Fuzzy Logic Controllers Improves Human Daily Life. The State-Of-The Art

(Best Accuracy & More Flexibility)

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ABSTRACT
Nowadays, science in all their fields tries to touch the limits of performance, the control policy is one of the most scientific fields who require very high level of accuracy and stability, therefore, scientists are always trying to bring new methodologies to improve the controllers criterias. The survey presented in this papers covers and explains the great contribution that brings the use of FLCs in very large/several fields of human daily life, such as : medicine, industrial process, chemical process, aircraft ext...

General Terms
Fuzzy Logic Controllers, Hybrid Control Policy, Industrial Controllers, Application of FLC.

Keywords
Fuzzy Logic Controllers; Intelligent Control; Hybrid Algorithms; Advanced Control Process.

1. INTRODUCTION
The characteristics of human intelligence can be emulated using techniques of intelligent control who presents a new and a very suitable alternative control policy. These characteristics include learning and adaptation, planning under any type of disturbance. Today, the area of intelligent control tends to include all that is not classified as conventional control.

The specification of the term Intelligent control is different in each scientific area stems from the fact that there is no agreed upon definition of human intelligence and intelligent behavior and the centuries old debate of what constitutes intelligence has yet to be decided, with on going debate and discussion still continued by educators, psychologists, computer scientists and engineers. In the 70's K.S. Fu has introduced for the first time the term of intelligent control. Reference [1] is the main source of the several descriptions of intelligent control. There are a number of areas related to the-field-of-intelligent-control.

Intelligent control is control policy that combines and extends theories and methods from areas such as control, computer applications and operations research. It brings theories from mathematics and seeks inspiration and mimics some behaviors of biological systems. Intelligent control methodologies are being applied to robotics and automation, communications, manufacturing, traffic control, to mention but a few areas of possible application. Neural networks, fuzzy control, genetic algorithms, planning systems, expert systems, and hybrid systems are all areas where related work is taking place.

The fields of computer science and specially artificial intelligence provide knowledge representation ideas, methodologies and tools such as semantic networks, frames, reasoning techniques and computer languages such as prolog. Systems and algorithms developed in the fields of adaptive control and machine learning help intelligent controllers to adapt and learn. Advances in sensors, actuators, computation technology and communication networks help provide the necessary technology for implementation of intelligent control hardware. From these many advances and variations in technology and methodologies, we choose to place a particular emphasis on fuzzy logic controllers in this survey as a strong and robust strategy of control. We aim to find out its advantages, flexibility and precision in different areas of human life through studying several publications which handle the problem of control in several fields; taking for examples, medicine, robotic manipulation, tracking systems, automotive vehicle, airplane drives, electrical machine and some other human daily use etc…

This article is presented as following. Part I, will be a general introduction on the area of control and FLCs. Part II will focus on the contribution of the FLCs in the area of intelligent control and its benefits. Part III will present several examples that demonstrate the effect of the use of FLCs in various human fields by different methods. In section IV we will attempt to justify the use of several techniques in parallel with FLCs, and last but not least in part V, a conclusion will be constructed that reflects the important role played by the introduction of FLCs for technology, progress, and what it means these innovative technologies could mean for the human race.

2. FUZZY LOGIC CONTROLLER (FLC) SUITABLE ALTERNATIVE TO CONTROL COMPLEX SYSTEMS
For many years ago PID (Proportional, Integral and Derivative) controller was the most widely used control structure in industrial plants. Accordingly to Aström and Hägglund [73], more than 90% of closed-loops have been controlled by PID

algorithms. The simplicity of design and the performance on linear systems are good reasons for the great acceptance of PID control in industrial and academic fields. However, when the process to be controlled has a high level of complexity, such as, time delays, time varying parameters, modeling mismatch and nonlinearities, the performances of a PID control system becomes unsatisfactory in order to guarantee the requirements of most of the practical situations. Most advanced control algorithms not only have had a great advance on the control theory but they also depend on the mathematical model, where, in hard practical conditions, it is not always possible to come up with the required model. Thus, there is a necessity for a general-purpose intelligent controller that can be used easily and effectively to control a wide variety of complex plants, in other words, a fuzzy control. Controllers based on fuzzy logic theory not only try to mimic the behavior of an expert operator but also do not have a need for model identification. Fuzzy logic theory is a particularly good choice for many control problems due to its several unique features [2].

