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A STUDY ON MACHINABILITY CHARACTERISTICS AN ALUMINIUM ALLOY MATERIALS IN CNC TURNING

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ABSTRACT: The life time of any work piece depends up on its surface properties. Because it is in direct contact with atmosphere. In today's manufacturing industries quality is one of the significant factors, the only component to influence the customer to a level of satisfaction. In every industrial sector surface quality is detected by the surface roughness of the component. The demand for high quality aluminium alloys with good surface finish increasing day by day because of newer applications in various fields like aerospace, automobile, die and mould manufacturing and thus manufacturers are required to increase productivity by improving surface quality by avoiding stress concentrators on the surfaces. Some of the parameters which effect the work piece at the time of machining are namely cutting speed, depth of cut, feed and nose radius, cutting environment(dry or wet), etc.

The experiment will be carried on three machining parameters, viz., speed, feed and depth of cut as independent variables and the surface roughness parameter as response variable

Keywords: Al-alloys, Cnc turning, optimization technique,Surface roughness.

1. INTRODUCTION

Increasing the productivity and the quality of the machined parts are the main challenges of metal-based industry; there has been increased interest in monitoring all aspects of the machining process. Turning is the most widely used among all the cutting processes. The increasing importance of turning operations is gaining new dimensions in the present industrial age, in which the growing competition calls for all the efforts to be directed towards the economical manufacture of machined parts and surface finish is one of the most critical quality measures in mechanical products.

Machining operations have been the core of the manufacturing industry since the industrial revolution [1]. The existing optimization researches for computer numerical controlled (CNC) turning were either simulated within particular manufacturing circumstances [2–5] or achieved through numerous frequent equipment operations [6, 7]. Nevertheless, these are regarded as computing simulations, and the applicability to real-world industry is still uncertain. Therefore, a general deduction optimization scheme without equipment operations is deemed to be necessarily developed. The machining process on a CNC lathe is programmed by speed, feed rate, and cutting depth, which are frequently determined based on the job shop experiences. However, the machine performance and the product characteristics are not guaranteed to be acceptable. Therefore, the optimum turning conditions have to be accomplished. It is mentioned that the tool nose runoff will affect the performance of the machining process [8]. Therefore, the tool nose runoff is also selected as one of the control factors in this study. Manufacturing enterprises presently have to deal with growing demands for improved product quality, greater product unpredictability, shorter product life-cycles, cheap cost, and global struggle . In the field of machining, manufacturers are turning increasingly more often to automation as an effective way to meet these demands. A solution issue for an unattended and automated machining system is the development of reliable and robust monitoring systems. Turning is the removal of metal from the outer diameter of a rotating cylindrical workpiece

Surface roughness:
Surface quality is a very essential requirement for many machined products. Any metal cutting processes are not only to shape machine components but also to produce a good dimensional accuracy, good geometric shape and fine surface.
Now a days there are an increasing demand of most quality products. Because of the increasing demand for quality products, manufacturing engineers are facing with the difficulties of increasing productivity without compromising quality. Notably, precision machine components require accurate processes. High precision

machine tools and cutting tools are being manufactured for this purpose which can be used at high speeds. These machine tools can be sensitively controlled by a computer. In the same way, the machining quality must be controlled. Surface roughness cannot be controlled as accurately as geometrical form and dimensional quality as it fluctuates according to many factors such as machine tool structural parameters, cutting tool geometry, workpiece and cutting tool materials, environment, etc. In other words, surface quality is affected by the machining process, e.g. by changes in the conditions of either the workpiece, tool or machine tool. Surface roughness changes over a wide range in response to these parameters [6]. The characteristics of any machined surfaces have significant effect on the ability of the material to withstand several conditions like stresses, temperatures, friction, and corrosion [7]. The demand for high quality products with good surface finish increasing day by day because of newer applications in various fields like automobile, die and mold manufacturing and thus manufacturers are required to increase productivity by improving surface quality to remain competitive in the market [8]. Surface topography of any machined surface is characterized by many parameters, among them surface roughness is the most important parameter. To evaluate the surface integrity of any machined components, because it directly controls the surface functions, such as friction, wear, lubricant retention and load carrying capacity. It improves the fatigue strength, corrosion resistance and creep life, which are prerequisite in the case of aerospace components [9].

