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A Feature-Enhanced Remote Machining Process Monitoring Method

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ABSTRACT

Machining process monitoring is essential to guarantee machining quality and reduce production cost, especially for the parts with complex structures and high accuracy requirement. However, effective machining process monitoring is still a challenge in industry. Particularly, a smooth communication between remote control computers and CNC (Computerized Numerical Control) systems is required. To address this requirement, a remote machining process monitoring method based on features and web is proposed. Machining feature model is established to facilitate the communication among the involved modules in the system. A web-based method is adopted to realize remote monitoring and control for multiple machines, as well as to alleviate the computational load of CNC systems. In addition, a feature-based database is constructed as a communication hub, where feature information, monitoring strategies and monitoring results are stored. A prototype system has been developed to validate the feasibility of the proposed method.

Keywords: feature, machining process, remote monitoring, web.

1. INTRODUCTION

The complexity and precision requirements of NC (Numerical Control) machining have become increasingly high due to the rapid changes of production capability and functionality [14]. NC machining enterprises are facing more and more thin-walled parts with freeform surfaces and other complex machining structures. These parts are easy to deform during machining processes. Besides, cutting tool wear [6] and cutting tool breakage always exist during machining. The occurrence of these machining conditions will affect the quality of products and even cause scraps with a consequence of cost increasing, while the cost of the product is critical issue for enterprises in global competition environment [13]. Enterprises are enforced to improve competition capability by advanced machining techniques [11]. Machining condition monitoring is proved to be an effective way to improve machining quality and reduce production cost [8]. There are two ways to monitor the machining conditions: locally and remotely. Each of them has its advantages and disadvantages. The local monitoring is intuitive for the machine tool operators to observe the real time machining conditions and to take corresponding actions, but limited by the knowledge and experience of the operators, as complex machining conditions can only be handled by experts; the remote monitoring provides a convenient way for the production management department to monitor the performance of machine tools and the machining conditions of workpiece, and it is convenient for experts to analyze the machining conditions in a remote way, but more developing work is required to realize the remote monitoring effectively.

Machining condition monitoring has been researched extensively in last decades. In terms of remote monitoring, Bllau *et al.* [2] presented a web based condition monitoring and remote control system, which consists of sensors, network cards and server with software system. In this system, the machine instability can be detected. Wang *et al.* [15] presented a web-based framework for remote device monitoring and control by using Java 3D technique, which can be used in distributed manufacturing environments.

In terms of monitoring techniques, acousto-optic emission [16], thermal infrared camera [10], spindle power [1], piezoelectric force sensor [4], and machine vision [9] are adopted to facilitate the process monitoring for surface quality, cutting tool wear, and machine condition. In order to enhance the machining process, feature-based and STEP-NC-based

