A Novel Application of Empirical Mode Decomposition (EMD) to Fault Signal Analysis of Gears using LabVIEW

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***Abstract* — Empirical Mode Decomposition (EMD) is a signal analysis method for non-stationary vibration signal. In order to apply EMD in signal processing, a LabVIEW based programming methods is introduced. EMD is developed as a Visual Instrument (VI) and added into the main program as a sub-function to facilitate other fault diagnosis procedures. The proposed method is exploited for fault diagnosis of gear. Intrinsic mode functions (IMF) is extracted and its frequency spectrum is analyzed to de-noise and detect the fault information of gear. The proposed method is validated by simulation and fault gear test rig.**

Keywords - EMD, LabVIEW, gear, signal processing

I. INTRODUCTION

Empirical Mode Decomposition (EMD) is a signal analysis method, which is effective for time-frequency signal processing and non-stationary signal analysis. It is able to decompose signal according to the characteristics of the signal itself and form a series of intrinsic mode functions (IMF) with different time scales [1]. Each IMF contains different information in various time and frequency scales. This EMD decomposition process is actually a process of multi-filter, in which multi-frequency components of the non-stationary signal with different frequency components are decomposed from high to low. These frequency components of the frequency band of EMD are able to change adaptively corresponding to the original signal and make EMD method becomes a self adaptive methods [2].

LabVIEW is a graphical programming language widely used into development test, measurement analysis, and systems control [3]. Compared with other programming languages, LabVIEW is more convenient and flexible, especially for the testing of data acquisition devices and real-time data processing. At the same time, LabVIEW has powerful mathematical analysis and signal processing capabilities, including probability and statistics, linear algebra, differentiation and integration, spectral analysis, etc. Thus, the EMD algorithm can be applied quickly and efficiently with LabVIEW [4].

Gear is one of the most important functional parts of the mechanical transmission system. The health condition of gear directly affects the working state of the whole transmission system. The signal of fault gear is a no-linear and no-statistic signal and unsuitable for traditional frequency transform method. In this paper, a LabVIEW based EMD algorithm is applied to decompose the signal of fault gear into different IMF. Through frequency analysis of each IMF, the fault feature frequency of gear is extracted and the health condition of fault gear is detected.

II. THE ALGORITHM PROCESS OF EMPIRICAL MODE DECOMPOSITION

EMD is a signal decomposition method basing on the characteristics of the signal itself. Signal can be decomposed into different time scale components, IMF, and each component is independent from others. IMF is a real number sequence, in which extremal point and zero crossing number are equal, one difference at most, or the mean value of the two upper and lower envelopes formed by connecting the local maximum value and the minimum value is zero. IMF can be any non-sinusoidal signal, even non-linear non-stationary signal and can be generated without training, that is quite different from Fourier transform. The basic idea of EMD is to determine the instantaneous equilibrium position by means of the average of the upper and lower envelopes of the time series and extract the corresponding IMF[3]. The EMD decomposition of an arbitrary signal $\mathrm{r}(t)$ is performed as follows:

(1) Initialize $x(t)=r_0(t)=s(t)$, $i=1$, $k=0$ and Determine all the local extrema points. Connect all the local maximum points with a cubic spline to form an upper envelope and all the local minimum points with cubic spline to form a lower envelope line, where the upper and lower envelopes should envelope all data points.

(2) Expresse the average value of the upper and lower envelopes as m1 and calculate the $x(t)-m_1=h_1$. Ideally, if h_1 is an IMF, then it is the first IMF component.

(3) If h_1 does not satisfy the condition of the IMF, the steps (1) and (2) should be repeated with h_1 as the

original data to obtain the average value of the upper and lower envelopes. Then, $h_{11} = h_1 - m_{11}$ is verified again to determine whether the IMF condition is satisfied. If still not, the cycle is repeated k times by $h_{1(k-1)} - m_{1k} = h_{1k}$ until h_{1k} meets the conditions of IMS. Set $c_1 = h_{1k}$, where c_1 is the first component of the signal.