Let us quote for example:

1. It is inherently robust since it does not require precise, noise-free inputs and can be programmed to fail safely if a feedback sensor quits or is destroyed. The output control is a smooth control function despite a wide range of input variations.
2. Since the FL controller processes user-defined rules governing the target control system, it can be modified and tweaked easily in order to improve or drastically alter system performance.
3. FL is not limited to a few feedback inputs and one or two control outputs, nor is it necessary to measure or compute rate-of-change parameters in order for it to be implemented.
4. Because of the rule-based operation, any reasonable number of inputs can be processed (1-8 or more) and numerous outputs (1-4 or more) generated, although defining the rule base quickly becomes complex if too many inputs and outputs are chosen for a single implementation since rules defining their interrelations must also be defined.
5. FL can control nonlinear systems that would be difficult or impossible to model mathematically. This opens doors for control systems that would normally be deemed unfeasible for automation.

Fuzzy Logic Controllers (FLC) can be used in various manners. The most obvious one is *direct control*, where the fuzzy controller is in the forward path in a feedback control system (Fig 1). The process output is compared with a reference, and if there is a deviation, the controller takes action according to the control strategy. In the figure, the arrows may be understood as hyper-arrows containing several signals at a time for multi-loop control. The sub-components in the figure will be explained shortly. The controller is here a fuzzy controller, and it replaces a conventional controller, say, a, *PID* controller.

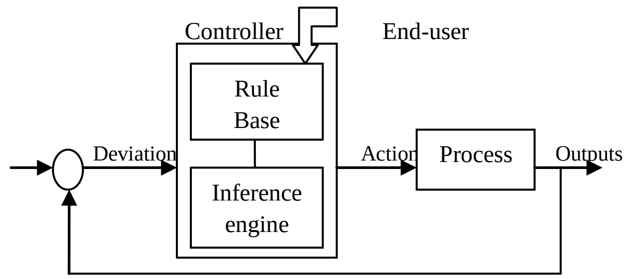

Fig 1: direct Control

In *feed forward control* (Fig 2) a measurable disturbance is being compensated. It requires a good model, but if a mathematical model is too difficult or expensive to obtain, a fuzzy model may be useful. Figure 2 shows a controller and the fuzzy compensator, the process and the feedback loop are omitted for clarity. The scheme, disregarding the disturbance input, can be viewed as a collaboration of linear and nonlinear control actions; the controller C may be a linear PID controller, while the fuzzy controller F is a supplementary nonlinear controller.

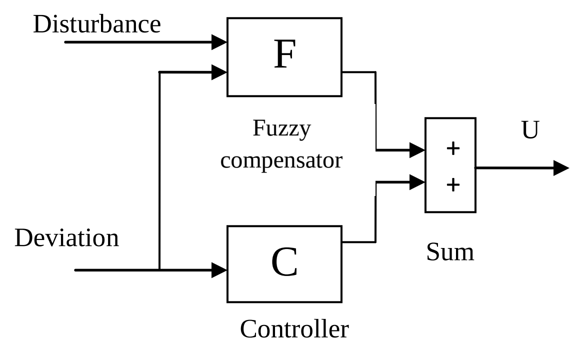

Fig 2: Feed forward Control

Several works and researches in the control area shown very clearly that using FLC as alternative strategy for non-linear and complex systems result more effective and more precise than other classical controller. But as for every algorithm or scientific application there are always some limitations and uncertainty, so if we want to continue our improvement we should adjust these intelligent techniques to minimize the uncertainty and overcome the limitations as best as possible by combining other intelligent algorithm like a Genetic algorithms, neural network and even by adjusting some internal parameters of our FLC.

In continuation with our discourse, this next section will focus on several publications to illustrate how FLC can control complex systems and how can we compensate for any disadvantage that may arise by combining it with other intelligent techniques.