AL-Alloy: Pure aluminium is soft, ductile, corrosion resistant and has a high electrical conductivity. It is widely used forfoil and conductor cables, but alloying with other elements is necessary to provide the higher strengths needed for other applications. Aluminium is one of the
lightest engineering metals, having a strength to weight ratio superior to steel. By utilising various combinations of its advantageous properties such as strength, lightness, corrosion resistance, recyclability and formability, aluminium is being employed in an ever-increasing number of applications.

Alloying elements are copper, magnesium, manganese, silicon, tin and zinc. There are two principal classifications, namely casting alloys and wrought alloys, both of which are further subdivided into the categories heat-treatable and non-heat-treatable. About 85% of aluminium is used for wrought products, for example rolled plate, foils and extrusions. Cast aluminium alloys yield cost-effective products due to the low melting point, although they generally have lower tensile strengths than wrought alloys. The most important cast aluminium alloy system is Al–Si, where the high levels of silicon (4.0–13%) contribute to give good casting characteristics. Aluminium alloys are widely used in engineering structures.

Series of Aluminium

1000 Series Aluminium: 99% pure aluminium. No major alloying additions. Most common type is I 100 which is commercially pure aluminium It is soft and very ductile, having excellent workability. Well suited for applications involving severe forming as it work hardens more slowly during forming. It is the most weld able of all aluminium alloys. It can not be heat treated. It has the best resistance to corrosion of any aluminium alloy, and is widely seen in the food and chemical processing industry. Can be chem film treated and anodized easily. Commonly used as the top or Alclad layer in other aluminium alloys needing extra corrosion resistance. Poor machine ability due to soft nature.

2000 Series Aluminum Alloys: Principal alloying element is copper with minor additions of manganese and magnesium. This series of aluminum is the original heat treatable alloy group developed in the 1920's. The best known, most widely used heat treatable alloy for aircraft and aerospace is 2024. Can be spot and friction welded but not fusion welded (a few exceptions being tank structures in the Titan Missile). Has good formability in the annealed temper condition and some formability in the solution treated and aged condition, but needs intelligent application in complex designs. Has excellent fatigue properties when compared to other aluminum alloys, excellent strength to weight ratio. Good machinability. Poor resistance to corrosion without alclad layer or secondary chem film, anodize and/or prime and paint. Can be chem film and anodized readily. Other 2000 series alloys include 2017 seen widely in aluminum rivets, fasteners and screw machine parts and 2014 which is used heavily in forgings. These three alloys, 2024, 2014, and 2017 can be considered the foundations of aluminum aircraft, missiles and space vehicles during these past 75 years.

3000 Series Aluminum Alloys: 3003 is the most widely used of all aluminum alloys when measured in thousands of tons per year. It is essentially commercially pure aluminum with the addition of manganese which increases its strength about 20% over the 1100 series aluminum. Normally not heat treatable. A popular alloy in this group is 3003, which is used as a general purpose alloy for moderate strength applications requiring good formability. Applications include home, recreational, commercial and light industrial. Not normally seen for aircraft and aerospace uses.

5000 Series Aluminum Alloys: Magnesium is the principal alloy addition. A higher strength, non heat treatable family of alloys. 5005 is an improved version of 3003, better suited for anodizing with less tendency to streak or discolor. Similar applications to 3003. 5052 is the highest strength. Has good resistance to marine atmosphere and salt water corrosion. Excellent formability. Good fatigue properties in higher temper conditions. Used in a variety of applications including home, marine, ground transportation and aircraft. Good weldability by all methods. Probably over a dozen different alloys in this 5000 series group. Other popular alloys include 5056, 5083, & 5086. Many times used for aluminum rivets (bucked and pulled).

6000 Series Aluminum Alloys: Magnesium and silicon are the major alloy additions, making these alloys heat treatable. 6061 is the principle alloy. It is one of the least expensive and most versatile aircraft aluminum alloys available. A good range of mechanical fatigue properties and excellent corrosion resistance for a heat treatable aircraft alloy. Can be fabricated by virtually all methods. Excellent spot and fusion weldability for a heat treatable grade. Can also be furnace brazed. Available as a clad alloy for even better corrosion resistance. Although not as strong as the 2000 or 7000 series of heat treatable alloys, its corrosion resistance is far greater. Far ranging applications including aircraft, missiles and space, ground and marine transportation, screw machine parts and some industrial commercial uses. 6063 is widely seen in extrusion products for architectural applications. Has excellent finishing characteristics it is the best alloy for anodizing applications, either plain or dyed.

