J2EE.

contrast to Active Server Pages, Person Home Pages, and Common Gateway Interface (CGI). Together, JSP and Servlets provide an attractive alternative to other types of dynamic web scripting/programming offering platform independence, enhanced performance, separation of logic from display, ease of administration, and ease of use. JSP/Servlet has been widely applied by many electronic commerce providers such as the famous E-Business. EJB + JSP + Servlet are almost to be a standard of developing electronic commerce. Hence, it is a better decision to develop dynamic web pages using JSP/Servlet.

Currently, the development platform of distributed application mainly includes Mirossoft.NET and J2EE from Sun. According to the requirements of the web-based manufacturing systems and Server-side scripting language, J2EE is selected to act as the development platform of distributed application for the web-based system. The architecture of development platform based on J2EE is shown in Fig. 3. The development environment of application is presented in Table 2. The development kits of application are reported in Table 3.

Figs. 4 and 5 show respectively the Class diagram and Component diagram which were created by UML modeling tool. The initial GUI of the precise quotation system is shown in Fig. 6(a). During the calculation process, some data are the calculating results from Servlet; other can root in user's setup according to the part features, or adopt the default values of the original system. Fig. 6(b) shows the interface of middle operation results.

Table 2
Development environment of application

Software component	Software product
Operating system	Windows 2000 Advanced Server
Web server	Internet Information Server 5.0
Database server	SQL Server 2000
Web browser	Internet Explorer 5.5
Java2 Development Kit	J2sdk 1.4.0
JSP/Servelets engine	Tomcat 3.2

Table 3
Development kits of application

Software component	Software product
JSP	JRunStudio3.0
JavaBeans	JBuilder 6.0
Web pages create	FrontPage 2002
Image processing	Adobe Photoshop 5.0 CS
Animation	Flash 5.0

3.3. Program development of the precise quotation in Client-side

The program development of the precise quotation in Client-side utilized an Active X control technique. An Active X control is really just another term for "OLE Object" or, more specifically, "Component Object Model (COM) Object." In other words, a control, at the very least, is some COM object that supports the IUnknown interface and is also self-registering. It usually supports many more interfaces in order to offer functionality, but all additional interfaces can be viewed as optional and, as such, a container should not rely on any additional interfaces being supported. By not specifying additional interfaces that a control must support, a control can efficiently target a particular area of functionality without having to support particular interfaces to qualify as a control. Active X controls have become the primary architecture for developing programmable software components for use in a variety of different containers, ranging from software development tools to end-user productivity tools. For a control to operate well in a variety of containers, the control must be able to assume some minimum level of functionality that it can rely on in all containers.

When downloading and completing the installation of the Active X control, a user will then start to perform the following operations:

Step 1: Load the STL file of an SL part.
Step 2: Set the technological parameters.
Step 3: Perform the calculation.
Step 4: Output the quotation.

Fig. 7(a and b) shows respectively the interface of opening STL file and the interface of displaying the quotation results.

3.4. Case study

An example from the prototyping development of TV frame is used to demonstrate the application of the web-based quotation system. Let us assume that a company was developing a new TV frame for which a physical model would be required. The mock-up was purely for the purpose of design visualization and would be used as a means of communication with other functional departments in the firm. The user simply uploaded the STL file of the part, define some specifications, and a custom, binding quote was presented instantly. Due to the commercial know-how, may be, the user does not expect temporary to upload the STL file of the part, he/she can also utilize the Client-side service mode. Completed the installation of the Active X control for calculating quotation, all operations will be performed on right his/her desktop. To obtain an instant quotation, he/she only loads the STL file of the part, and selects some technological parameters (or use the default values), and then clicks on "Go Pricing". A quotation is instantly calculated and presented to the user. If selecting the rough quotation method, it can become much easier. The 3D CAD model of the TV frame is illustrated in Figs. 8 and 9 shows the interface of the quotation results in Server-side.