3. USING FLCs: HIGH LEVELS OF ACCURACY & TOUCHING THE PERFORMANCE LIMITS IN DIFFERENT HUMAN APPLICATIONS

The development of Scientific Research had always intended to improve human life through developing currently used techniques and creating new ones that are able to facilitate and give more comfort to life. In 1965 Lotfi Zadeh introduced for first time the concept of fuzzy set theory, and later in 1974, British Ebrahim Mamdani demonstrates the applicability of fuzzy logic in the field of control through creating the first fuzzy logic controller which was an example of the usefulness and the capability of these types of controllers in respect to its ease of controlling complex systems without needing any kind of mathematical identification of controlled process. In fact, FLCs have given the control field a substantial flexibility to control easily non-linear systems without needing to understand and analyze her complex mathematical models, which justifies its extensive use in various human´s applications that require intelligent control systems, without forgetting of course, its precision and speed in action. An extensive study in the area of intelligent control in the last decade will further emphasize the importance and the positive effect that the use of FLCs have had in various fields of human life. Some of the most valuable contributions of FLC's will be shown here in order to further give support to our thesis.

3.1 Human Health Enjoys the Advantages of FLC (Medicine Applications)

One of the areas of greatest concern to humans is certainly their health, thus we are always constantly striving to improve performance in this area and develop and invent new techniques to make the applications of this field ever more accurate and more effective. Although medicine is a science that is not related to control engineering, it is being changed to such an extent that it is now possible to use available control techniques for on-line devices, especially during surgical operations and in intensive care units. The current applications area of control engineering in medicine constitute a wide spectrum ranging from simple dosage prescription schemes to highly sophisticated adaptive controllers. In fact, due to the great advantages that FLCs have shown, their use has become almost imperative in this vital field.

The use of FLCs in the medical applications is very diverse; and they cover various types of medical applications like control of injected doses, surgery, or physical therapy [3]. In [4] we can see a very clear example of how FLCs can be useful to try and mimic the cardiovascular system of a natural heart by controlling their attitudes with FLCs in heart surgery. The fuzzy controllers systems were designed to control two variables, mean arterial blood pressure and cardiac output by administering three drugs; dopamine, Sodium Nitro Prusside and Phenylephrine which perform the function of increasing heartbeat rate, decreases and increases in blood pressure. The FLC manages these tasks by controlling the drugs delivery unit. Another application of FLC regarding the same focus is the development of an artificial heart and how it is possible to replicate a real heart; the modeling of the artificial heart was discussed in detail in [10]. This model developed is based on the simplification of the model developed by Hassani et al. [11], the performance of the proposed fuzzy controller has been consistently proven in clinical experiences. The heart is a part of the circulatory system, which regulates blood to the rest of the body. An artificial heart must be robust and adaptable with variations within the system and must be compatible with the other parts of the body. A natural heart has a very complex feedback control system to regulate the blood pressures and the blood flow through the body, Sudan Basnet and Niranjan Venkatraman et al.[9] prove that using a FLC in the creation of a complex system such as an artificial heart is something achievable by developing two algorithms, the first one´s for implement a fuzzy-logic based controller for an artificial ventricle of the heart, the second algorithm was developed to obtain the heart rate from various parameters. This is simple and describes with reasonable accuracy the dynamics of the circulation of the blood in the major arteries and veins. The algorithm was verified by way of two separate examples.

Always within the block of operations, the FLCs continues to demonstrate their great contribution to the field of medical Applications, this time about control of general or partial anesthesia by drugs. En [5] we find a application of FLC in chirurgical operation to control a depth muscle relaxation using cisatracurium during surgery, the control algorithm proposed can demonstrate that the FLC´s strategy can be very useful due to his robustness and stability, furthermore, clinical result shows that using automatic FLC can effectively overcome the system delay problem, effectively maintain the muscle relaxation level of the patient, and reduce anesthetist workload during surgery. Usually in the biomedical control Algorithms, there are huge variations among patients, for example: the reaction time for drugs and other aspects that make a difference between human beings, therefore these limitations make the designed controller be like a simple application especially for this model [5, 8, 9].

During a surgical operation for patients with severe head injury and unconsciousness continuous propofol sedation is indispensable in order to reduce the effect of intracranial pressure (ICP) we can use fuzzy logic control in a neurosurgical intensive care unit (NICU) [12], for a simple model of FLC can easily mimic the rule-base of human experts to achieve stable sedation. That said, we still have the problem of enormous patient-to-patient variations [6], to overcome these, a self-organizing fuzzy logic controller (SOFLC) was designed to be able to change its rule base according to the case treated. Effectively the results show that a SOFLC can provide more stable sedation of ICP pattern because it can modify the fuzzy rule-base to compensate for inter-patient variations.