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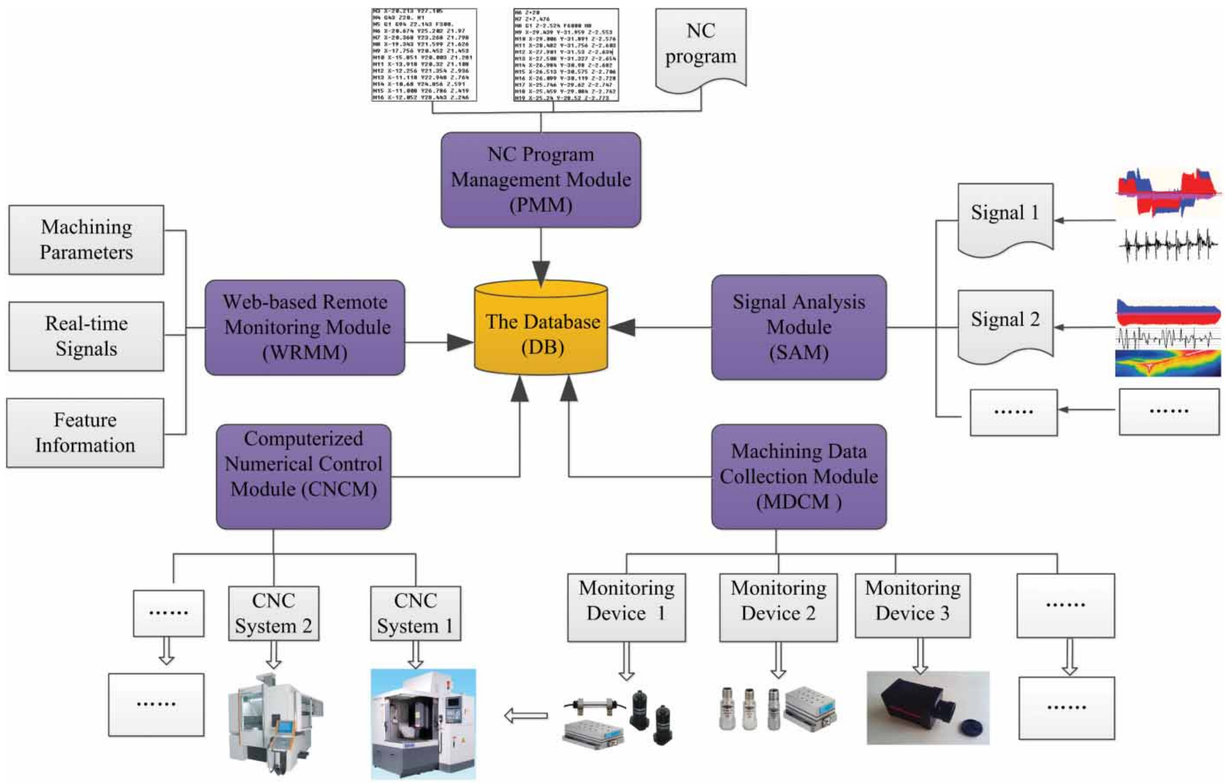

Fig. 1: Structure of the machining process monitoring framework.

information model are introduced [3, 12, 17], where geometric information and process information have been focused.

The research efforts mentioned above have made great contributions for machining condition monitoring. However, there are still some gaps required to be bridged: (1) a smooth communication between remote control computers and CNC systems is required; (2) an information model to represent different application views should be developed.

The rest of the paper is organized as follows: Section 2 presents the proposed web-based monitoring framework; Section 3 describes the feature-based database for communication among different modules; Section 4 introduces the implementation of the proposed approach; Section 5 concludes the paper and discusses our future work.

2. THE PROPOSED FRAMEWORK

In order to address the issues mentioned above, a web-based machining process monitoring framework is constructed to achieve remote and real-time machining condition monitoring, as well as to detect and handle abnormal machining conditions in real time. A web-based remote monitoring module (WRMM), a machining data collection module (MDCM), a signal analysis module (SAM), a NC program management module (PMM), a CNC module (CNCM), and a database management module (DBM) are contained in the framework, as shown in Fig. 1.

The connection among different modules is established by communicating with the database. WRMM and CNCM are located in the bottom of the system. The network communication method is utilized to read and write the database. The multi-thread method is used to communicate with the database by WRMM and SAM. To ensure different modules to have the same understanding of the information, the information should use the same language and protocols [5]. In this system, a feature model is used as the information carrier for communication.

The web-based method can realize remote monitoring and control of multiple machines. Much of the calculation work of CNC system can be executed via serving computers where the WRMM is located, and therefore the computational load of CNC system will be alleviated. In this system, the database is adopted as a communication intermediate by taking advantage of its convenience in storing and transmitting information. Additionally, it can record the information of the whole machining process which would make the enterprise managers convenient for the control of the production. The enterprise can improve the subsequent processes by analyzing the saved data. In terms of data transferring among different modules, cyclic redundancy checking (CRC) method is used to verify the data transmission.

Feature	*Monitoring object*	*Monitoring signal*	*Sensors*
Pocket	Bottom thickness, bottom deformation	Cutting force, vibration, thermal radiation	Dynamometer, vibration sensor, thermal imager
Rib	Thickness, deformation	Cutting force, vibration, thermal radiation	Dynamometer, vibration sensor, thermal imager
Hole	Deformation	Cutting force, vibration	Dynamometer, vibration sensor,
Profile	Deformation	Cutting force, vibration, displacement sensor	Dynamometer, vibration sensor, displacement value

Tab. 1: The monitoring signals and sensor for some features.