(4) Separate c_1 from $x(t)$ and calculate $r_1 = x(t) - c_1$. Use the r_1 as the original data to repeat step (1) to (3) and obtain the second component c_2 satisfying the condition of IMF. Repeat the cycle n times and obtain the nth IMS components of the signal. Then we have:

$$\begin{cases} r_1 - c_2 = r_2 \\ \cdots \\ r_{n-1} - c_n = r_n \end{cases} \quad (1)$$

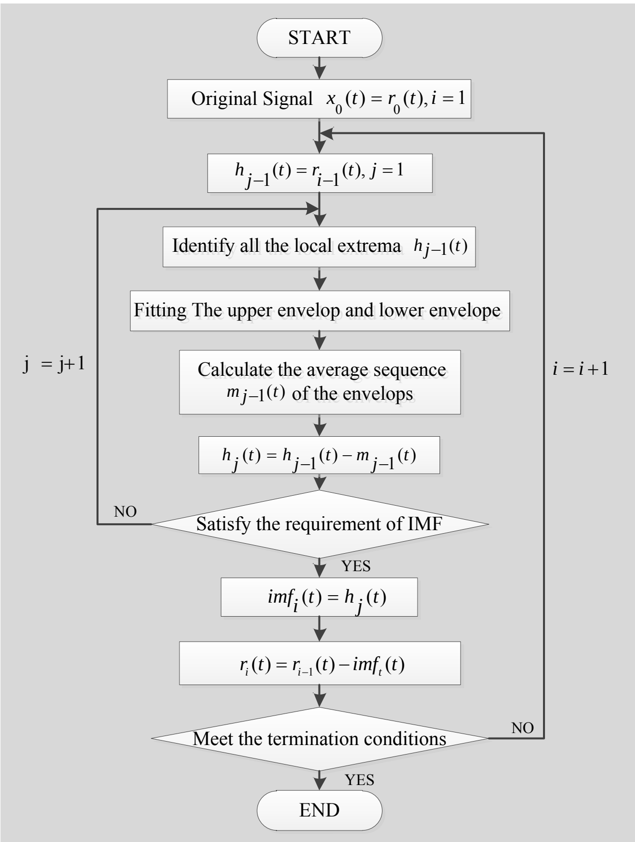

Fig.(1). The flow chart of EMD decomposition

When r_n is a monotonic function and no component can be extracted to meet the demands of conditions of IMF, the cycle will end and signal can be expressed as:

$$x(t) = \sum_{i=1}^{n} c_i + r_n \quad (2)$$

Where is the ith IMF component of the signal , which reflects the distribution of in different frequency bands. is the residual, representing the average trend of the signal.

The flow chart of EMD decomposition is shown in Fig. (**1**).

III. THE IMPLEMENTATION OF EMD ALGORITHM BASED ON LABVIEW

(1) Searching the local mean: use Peak Detector.vi to find the original data of the maximum and minimum values and their corresponding location. The program is shown in Fig. (2).

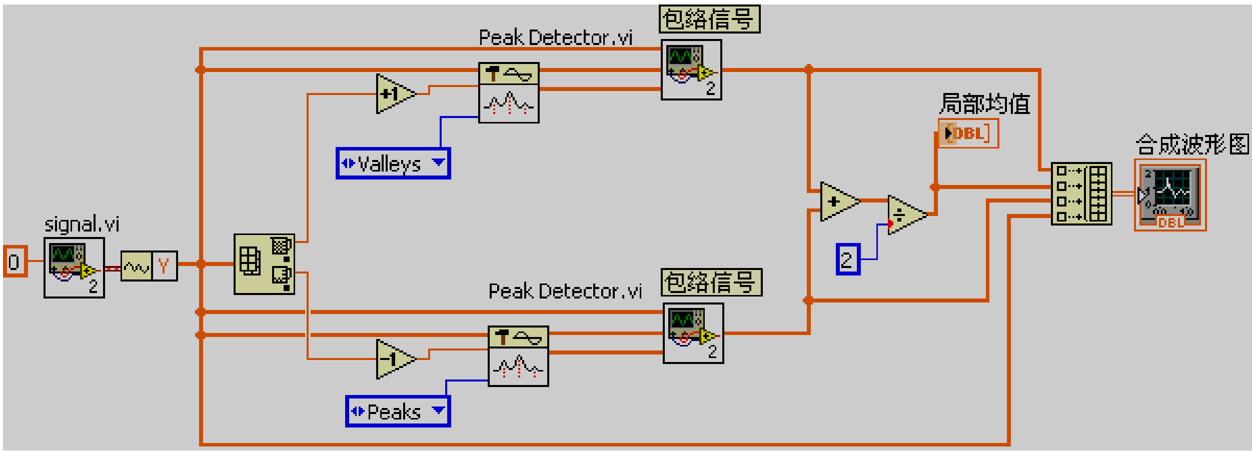

Fig. (2). The program of Searching the local mean.