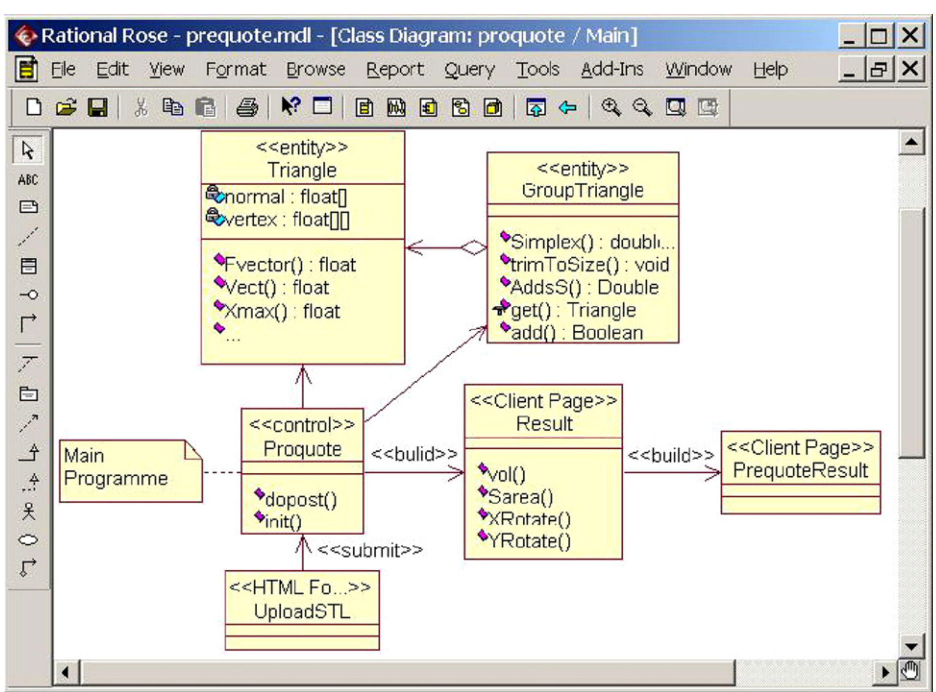


Fig. 4. Class diagram of the application.