7000 Series Aluminum Alloys: Probably the highest strength series of aluminum alloys for aircraft applications. Relies on zinc as the primary alloy addition. Excellent fatigue properties, but in the T6 temper the fracture toughness can be inferior to other alloy choices. Many aircraft applications in the late 1940's and 1950's used 7075 T6 before some bad habits were understood. Normally formed fabricated in the annealed (0) condition. Can be spot welded but not fusion welded. Poor corrosion resistance if not protected by chem film, anodize, prime or paint. In sheet forms almost always used as a clad alloy. Other popular alloys now include 7049, 7050 in the overaged temper condition (T7xxx).

Clad Aluminum: Sometimes called Alclad. Many times the design engineer specifies a clad alloy, or a specific alloy type with a very thin layer of pure aluminum roll bonded to both sides of the alloy sheet. This provides us with the best of both worlds the high strength of the heat treatable alloy with the superb corrosion resistance of a purer aluminum top layer. This roll bonding is a true metallurgical bond and it's strong as the aluminum itself. Our U.S. coins are roll bonded clad alloys take a look at the dime or quarter in your pocket. Yes, it is nickel, roll bonded to a copper core.

CNC TURNING:

Numerical control (NC) refers to the automation of machine tools that are operated by abstractly programmed commands ,encoded on astorage medium ,as opposed to manually controlled via handwheels or levers ,or mechanically automated via cams alone. these systems are hardware controls in which most of functions are carried out by electronic hardware based upon digital circuit technology. Numerical Control is a technique for controlling machine tools or processes using coded command instructions. These coded command instructions are interpreted and converted by NC controller into two types of signals namely; motion control signals and miscellaneous control signals. Motion control signals are a series of electric pulse trains that are used to control the positions and the speed of the machine table and spindle, whereas miscellaneous control signals are set of ON/OFF signals to execute the spindle rotation and direction, control of coolant supply, selection of cutting tools, automatic clamping and unclamping, etc

Direct numerical control (DNC) is defined as a manufacturing system in which a number of NC machines are controlled by a computer through direct connection in real time“A system connecting a set of numerically controlled machines to a common memory for part program or machine program storage with provision for on-demand distribution of data to machines.”

In DNC, several NC machines are directly controlled by a computer, eliminating substantial hardware from the individual controller of each machine tool. The part-program is downloaded to the machines directly (thus omitting the tape reader) from the computer memory.

Computer numerical control (CNC) is the numerical control system in which a dedicated computer is built in to the control to perform basic and advanced NC functions.CNC controls are also reffered to as soft-wired NC systems because most of their control functions are implemented by the control software programs.CNC is a computer assisted process to control general purpose machines from instructions generated by a processor and stored in a memory system "A numerical control system wherein a dedicated, stored program computer is used to perform some or all of the basic numerical control functions in accordance with control programs stored in the read-write memory of the computer."

. **G Codes Turning**

STD DESCRIPTION
G00 Rapid Linear Positioning
G01 Linear Feed Interpolation
G02 CW Circular Interpolation
G03 CCW Circular Interpolation
G04 Dwell
G07 Hypothetical Axis Interpolation, Sine Curve
G09 Exact Stop
G10 Offset Value Setting
G20 Input In Inches
G21 Input In Millimeters
G22 Stored Stroke Limit On
G23 Stored Stroke Limit Off
G27 Reference Point Return Check
G28 Return To Reference Point
G29 Return From Reference Point
G30 Return To 2nd, 3rd, and 4th Reference Point
G31 Skip Cutting
G32 Thread Cutting
G34 Variable Lead Thread Cutting
G36 Automatic Tool Comp. X
G37 Automatic Tool Comp. Z
G40 Tool Nose Rad. Comp. Cancel
G41 Tool Nose Radius Comp. Left
G42 Tool Nose Radius Comp. Right
G50 G92 Programming Of Absolute Zero
G65 User Macro Simple Call
G66 User Macro Modal Call
G67 User Macro Modal Call Cancel
G68 Mirror Image For Double Turrets On
G69 Mirror Image For Double Turrets Off
G70 G72 Finishing Cycle
G71 G73 Stock Removal, Turning
G72 G74 Stock Removal, Facing
G73 G75 Repeat Pattern
G74 G76 Peck Drilling, Z Axis
G75 G77 Grooving, X Axis
G76 G78 Thread Cutting Cycle
G90 Cutting Cycle A
G92 Thread Cutting Cycle
G94 G79 G24 Cutting Cycle B
G96 Constant Surface Speed Control
G97 Constant Surface Speed Cancel
G98 Feed Per Minute
G99 Feed Per Revolution
G90 Absolute Programming
G91 Incremental Programming

Design of experiments:

This branch of applied statistics deals with planning, conducting, analyzing and interpreting controlled tests to evaluate the factors that control the value of a parameter or group of parameters.