As demonstrated here, fuzzy logic not only accommodates uncertainty by dealing with imprecise, qualitative terms, such as low, medium, and high [4,5,6,7,8], but also provides control rules, which are easy to understand and modify when discussing them with experts. However, the derivation of fuzzy rules is a common bottleneck in the application of fuzzy logic controllers (FLC). Conventionally, these fuzzy rules are derived by emulating the control actions of an expert (i.e., medical doctors). There are several reports on the clinical application of fuzzy logic control to muscle relaxation regulation [13,14]. However, with newer neuromuscular blockading drugs, experience is not readily available on how to derive the fuzzy rule-base. This difficulty was the main driving force behind the introduction of self-organizing fuzzy logic controllers (SOFLC), like first proposed by Procyk and Mamdani [15]. In 1991, Linkens and Hasnain [16] published an early study on SOFLC for muscle relaxation, but using only computer simulations. It is only recently, that this approach has been implemented in clinical trials of both muscle relaxation [17] and depth of anesthesia [18,19].

3.2 FLCs in Industrial Process: More Flexibility and Best Accuracy

Industry is a crucial aspect of modern life, every advance in this field has a direct impact on human life, in fact, improvement of its use has always been the subject of several investigations. The introduction of the Fuzzy Set Theory in the industry through the operating of FLCs was an attempt to exploit the advantages presented as robust controllers, however, whether the FLCs will come to ensure more effective control of what previously existed, would be a valuable improvement, with significant influences on both the quality and performance of industry technology. Numerous articles focus on different modes of use of FLCs in several industrial fields and the subsequent improvements made in each of them, in this subsection we will study the effect of the utilization of the FLCs in some industrial process.

- **Fuzzy Logic Controllers for Some Transportation Device**

One of the industries that require high precision and precaution is the aviation industry due to its complexity and risk, in fact, the use of an FLC was an asset in several applications that require control in aircraft. We can site for example, Ioan Ursan and Felicia Ursan at.el [20] have proposed a new control algorithm for the antilock-braking system (ABS) of a Romanian military jet system. This new development using FLC improves its working remarkably. In fact, fuzzy logic was used to creating a new strategy of control for ABS system, the control target is to maintain friction coefficients between tire and road within "safe" ranges, to ensure the avoiding of wheel's blockage and, consequently, the preservation of vehicle lateral stability and an as reduced as possible stopping distance. The simulation results show that proposed ABS algorithm ensures the avoiding of wheel's blockage, even in the worst road conditions, with additive measurement noise. Moreover, as a free model strategy, the obtained fuzzy control is advantageous from viewpoint of reducing design complexity and, also, antisaturating, antichattering and robustness properties of the controlled system. It is clear that in the field of aircraft industry, [21] and [22] demonstrate again the utility of FLCs.

The environmental control of aircraft cabin can be synthesized by employing Fuzzy Logic, the control approach is based on the integration of several blocks representing the fuzzy regulators that control the temperature and the humidity as they control the air-conditioned flow. In [21] the results show that the FLC can be used to develop a new and good controller that satisfies the essentials requirements for a control system: stability and performance hardness. In addition, there are more advanced and complex applications for aircraft which also use the FLCs, giving an example like the autopilot function, a well known technology which controls a plane without any human intervention. [22] By using Fuzzy Logic for autonomous flight controller for unmanned aerial vehicles, we can demonstrate the success of this algorithm and illustrate that the unmanned aerial vehicle can apply a Standard Instrument Departure and Tactical Air Navigation if it aircraft-like performance without human control.

Vehicles have also enjoyed the benefits offered by the FLCs to gain improvements in performance in specific tasks; in the following we can see some aspects of these improvements through multiple examples. Automotive internal combustion engine control is one of the most complex control problems for control system engineers and researchers [28]. Due to the increasing requirements of governments and customers, car manufacturers always strive to reduce carbon emissions and fuel consumption while maintaining the best engine performance possible [30]. To satisfy these requirements, a variety of variables need to be controlled, such as engine speed, engine torque, spark ignition timing, fuel injection timing, air intake, air–fuel ratio (AFR) and so on [29]. The use of FLC to control ``some´´ or ``all´´ of these variables can provide better performance of other classical controllers for air-fuel ratio in an automobile spark ignition engine [23], also, the FLCs were able to show that they can optimize the use of fuel through the Hybrid system, controlling the use of electric power and diesel/gasoline use [24][27], the wide freedom of cars behavior using FLCs was discussed in [31] by citing an example of fuzzy parking control, a new innovation where the vehicle can park without any human help.