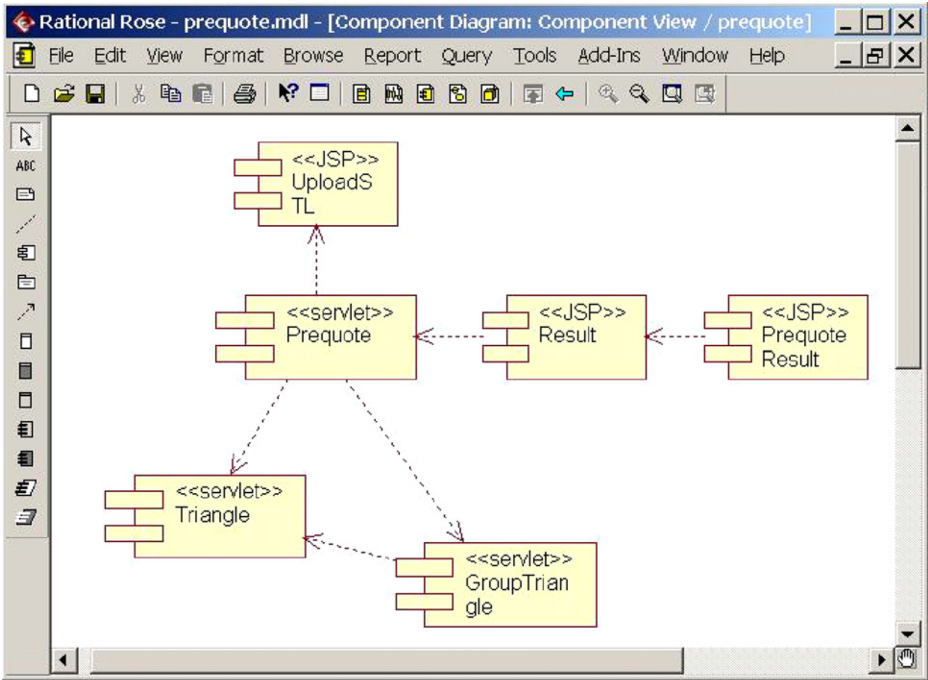
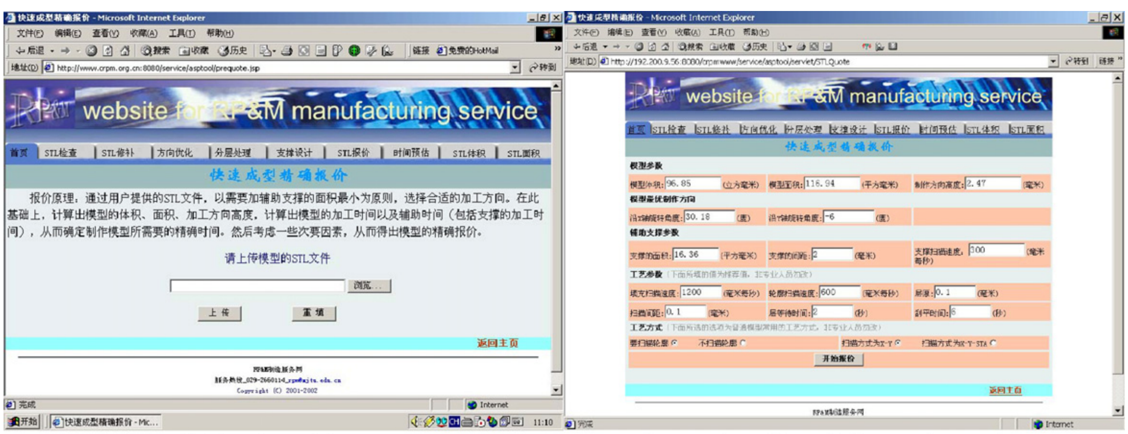
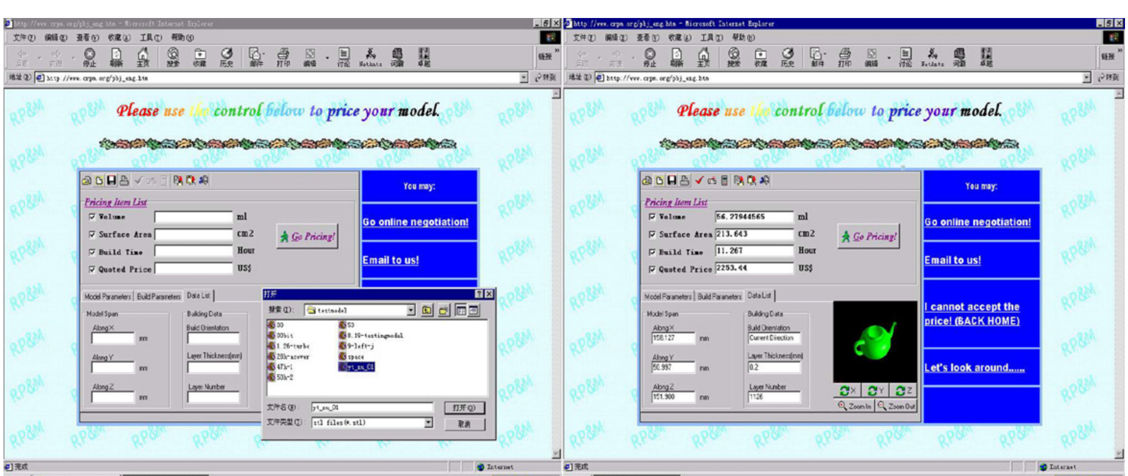


Fig. 5. Component diagram of the application.



(a) Initial interface of the system (b) Interface of the middle operation results

Fig. 6. Price quotation in Server-side.



(a) Interface of opening STL file (b) Interface of displaying the quotation results

Fig. 7. Price quotation in Client-side.