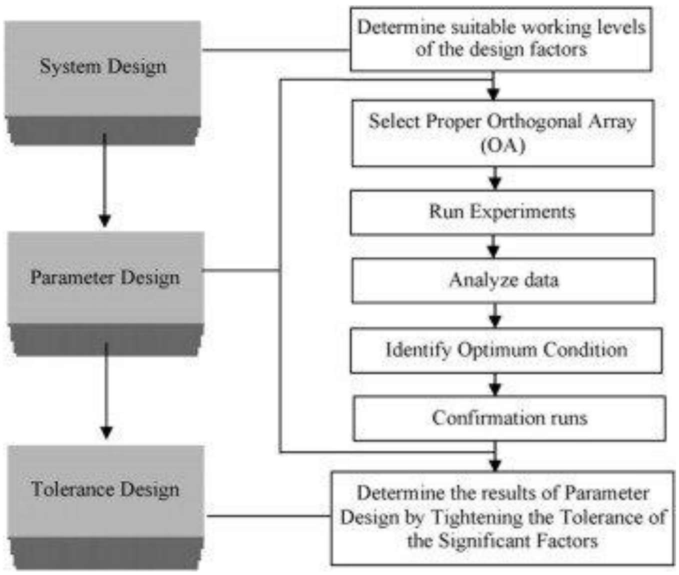
The Design of Experiments is considered as one of the most comprehensive approach in product/process developments. It is a statistical approach that attempts to provide a predictive knowledge of a complex, multi-variable process with few trials. Following are the major approaches to DOE

Design of experiments is a powerful analysis tool for modelling and analysing the influence of control factors on performance output. The traditional experimental design is difficult to be used especially when dealing with large number of experiments and when the number of machining parameter is increasing [8]. The most important stage in the design of experiment lies in the selection of the control factors [9]. Therefore, the Taguchi method, which is developed by Dr. Genichi Taguchi, is introduced as an experimental technique which provides the reduction of experimental number by using orthogonal arrays and minimizing the effects out of control factors [8]. Taguchi is a method which includes a plan of experiments with the objective of acquiring data in a controlled way, executing these experiments and analysis data in order to obtain the information about behaviour of the given

process [1], [10] and [11]. Besides that, it is a set of methodologies that took into account of the inherent variability of materials and manufacturing process during the design stage [12]. It is almost similar to the design of experiment (DOE) but the Taguchi design's balanced (orthogonal) experimental combination offers more effective technique than the fractional factorial design [12]. This technique has been applied in the manufacturing processes to solve the most confusing problems especially to observe the degree of influence of the control factors and in the determination of optimal set of conditions [1].

In the Taguchi definition, the quality of a product is defined in terms of the loss imparted by the product to the society from the time it is shipped to the customer [13]. The losses due to the functional variation are known as losses due to the deviation of the product's functional characteristics from its desired target value. Besides that, the noise factors are the uncontrollable factors which cause the functional characteristics of a product that do not achieve its targeted values [13]. The noise factors can be classified as the external factors (temperature and human errors), manufacturing imperfections and product deterioration. The main purpose of quality engineering is to make sure that the product can be robust with the respect of all possible noise factors [13]. So, the Taguchi method could decrease the experimental or product cycle time, reduce the cost while increasing the profit and determines the significant factors in a shorter time period as it can ensure the quality in the design phase [8] and [12].

The procedure of Taguchi's design as shown in Fig. 1 can be categorized into three stages viz. system design, parameter design and tolerance design [12]. Parameter design, considered as the most important stage, can determine the factors affecting quality characteristics in the manufacturing process. The first step in Taguchi's parameter design is selecting the proper orthogonal array (OA) according to the controllable factors (parameters). Then, experiments are run according to the OA set earlier and the experimental data are analysed to identify the optimum condition. Once the optimum conditions are identified, then confirmation runs are conducted with the identified optimum levels of all the parameters



The S/N ratio can be characterized into three categories when the characteristics are continuous: Nominal is the best characteristic

$$S/N = 10 \log \frac{\overline{y}}{S_y^2}$$

Smaller the better characteristic

$$S/N = 10 \log \frac{1}{n} \left(\sum y^2 \right)$$

Larger the better characteristics

$$S/N = 10 \log \frac{1}{n} \left(\sum \frac{1}{y^2} \right)$$

where ‘ $\overline{y}$ ’ is the average observed data, ‘ S_y^2 ’ the variance of ‘y’, ‘n’ the number of observations, and ‘y’ the observed data. For each type of characteristics, higher or lower value of S/N ratio indicates the better result value