Tool wear, workpiece deformation and cutting tool vibration induced by unexpected factors such as using inappropriate machining parameters are expected to be monitored and detected in this system. During the process of NC machining, the information of the current machining feature is transmitted from CNCM to the database so as to associate the information of different application views. The monitoring strategy for the feature is determined by WRMM according to the feature information, i.e., what kinds of sensors to use and when to monitor the corresponding feature. Meanwhile, the current machining condition is determined by SAM through analyzing the real-time signals. In the view of different activities in the system, the functionality of different modules is described as follows:

1) Web-based Remote Monitoring Module (WRMM): This module is located at the top level of the system. The machining information is gathered from the database and displayed on the webpage, such as the geometric information of the current machining feature, the spindle speed, the feedrate speed, the current coordinates of the cutting tool, the tool path movement, the real-time monitoring signals and as like. In addition, the real time loads of the machine tools are also displayed, i.e., power and torque. The observers especially for the process planner who planned the NC program, can observe exactly how the NC program is performed without going to the machining scene. Control command can be sent directly from WRMM to CNC systems via intranet. Three kinds of authority levels are defined. The highest authority level is controlling the machine tool in real time, which is authorized to the production manager; the second authority level is controlling the machine tool in non-real time, e.g., the adjustment of the NC programs, which is authorized to the process planner who made the process planning of the current part; the third authority level is only for observing the machining performance, which can be logged in by general process planners for training. Each machine tool is numbered by an identifier, and the observing view can be switched to different machine tools by choosing different identifiers.

2) Machining Data Collection Module (MDCM): The monitoring signals are collected and sent to the database by this module. The physical signals which are usually used in real-time process monitoring for NC machining include cutting force, vibration, displacement, and thermal radiation. Different machining features are monitored by different signals due to the difference machining requirement and feature structures. There is a special computer in the machining site to collect the monitoring signals and send them to database center. The signals that need to be collected and the corresponding sensors for some feature are listed in Table 1.

The information of the current machining feature is obtained from the database and the monitoring strategies are determined by the WRMM according to the corresponding machining feature. When the signals are collected, they are associated with the corresponding features, and then are sent to the database in real time.

3) Signal Analysis Module (SAM): The function of this module is to analyze the monitoring signals in real time and to determine whether current machining is in a normal condition. The system can make a decision for emergency stop for abnormal conditions. The signal processing method used in this module is wavelet decomposition (which will be reported in a separate paper). In addition to real time analysis, post-machining analysis is also made in this module, which includes the evaluation of the manufacturing capacity of machine tools and the planning capacity of the process planners. Both of the capacity of machine tools and process planners can be evaluated from two aspects, i.e., overall evaluation and detailed evaluation. The evaluation is calculated by monitoring signals, the load of machine tools, the cutting parameters, the machining efficiency, and machining quality. As feature information is associated with physical signals, detailed evaluation can be made, which means that the capacity of machine tools and process planners for specified machining features can be evaluated.

4) CNC Module (CNCM): Interpolation operation is the main task for CNC module. Besides, communication interface is developed to receive the commands from WRMM for remote control. The real time control to CNC kernel is realized by sharing memory method.

5) NC Program Management Module (PMM): This module is in charge of NC program, and this module is mainly performed by the process planner who made