(2) Spline interpolation: Spline Interpolant and Spline Interpolation module is applied for cubic spline interpolation. Then the envelope can be obtained according to all the maximum and minimum points. The program is shown in Fig. (**3**).

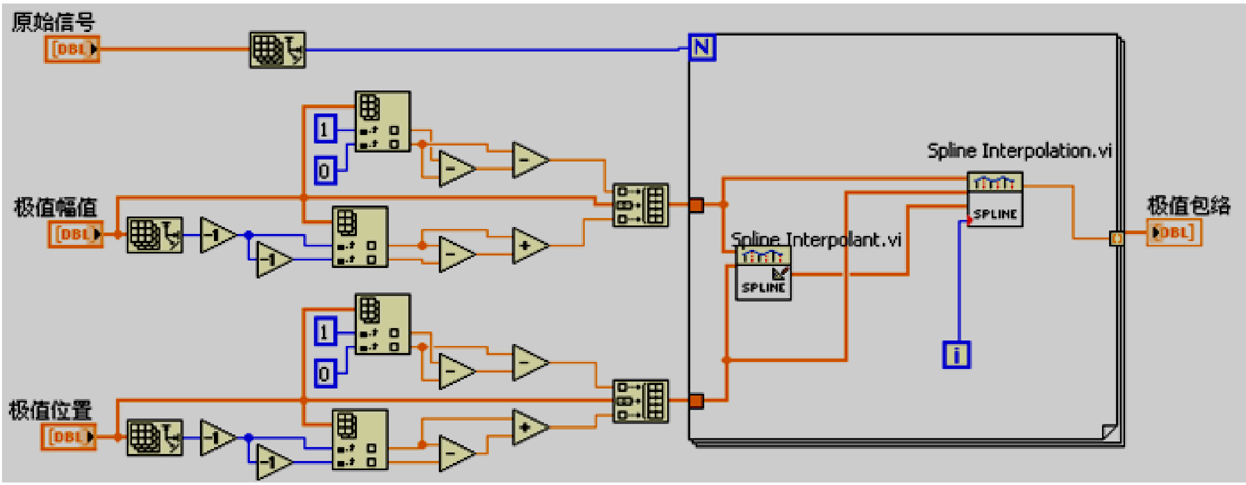

Fig. (3). The calculation of the envelop of signal.

(3) The determination of IMF conditions: the EMD process is a screening process. It benefits from the advantage of a finite number of IMF components and each IMF component can correspond to a certain physical process. However, if the EMD The decomposition process is not correct, it is easy to cause the frequency confusion between different IMF components, which make different IMF components contain the same time feature scale without any information of physical process. In addition, it is necessary to determine the IMF criterion to decompose the IMF component. The reason is that the EMD decomposition process is a "screening" process, in which fitting the cubic spline may produce human interference. In general, multiple iterations is required to decompose an IMF component. Although the IMF component requires the average of its upper and lower envelope is zero, the actual signal separation of IMF components of the average envelope can not be definitely zero. The more the number of "screening" is, the closer to zero the average envelope will be. However, if it is screened too many times, a constant amplitude of the FM wave would be obtained and the original meaning of the original signal would be lost. In general, the number of iterations is controlled using the standard deviation obtained from the results before and after "screening", i.e. $SD = \sum_{t=0}^{T} \frac{\left[h_{k-1}(t) - h_k(t)\right]^2}{h_{k-1}(t)^2}$. Many practices show that the iterative threshold SD is appropriate within the range of 0.2 to 0.3. The program development of this article takes 0.25. IMF solution block program is shown in Fig. (**4**).

The three steps above is the core of EMD. After screening, a number of IMF is obtained.

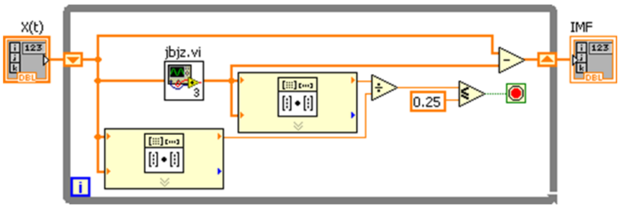

Fig. (4). IMF solution block program.