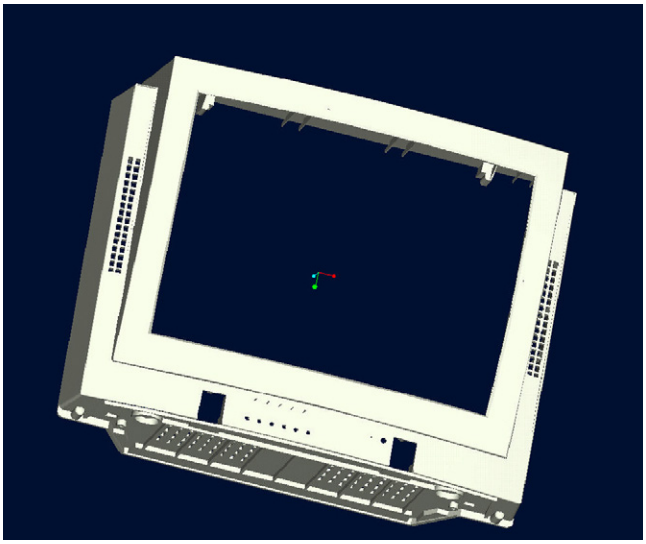


Fig. 8. 3D CAD model of the TV frame.

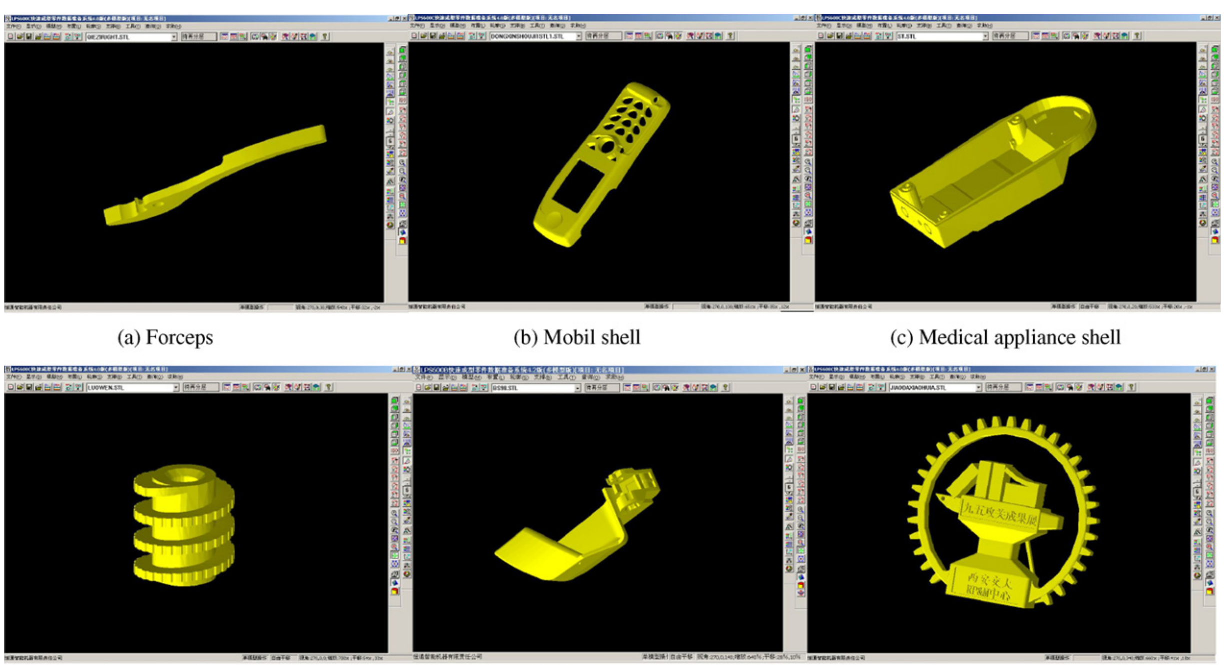
Fig. 9. Interface of the quotation results in Server-side.