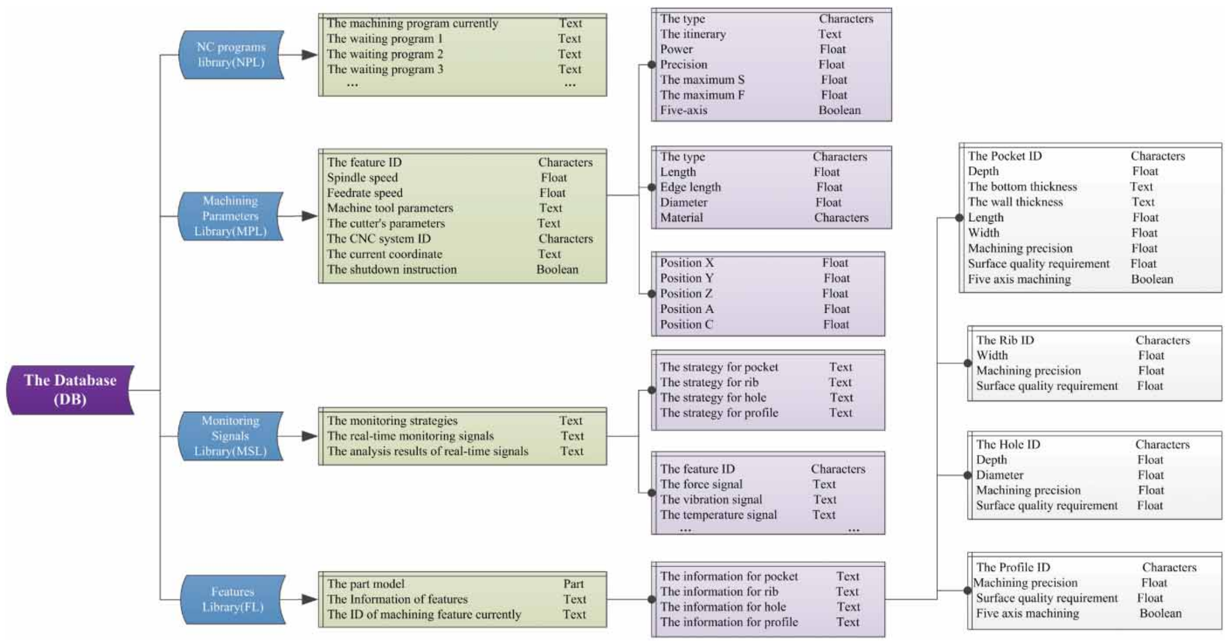

Fig. 2: Feature-based database structure.

the program of the parts. The operations to the NC programs include the adjustment of cutting parameters and cutting tool path. Basically, the NC programs are stored in the database for the convenient reading by the CNCM.

6) Database Management (DBM): This module is the kernel of the system, which is responsible for the transferring and saving of machining process related information. Machining related data are read and written in this module. The details of this module will be described in the subsequent section.

3. THE STRUCTURE OF FEATURE-BASED DATABASE

In this system, the database is used to establish the connection between the modules. Each module reads the required information from the database and writes the produced information to the database during machining. By using the database method, the system can provide data support for each module and record the whole process of machining to manage and search data.

A hierarchical model which has three layers is utilized in the database. The three layers include the main database, the library layer, and the parameter layer, as shown in Fig. 2. The library layer contains three blocks which are machining parameters library (MPL), monitoring signals library (MSL) and features library (FL). The functionalities of the blocks are described as follows:

- The MPL stores the information of spindle speed, feedrate speed, machine tool parameters, the cutting tool parameters, the CNC system ID, and the current coordinate of cutting tool.
- The MSL contains the information of monitoring strategies for different features, the real-time monitoring signals such as force signals, vibration signals, and thermal signals as like, and the analysis results of real-time signals.
- The FL includes part model, the NC program of features, and the ID of the machining feature.

It should be noted that the feature-based information contains the geometric information and the non-geometric information such as the machining precision and surface quality requirements. In terms of storage, monitoring information should be associated with the feature and time so as to realize the feature-based information search and record the machining process. During machining, the feature ID of the current machining feature is read from the CNC system, and then the monitoring data are associated with the feature ID. The machining information of different machine tools are stored by separated files, and are identified by identifiers of machine tools, part numbers, and the created times.

In order to solve the communication conflicts, three priorities for different kinds of information are defined. The shutdown command for the machine tool and the analysis results for real-time signals have the highest priority. The spindle speed, feedrate speed, monitoring strategy, real-time monitoring signals and the information of current machining feature have the second priority. The rest of the information, such as the current machining program, the waiting programs and the machining sequence of them, the