IV. EXPERIMENT AND ANALYSIS

A. Analysis of Simulation signal

A typical vibration signal with periodicity, frequency modulation, amplitude modulation, and noise background is simulated to verify the effectiveness of the proposed algorithm. The signal is described as:

S(t)=1*sin(100*pi(1)*t)*(1+0.2*cos(100*pi(1)*t))+0.8*sin (120*pi(1)*t+sin(10*pi(1)*t))+0.5*sin(1800*pi(1)*t)+2*(r and(-1)-0.5)

The signal contains the frequency components of 50Hz, 55Hz ~ 65Hz, 900Hz. With the 2000Hz sampling rate and 1000 sampling points of vibration signal, the time-domain waveform of the signal is shown in Fig. (**5**).

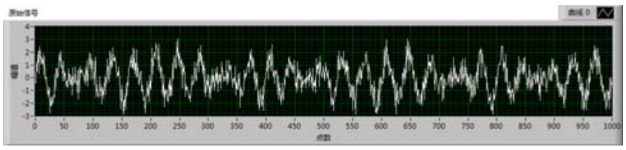

Fig. (5). The time-domain waveform of the simulated signal.

After EMD decomposition, the IMF component waveform and the IMF component of the power spectrum of the signal is shown in Fig. (**6**) and Fig. (**7**). From the Fig. (**7**), we can clearly see the amplitude of the 50Hz, 55Hz ~ 65Hz, 900Hz frequency components. The result of the simulated signal verifies the effectiveness of the proposed method.

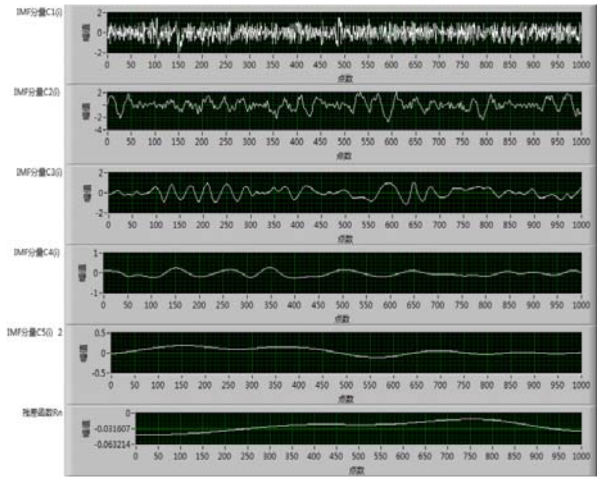

Fig. (6). The time-domain waveform of each IMF component of the simulated signal.

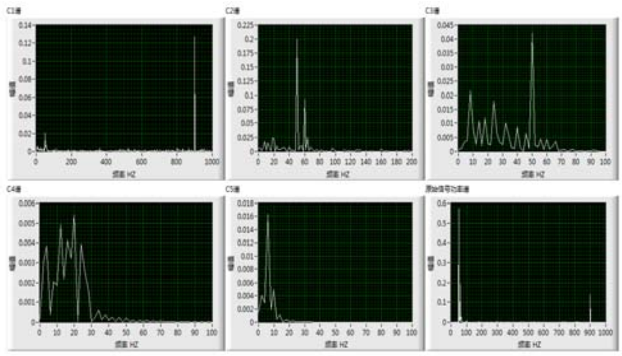

Fig. (7). The power spectrum of each IMF component of the simulated signal.

B. Analysis of fault signals of gear test rig

We use the gearbox failure test rig to carry out the experiment. The number of gear teeth is 75, and the fault type is local damage. A vibration sensor is located in vertical direction to monitor the health condition of gear. NI-Compact DAQ 9172 chassis with 9233 data acquisition card is used to acquire signal with 25.6kHz sampling rate and 25600 sampling points under speed of 633 rpm. Fault frequency of the gear is 10.55Hz and meshing frequency is 791Hz. The time domain waveform of the original vibration signal of the gearbox is shown in Fig. (**8**).