Such a system can save much time that customers would otherwise spend waiting for RP providers to get back to them with quotations, and meet the current needs of quick response to the business opportunity. The service will be extended to allow customers to convert quotations into orders, which are subsequently processed by RP service bureaus and providers. The system has also been integrated an RP&M networked service platform that the authors have been developed [18,19]. The prominent advantage for the system is that it can provide two quotation methods and offer two use options (Server-side and Client-side) for users according to their actual requirements.

4. Discussion

In order to evaluate the performance of the quotation system developed, some experiments have been conducted. Six typical stereolithography parts, shown in Fig. 10, were selected to perform the test. Experiments were carried out on the SPS600 laser RP machine using HXJ-971 photocurable resin. The comparison results between the actual production cost (P_t) and the calculating cost (P_j) by the quotation system are shown in Table 4. In order to evaluate fully the proposed quotation methods and developed a web-based automated quotation system, the comparison results between the real build-time (T_t) and calculated build-time (T_j) using Eq. (3) are also presented. Fig. 11 illustrates the comparative view of T_j and T_t. And the comparative view of P_j and P_t is shown in Fig. 12. The corresponding error analysis is presented in Tables 5 and 6, respectively. The results indicate that the quotation error is about 10% for most of the test cases. Why did the real cost differ from the estimated cost? In the following section, we will attempt to perform an analysis of the quotation errors.

The product price generally consists of the production cost, circulating expenditures, tax and profit. Customers usually



(a) Forceps (b) Mobil shell (c) Medical appliance shell

(d) Screw thread (e) Auto handle (f) School badge of XJTU

Fig. 10. CAD models of test parts.

Table 4
Comparison results between the actual production cost (P_t) and the calculating cost (P_j)

Test part number	T_j (h)	T_t (h)	Deviation (%)	P_j (YUAN)	P_t (YUAN)	Deviation (%)
1 (a)	2.86	2.65	−7.	857	813	−5.1
2 (b)	1.32	1.42	+7.6	396	418	+5
3 (c)	2.33	2.59	+11.2	698	762	+9.2
4 (d)	0.23	0.19	−17.4	68	59	−13.2
5 (e)	0.74	0.84	+13.5	222	246	+10.8
6 (f)	0.24	0.27	+12.5	72	79	+9.7

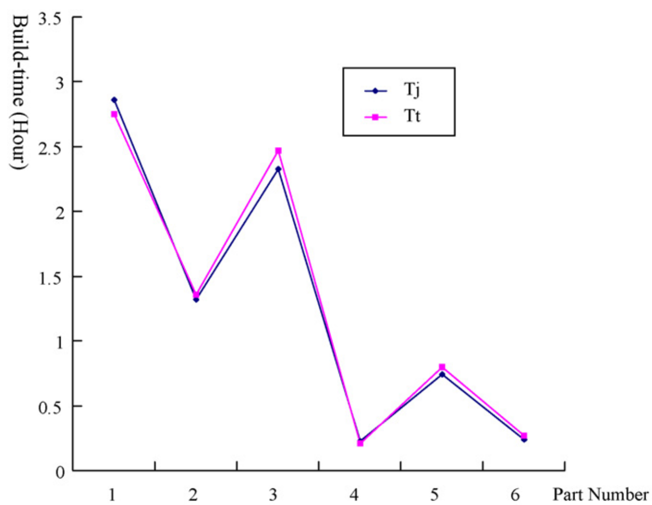


Fig. 11. Comparative view of real build-time (T_t) and calculated build-time (T_j).

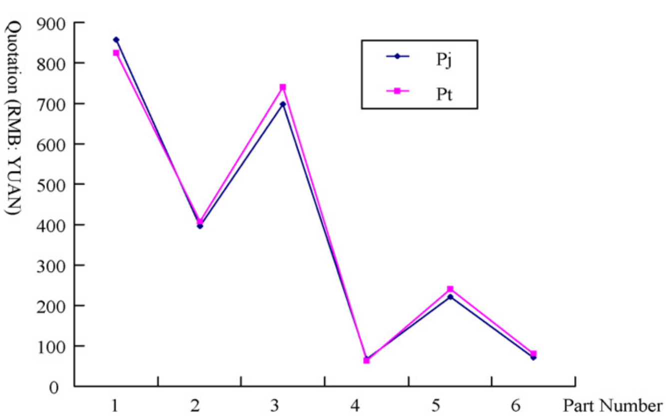


Fig. 12. Comparative view of the actual production cost (P_t) and the calculating cost (P_j).