In addition, the braking system on a vehicle is a very important and sensitive option in fuel quality, the establishment of a robust and effective system is the target of several projects, use of FLCs and braking technology have been greatly improved [25]. The use of FLCs in braking systems generated very interesting results in full quality and braking time, reflecting the importance that submits [26].

- **Fuzzy Logic Controllers in Intelligent Machines**

New research in intelligent life facilitates human existence through the use of intelligent machines in various tasks of life; but in keeping with human nature, all of these machines must have a degree of independence in making decisions. FLCs presents a very attractive alternative because it offers an independent strategy of mathematical models of controlled plants and acts in accordance with the Data Base previously defined by a human expert which gives the advantage to mimic human behavior. A simple example of a machine that can incorporate a Fuzzy Logic Controller is the washing machine. The Fuzzy Logic application for a washing machine uses a data extracted from different operation regimes, creating several new advantages like conservation of energy and time [32]. Another example of FLC would be in [34], where an intelligent robot was used to avoid obstacles and to establish control of the robot. In this particular case the utilization of FLC was needed to minimize the uncertainty of the sensors, by using fuzzy logic system it ensured that this lack of precision has minimal effects on the overall functionality of the program.

Besides avoiding obstacles for robots, stabilization, trajectory tracking and control of motion are discussed in [33] and [35] more specifically, the development of a tracking controller of a dynamic model of unicycle mobile robot by integrating a kinematic controller and a controller torque based on Fuzzy Logic theory. Through simulation results, it can be seen that fuzzy logic control can be applied to the control of a manipulator robot [33], in [35] the experience can prove that the implementation of FLC in real time can control a motion of differential drive mobile robot, this type of control can be used in a lot of real world application, like inter-office mail delivery, exploration of building in disasters areas, autonomous cars… The autonomous behavior for robot, as is the aircraft case [22], was presented [36], The FLC was used to get an autonomous robot to act autonomously and navigate with significant freedom.

- **Fuzzy Logic Controllers in Power Engineering**

Economize energy, improve performance of electric motors, speed and accuracy in electrical devices is the main goal of all engineers. FLC as a strategy and control policy has been widely used in many applications of optimization in the energy field. The modeling of the functioning mode of the reluctance and inductance was the most touched application by the FLCs due to the important role it plays in performance and efficiency of electric motors, [37,39,40,41,42] these cases present several examples for the use of FLCs to control engine speed by adjusting the mode of feeding and arousal of reluctances or inductances. All results show the great contribution offered by this new technique of control, more robustness, a superior tracking precision and the increase of efficiency [38], while in [39] the intelligent control algorithm has been used for the elaboration of an electric brake system that can provide a maintenance advantage when compared with the mechanical braking systems.

Another aspect of the use of FLCs in electrical engineering appears in the converters. Converters are an essential part of a lot of electrical application. Sometimes the conversion requires great precision because of the sensitivity of some devices, through the exploitation of FLCs, has been possible to ameliorate the outputs of the converters and to control them with a wide range of success [43], several studies tried to exploit the flexibility of the FLCs in this area. Many studies focus on the tracking and the regulation of frequency mode or modulation of an input signal of the converter to find out the best possible performance capability [44, 45, 46, 47].

- **Fuzzy Logic Controllers in Chemical Process**

Although it appears that chemistry is a science that does not require many technologies, but regulation and control are indeed vital technologies for almost all tasks in most chemical applications. Stating for an example, the need to have real-time control of wastewater treatment plants which demand a FLC. This system proved to properly react in order to set adequate operating conditions that timely led to recover efficiently the removal rates [49]. Some chemical processes require certain conditions to carry out the completed application like a fermentation process; where a fixed degree of temperature is necessary [50], designing a FLC to maintain the temperature show that the FLC method gives a better overall performance with minimal or no overshoot and undershoots.