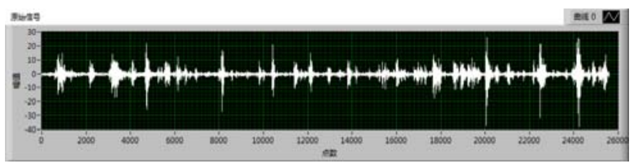

Fig. (8). The time domain waveform of the original vibration signal of the gearbox.

The EMD decomposition of the signal is carried out through the above programs. The waveform and the power spectrum of each IMF component of the gear fault signal are shown in Fig. (**9**) and Fig. (**10**), respectively.

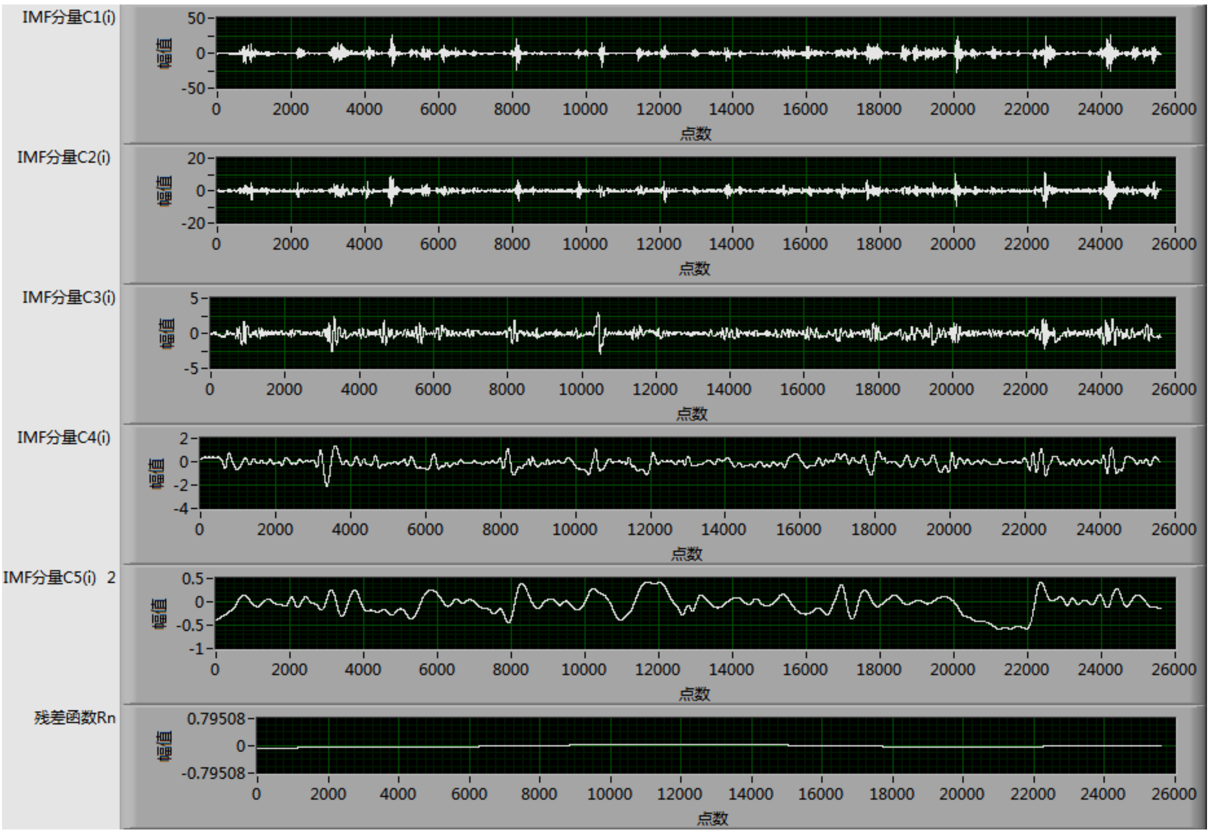

Fig. (9). The time-domain waveform of each IMF component of gear fault signal.