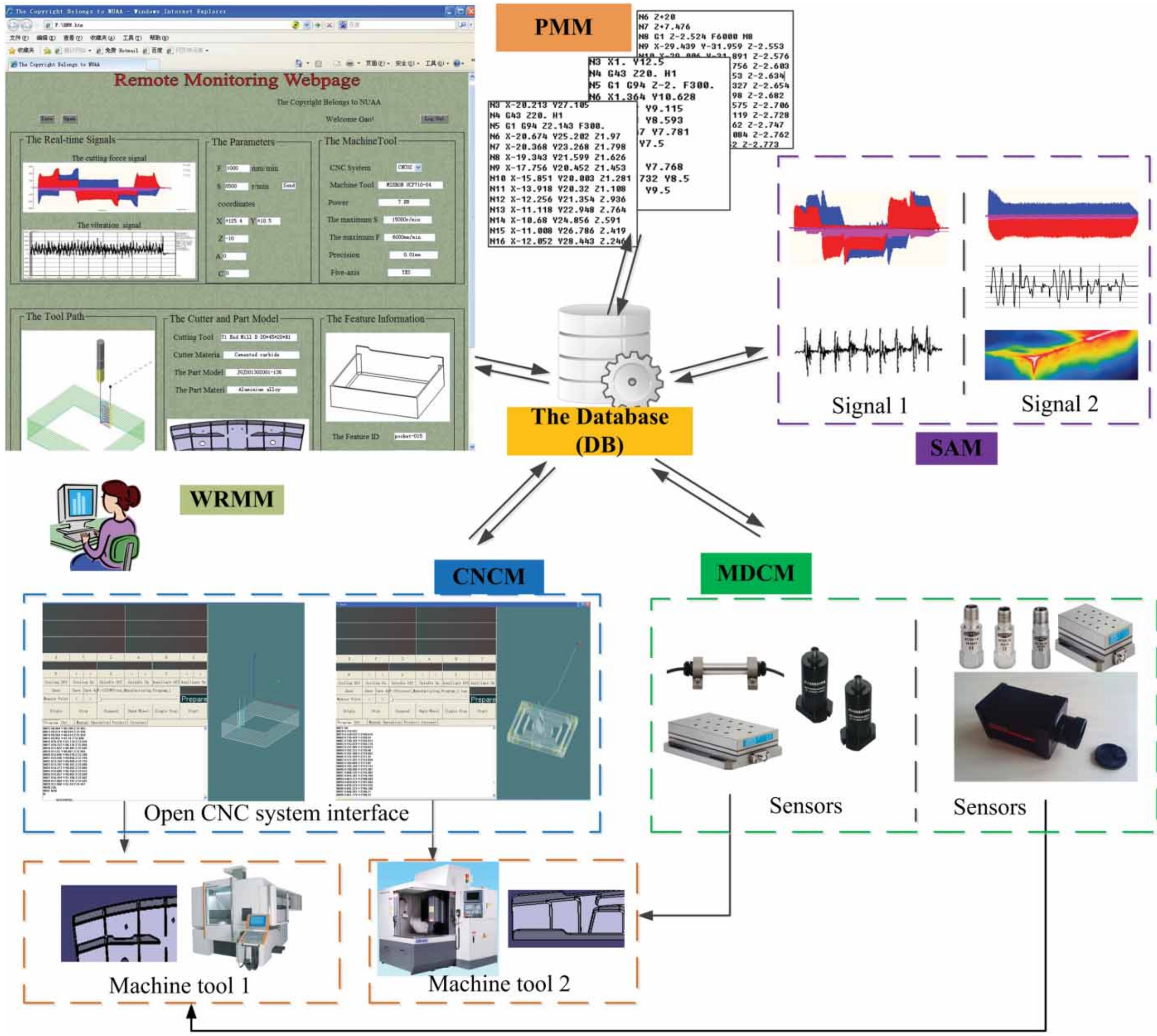

Fig. 3: Application case study.

machine tool parameters, the cutting tool parameters, the CNC system ID, the current coordinate of cutting tool, the part model, and the feature-based information have the lowest priority.

In order to search and locate information rapidly during machining, unique identifier is built for each kind of information. For example, the identifier for shutdown instruction of the machine tool is "1.2.8". The first digit in the identifier represents the level of priority, the "1" shows that the information has the highest priority. The second digit in the identifier represents the order of library, the "2" shows that the information is stored in MPL. The third digit in the identifier represents the order of information in the library, the "8" shows that the information is the identifier for the shutdown instruction for the machine tool.