3 APPLICATION OF DOE IN GREY RELATION ANALYSIS

OrthoGrey relational analysis is an impacting measurement method in grey system theory that analyzes uncertain relations between one main factor and all the other factors in a given system. In the case when experiments are ambiguous or when the experimental method cannot be carried out exactly, grey analysis helps to compensate for the shortcomings in statistical regression. Grey relational analysis is actually a measurement of the absolute value of the data difference between sequences, and it could be used to measure the approximate correlation between sequences.

In the grey relational analysis, the experimental data of the wear volume and friction coefficient are first normalized to be in the range of zero to one, which is also called the grey relational generating. The grey relational coefficient is calculated from the normalized experimental data to express the relationship between the desired and actual experimental data.

Then, the grey relational grade is computed by averaging the grey relational coefficient corresponding to each process response. The overall evaluation of the multiple process responses is based on the greyrelational grade. As a result, optimization of the complicated multiple process responses can be converted into optimization of a single grey relational grade. In other words, the grey relational grade can be treated as the overall evaluation of experimental data for the multi-response process. The optimal level of the process parameters is exactly the level with the highest grey relational grade.

3.4.2 Data pre-processing

Data pre-processing is normally required since the range and unit in one data sequence may differ from the others. Data preprocessing is also necessary when the sequence scatter range is too large, or when the directions of the target in the sequences are different. Data pre-processing is a means of transferring the original sequence to a comparable sequence. Depending on the characteristics of a data sequence, there are various methodologies of data pre-processing available for the grey relational analysis.

If the target value of original sequence is infinite, then it has a characteristic of the “higher is better”. The original sequence can be normalized as follows:

$$x_i^*(k) = \frac{x_i^0(k) - \min x_i^0(k)}{\max x_i^0(k) - \min x_i^o(k)} \text{ ------- (3.1)}$$

When the “lower is better” is a characteristic of the original sequence, then the original sequence should be normalized as follows:

$$x_i^*(k) = \frac{\max x_i^0(k) - x_i^0(k)}{\max x_i^0(k) - \min x_i^o(k)} \text{--------(3.2)}$$

However, if there is a definite target value (desired value) to be achieved, the original sequence will be normalized in form:

$x_i^*(k) = 1 - \frac{|x_i^0(k) - x^0|}{\max x_i^0(k) - x^0}$ -------- (3.3)

Or, the original sequence can be simply normalized by the most basic methodology, i.e. let the values of original sequence are divided by the first value of the sequence:

$x_i^0(k) = \frac{x_i^0(k)}{x_i^o(1)}$ ------- (3.4)

Where i= 1, . . . ,m;
k = 1, . . . , n.
mis the number of experimental data items and
nis the number of parameters.
$x_i^0(k)$denotes the original sequence,
$x_i^*(k)$the sequence after the data pre-processing,
$\max x_i^0(k)$the largest value of $x_i^0(k)$,
$\min x_i^o(k)$the smallest value of $x_i^0(k)$, and
$x^0$is the desired value.

3.4.3 Grey relational coefficient and grey relational grade

In grey relational analysis, the measure of the relevancy between two systems or two sequences is defined as the grey relational grade. When only one sequence, $x^0(k)$, is available as the reference sequence, and all other sequences serve as comparison sequences, it is called a local grey relation measurement. After data pre-processing is carried out, the grey relation coefficient $\xi_i(k)$ for the k^{th} performance characteristics in the i^{th} experiment can be expressed as:

$\xi_i(k) = \frac{\Delta_{min} + \xi\Delta_{max}}{\Delta_{0i}(k) + \xi\Delta_{max}}$ -------- (3.6)

Where,ξ is the distinguishing coefficient, a value of ξ is the smaller and the distinguished ability is the larger. ξ = 0.5 is generally used. $\Delta_{oi}$is the deviation sequence of the reference sequence and the comparability sequence.

$\Delta_{oi} = \|x_o^*(k) - x_i^*(k)\|$ denotes the absolute value of the difference between $x_0(k)$ and x_i (k),$\Delta_{min} = \min_{\forall j \in i} \min_{\forall k} \left\|x_0^*(k) - x_j^*(k)\right\|$is the smallest value of Δ_{0i},
$\Delta_{max} = \max_{\forall j \in i} \max_{\forall k} \left\|x_0^*(k) - x_j^*(k)\right\|$is the largest value of Δ_{0i}.