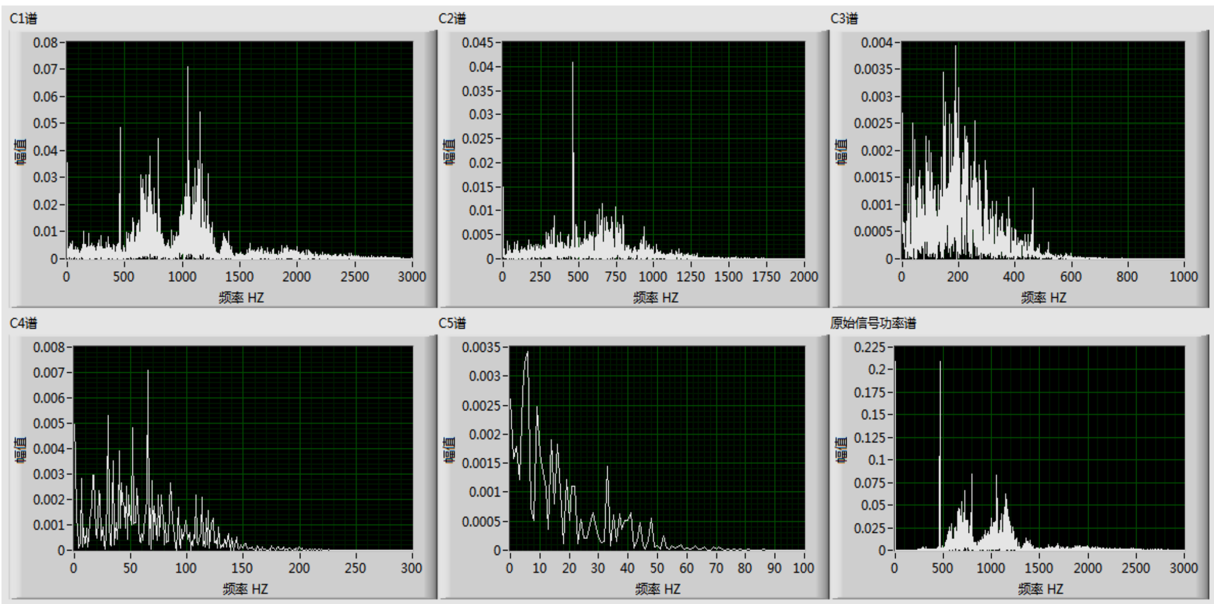

Fig. (10). the power spectrum of IMF components of gear fault signal.

When the cracks, broken teeth and other local damage of gear occur, the vibration signal in the time domain shows large amplitude of the regular impact-type vibration and frequency of the impact is equal to the frequency of broken teeth. In the frequency domain, the side band appears around the meshing frequency as well as its higher harmonics. The side frequency bands generally have a large amount and show a high amplitude and width in distribution. In the low frequency, rotation frequency and its high harmonics often appear and the modulation by natural frequency of the gear is also activated, where side bands appear around the center frequency of natural frequency of the gear broken teeth.

From Fig. (**10**), we can see the *C5* spectrum of the vibration signal contains the gear rotation frequency f_r=$10.55Hz$ and high harmonics, such as $0.5f_r$, $2f_r$, $3f_r$. From the *C1 ~ C3* spectrum and the original signal power spectrum, meshing frequency f_c=$791Hz$ and $0.5f_c$ with its high harmonics can be found, from which we can determine the gear A has local injury and maintenance should be carried out immediately.

V. CONCLUSION

In this paper, the principle of EMD algorithm is introduced and analyzed. The EMD is developed through the LabVIEW platform, which is convenient and reliable for debugging, modifying and visualization of waveform and analysis result. The effectiveness of the proposed method is validated by simulation signal and the signal of fault gear test rig. The result shows that the proposed method can be adaptively adjusted to the non-stationary characteristic of vibration signal and diagnose the health conditions of fault gear.

REFERENCES

[1] Xu Xiaoli, Wang Hongjun. "Large rotating machinery operating state trend prediction". *Beijing: Science Press*, 2011.

[2] Qiao Hui-hui. "Excavator remote state monitoring and fault diagnosis system". *Shijiazhuang: Shijiazhuang Railway University*, 2016.

[3] Zhang Li, Wang Ying. "Realization of Serial Communication Between LabVIEW and Mitsubishi PLC". *Microcomputer and Applications*, Vol . 31, pp: 51-53, 2013.

[4] Li Bo. "LabVIEW-based HHT method and its application in bearing fault diagnosis". *Taiyuan: Taiyuan University of Technology*, 2008.