As feature information is well structured, only the changed information is transferred in the form of feature package when communicating among different modules. Therefore, the data transferring load is significantly reduced.

4. IMPLEMENTATION OF PROTOTYPE SYSTEM

A prototype system of the proposed approach is developed based on an open CNC system which is a previous work of our research team. A web server to monitor and control machining process, as well as a database management center are implemented. The real-time monitoring signals, cutting parameters, machine tool information, and cutting tool information are displayed on the main webpage. Besides, the information of the current machining feature can also be viewed by taking advantage of feature ID, such as the geometric structure, tool path, and as like. OpenGL^{TM} is imbedded to display images in the webpage. A user can change the view of different machine tools by selecting the identification of machine tools. The machining and monitoring processes of two sample parts are presented to illustrate the system workflow and also to validate the feasibility of the proposed approach, as shown in Fig. 3.

Two pockets of typical structural parts are taken as a case study. An experiment is designed, and the two pockets are machined by two machine tools separately. Cutting force sensors, vibration sensors, and a thermal image sensor are used to collect the physical signals during machining. During the machining and monitoring process of the pockets, the machine programs are transmitted to the CNCM from the database so as to observe the machining conditions of the machine tools. The information which contains the feature ID of current machining feature, spindle speed, feed speed, the CNC system ID, the machine tool parameters, the cutting tool parameters, and the current coordinate of cutting tool is transmitted to the database by the CNCM. The information is displayed on the webpage in real time. Then the monitoring strategies, i.e., how to monitor the current machining feature, are transferred to the WRMM from the database. The real-time monitoring signals collected by sensors are transferred to SAM via the database. During machining, the feature ID of current machining feature is obtained by WRMM, and the monitoring signals are separated into different pieces and identified by feature IDs. As an over wear cutting tool is used in one of the machining process, the machining condition is detected by the SAM, so an emergent stop command is sent to the machine tool. After the change of the cutting tool, the machining process is finished. Finally, all of the machining parameters including cutting parameters and monitoring signals are stored in the database.

In addition to cutting tool wear that can be detected, the deflection of profile can also be detected by the proposed approach. The profiles of structural parts are always composed of thin-walled structures, so it is easy to deform during machining. A displacement sensor is adopted and fixed opponent to the machined profile. The displacement value is collected by MDCM, and analyzed by SAM. A threshold value for the displacement of profile deflection is set to detect whether the machining needs warning or compensation for the deflection so as to ensure the machining accuracy. This function is essential for the machining of thin-walled structural parts.

The performance of the experiments shows that the developed system can monitor multiple CNC machines simultaneously, and the information can be collected and processed in the database. The emergent machining condition indicates that the system has a control capacity to the machine tool in a remote way.

When comparing the proposed approach with the existing work, the advantages are that all of the machining information is associated by features, and the database provides a communication center to smooth the collaboration of different modules. The communication load is also reduced significantly due to the use of features. The computational load is alleviated because of the web-based method. Besides, the remote monitoring and control method for multiple machines makes the production process more reliable and convenient.

5. CONCLUSIONS

In order to address the issues of machining process monitoring, a feature enhanced method is proposed. The contributions of this work include:

(1) A feature-based model that can facilitate the communication among different modules in the process monitoring system and also provide support for the decision making of process monitoring;
(2) A web-based system that can monitor multiple CNC systems simultaneously and alleviate the computational load of the CNC systems;
(3) A prototype system that has been developed to validate the feasibility of the proposed approach.

Our future work includes the further development of the proposed approach, such as more exact association between the geometries of machining features with monitoring signals, more accurate geometric display of real time machining conditions. Besides, online process planning against abnormal machining incidents will be conducted by taking advantages of our previous work, i.e., dynamic feature model [7]. Furthermore, inspection is also expected to be integrated into the system to make a higher control capacity of the machining process.

ACKNOWLEDGEMENT

The authors would like to acknowledge the financial support by the National Natural Science Foundation of China [No. 51375239], Funding of Jiangsu Innovation Program for Graduate Education [No. CXZZ12_0171] and Funding of Ph.D. Thesis Innovation and Merit of Nanjing University of Aeronautics and Astronautics [No. BCXJ12-06].

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