After the grey relational coefficient is derived, it is usual to take the average value of the grey relational coefficients as the grey relational grade. The grey relational grade is defined as follows:

$\gamma_i = \frac{1}{n}\sum_{k=1}^{n} \xi_i(k)$ ------- (3.7)

Where n is the number of process responses.

A high value of the grey relational grade represents a strong relational degree between the reference sequence $x_0(k)$ and the given sequence x_i (k). As mentioned before, the reference sequence $x_0(k)$ is the best process response in the experimental layout. A higher value of the grey relational grade means that the corresponding process parameter is closer to the optimal one. In other words, the optimization of the complicated multiple process responses can be converted into the optimization of a single grey relational grade.

3.4.4 Decision for Grey multiple attributes.

To solve problems, if many ways or feasible methods exist, we normally make a complete evaluation on those resolutions. Then decision is made based on the evaluation results. It is noted that the multiple attributes decision-making is defined when more than one-evaluation factors are considered. Hence, the application of Grey relational analysis to multiple purposes and attributes is called as Grey multiple attributes decision.

Moreover, this method regards each comparative series as a feasible solution, and the numeric score for each evaluation factor becomes the numeric value for each comparative value. The relational grade between comparative series and standard series is then determined. Finally, the decision can be made based on the ranking of each feasible solutiongonal array and experimental factors

In the parameter design stage of the Taguchi method in , the first step is to set up and select a proper orthogonal array (OA). To accommodate three control factors into the experimental study, a standardized Taguchi-based experiment design, $L_{27}(3^3)$ was chosen to be used in this study and is shown in. This basic design makes use of three control factors with three levels each and the design has capability to check the interaction between the factors. From the standard design there are 27 experimental runs that need to be conducted with the combination of levels for each control factor (A–C). As the incorporation of the noise factors into the OA is optional, the noise factor is omitted from this experimental study. The selected parameters are displayed in together with their codes and values for the application in Taguchi parameter design study. In this study, the control factors (Depth of cut, Spindle speed, and Feed rate) are the independent variables while the response factors (Surface roughness, Cutting force) are the dependent variables.

AVAILABLE ORTHOGONAL ARRAYS The following Standard Orthogonal Arrays are commonly used to design experiments: 2-Level Arrays: L-4 L-8 L-12 L-16 L-32 L-64 3-Level Arrays: L-9 L-18 L-27 (L-18 has one 2- level column) 4-Level Arrays: L-16 & L-32 Modified

Optimization:
Maximizing or minimizing some function relative to some set, often representing a range of choices available in a certain situation. The function allows comparison of the different choices for determining which might be "best."
Types of optimization techniques:

Taguchi:
Taguchi methods start with an assumption that we are designing an engineering system - either a machine to perform some intended function, or a production process to manufacture some product or item. Since we are knowledgeable enough to be designing the system in the first place, we generally will have some understanding of the fundamental processes inherent in that system. Basically, we use this knowledge to make our experiments more efficient. We can skip all the extra effort that might have gone in to investigating interactions that we know do not exist.

Gray relation analysis:
Grey relational analysis is an impacting measurement method in grey system theory that analyzes uncertain relations between one main factor and all the other factors in a given system. In the case when experiments are ambiguous or when the experimental method cannot be carried out exactly, grey analysis helps to compensate for the shortcomings in statistical regression. Grey relational analysis is actually a measurement of the absolute value of the data difference between sequences, and it could be used to measure the approximate correlation between sequences.

Genetic algorithm:
Genetic algorithms (GA) were developed with the primary intention of imitating the processes that exist in nature. Basic principles of genetic algorithms were published in 1962 (Holland) and the mathematical framework for their development was published in 1975 by the same author. In the field of optimization, these algorithms were used to: optimize functions, process of images, solve trade man problem, identification systems and control and so on. In the area of machine learning, GA were used to implement simple "If-Then" rules in an arbitrary environment [7].

Artificial of neural networks:
An artificial neuron is a mathematical function conceived as a crude model, or the abstraction of biological neurons. Artificial neurons are the constitutive units in an artificial neural network. The input layer, hidden layer and output layer, includes several processing units known as neurons. The path connecting two neurons is associated with a certain variable weight which represents the synaptic strength of the connection. The input to a neuron from another neuron is obtained by multiplying the output of the connected neuron by the synaptic strength of the connection between them. The artificial neuron than sums up all the weighted inputs coming to it.

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