Another aspect of chemical use of FLCs is in the fuel cell, several works focus on the improvement of using FLC for this topic [51] [48] [52] and can show how to improve significantly the load performance of the fuel cell stack.

The effectiveness of the proposed intelligent fuzzy controller has been verified by experimental results.

Above we have tried to present the importance and the tremendous contribution made by the use of FLCs in some areas of human life, surely the advantage of this technique is very clear in all fields we have seen. Due to the large utility that has been submitted, their use has become logical and interpretable in all applications that require control. Actually, FLCs have been used widely, and there have been attempts to manifest the important contribution of this new technique in vital aspects of human life. Indeed, we have not had time to go through each technology that uses FLCs because currently this technique is a fundamental part in intelligent control policy and it can be found by nearly all processes that require a control algorithm, to which we can cite several examples: Tracking systems (GPS map tracking [54], laser for robot tracking and position tracking [55, 53]) or traffic light systems [56, 57, 58] and many other applications.

4. HYBRID FLC; EXPLOITING SEVERAL ADVANTAGES OF CONTROL POLICIES

A quick review of publications addressing the topic of intelligent control over the past ten years may reflect the great value of FLCs as a strategy of control, especially in cases of non-linear processes. The use of FLCs was intended to improve performance and overcome the limitations of classical controllers. Despite the excellent results obtained by using only FLCs as a main control policy, researchers still require more precision and stability for the controllers used. In fact the combination of various intelligent control techniques showed that is an successful operation because it offers to the human expert the opportunity to enjoy the benefits of combined techniques to overcome the limitations of the algorithms, the fulfillment of this requirement is also possible by modifying the FLC itself, the implementation of an adaptive algorithm [54, 55, 56] or self-learning [6, 57] who control plants while they adjust and learn how to act in the case treated.

In most works who adopt hybrid control policy use control algorithms such as (Genetic Algorithms, Neural Network, PID, Self-Learning) according to the needs of each case. For controllers who use the adaptation or self-directed learning, they are based on the classic FLCs but with new perspectives that allow them to modify their startup settings and make decisions that vary depending on the state of the plant without any off-line intervention or preconstructed rules of expert [55], thus improvement of controllers is guaranteed due to these techniques.

Several works are proving the effectiveness of hybrid systems. In [59], the design of an optimal Proportional Derivative fuzzy logic controller (PD-FLC) using genetic algorithm technique and implementing it in the temperature control system proves that combining more than one algorithm can give us better results than when we use only one technique (a conventional PID controller) in terms of the rise and settling time, the combination of FLC & PID algorithms, was also a subject of many researches that make very clear the advantages of this hybridizations [58, … ,65].

The adaptation and self-learning are techniques that can improve the performance of controllers; they are based on the algorithms of usual controllers or even on hybrid control algorithm [54], other aspect of adaptive controller is the self tuning of FLC, his design was investigated by many researchers for various problems [71,72].

The results reported in the literature are usually application specific and not easily portable. The complexity of the control algorithm and the lack of intuition in limiting the scope of the applications for many proposed methods, in [58] a unique FLC using a small number of rules and straightforward implementation is proposed to solve a class of temperature control problems with unknown dynamics or variable time delays commonly found in industry. These results show significant improvement in maintaining performance and stability over a wide range of operating conditions.

The answer to the question of this paragraph is indeed relative, because as the issue of control is also relative, the FLCs are dependent on us specifying exactly the level of accuracy we want. Scientists and researchers all over the world are always looking to find and develop new control algorithms, regardless of the advances and progresses of the last 30 years in FLC technology. In order to obtain the best possible accuracy we must use and develop other algorithms controls.

5. CONCLUSION

This survey intends to explain and / or justify the intensive use of Fuzzy Logic Controllers in most processes that require control algorithms. We will present the advantages and strengths of this algorithm which makes it a favorite technique on many occasions, a wide range on the utilization of the FLCs in various fields of human life, shows how they have been able to enhance control processes, which directly improves the quality of human life. Lately the flexibility of the FLCs in collaborating with other algorithms in order to ameliorate the performance and the precession of the controllers has been proved by presenting several works that handle the hybrid controllers. In effect, the combination between FLCs and intelligent algorithms like GA, PID and some neural network systems have proven the effectiveness of this strategy in improving the performance of Fuzzy Logic Controllers.

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