Table 5
Deviation of the build-time for different cases

Average error (%)	Maximum value of positive error (%)	Maximum value of negative error (%)	Standard deviation (%)
11.6	13.5	−17.4	8.52

Table 6
Deviation of the quotation for different cases

Average error (%)	Maximum value of positive error (%)	Maximum value of negative error (%)	Standard deviation (%)
8.8	10.8	−13.2	3.3

negotiate directly with RP service bureaus or providers, and get the price quotation. The price for the RP part does not involve the circulating expenditure. However, the sale expenditure that mainly includes the mailing and after-sales service expenses should be added. Based on the cost analysis and past experience, the production cost of SL parts usually account for over 75% of total price. The total production cost can usually be calculated as the linear sum of the pre-processing cost, build cost and post-processing cost,

$$C_{tot} = C_{pre} + C_{build} + C_{post} \quad (4)$$

Compared with the pre-processing cost (e.g., verifying and fixing an .STL file, determining build orientation, generating support structure, slicing for an .STL file) and post-processing cost (removing any excessive resin, removing supports, finishing the part surface, solidifying the part in the oven), the cost of the actual build process can have a much more strong impact on for the total production cost. Furthermore, it has a large difference for various SL parts built, e.g., geometric features (maximum and minimum dimensions in length and width, support structures, minimum wall thickness, etc.), dimensional accuracy, surface roughness, etc. These elements can have a little effect on the product cost. However, it is especially difficult for the developed system to consider all factors so as to obtain the absolutely precise quotation at the early stage of product development. Actually, it also seems not to be necessary.

Based on the above analyses, we suppose that the quotation errors of the presented system can mainly result from following several aspects. For rough quotation method, the weight of a built part is only factor to be considered. Some fundamental elements (e.g., support structures, maximum dimensions in length and width, etc.), which can have an important effect on the quotation, have been neglected. That can result in rather large errors, in some cases, the maximum error value can exceed 30%. But the real situation for many RP providers is that the final price can indeed be determined based on the weight of an SL part which has been completed. In order to reduce the error of the rough quotation method, it is a good measure to determine a proper adjusting coefficient (K) according to the actual model features and RP provider situations. For the precise quotation method, build-time estimation for support structures is a statistical value which can lead to a rather error. Using the approximative integral method to calculate the volume and surface area of an SL part is also cause the error. In addition, the difference between the setting technological parameter values and actual usage values can also result in a little error.

5. Conclusions

The ability to respond quickly and effectively to requests for quotations from customers can be a significant source of competitive advantage to manufacturing companies. This paper investigates and develops a web-based automated quotation system which can provide instant price quotations for SL parts. Two quoting approaches, namely, the rough quotation and precise quotation, are proposed in this paper. The former approach is based on the weight of RP part and the latter is based on build-time of an SL part. Implementation of precise quotation method based on the build-time, as a typical module, was demonstrated to show the development of whole system. A Java-enabled solution together with web techniques is employed for developing the on-line price quotation system. Such a system can save much time that customers spend waiting for RP providers to get back to them with quotations, and meet the current needs of quick response to business opportunity. The further service will be extended to allow customers to convert quotations into orders, which are subsequently processed by RP service bureaus and providers. The system has also been integrated a RP&M networked service platform that the authors have been developed.

Acknowledgements

This project was partly supported by the National Science Foundation of Shandong Province (Grant No.Y2007F49). We would like to especially acknowledge these anonymous referees who give us many significant suggestions and point out some mistakes in our paper, which can result in largely improvement for the paper.

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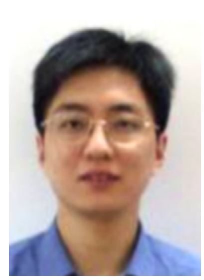

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