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# APPLICATIONS OF FUZZY LOGIC TO CONTROL AND DECISION MAKING

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## ABSTRACT

Long-range space missions will require high operational efficiency as well as autonomy to enhance the effectivity of performance. Fuzzy logic technology has been shown to be powerful and robust in interpreting imprecise measurements and generating appropriate control decisions for many space operations. Several applications are underway at the Software Technology Laboratory, Johnson Space Center, investigating the fuzzy logic approach to solving control and decision making problems. Fuzzy logic algorithms for relative motion and attitude control have been developed and demonstrated for proximity operations. Based on this experience, motion control algorithms that include obstacle avoidance were developed for a Mars Rover prototype for maneuvering during the sample collection process. A concept of an intelligent sensor system that can identify objects and track them continuously and learn from its environment is under development to support traffic management and proximity operations around the Space Station Freedom. For safe and reliable operation of Lunar/Mars based crew quarters, high speed controllers with ability to combine imprecise measurements from several sensors will be required. A fuzzy logic approach that utilizes high speed fuzzy hardware chips for such a task is under investigation.

## INTRODUCTION

Since its inception by Lotfi Zadeh [1] in the 1960's, fuzzy logic has been applied to many fields [2] including space operations. Applications of fuzzy logic have been developed for the star-tracker data processing system of the Space Shuttle [3], the attitude control [4] and a combined translational and rotational control of a spacecraft [5]. Currently, there is some concentrated effort in the Software Technology Branch of the Information Technology Division at the NASA Johnson Space Center (JSC), directed towards the development of fuzzy logic software capabilities for building expert systems. Particularly, the emphasis has been on developing intelligent control systems for space vehicles and robotics. Also the problem of sensor data monitoring and control of data processing, which includes detection of potential failures in the system and in some cases reconfiguration, has been investigated. Results of the performance tests made on simulated operational scenarios have been very promising. The issues of when, why, and how hardware implementation can be beneficial are also being studied carefully.

There are certain key technology utilization questions to be answered relative to the use of fuzzy logic control over conventional control.

1) Is it possible to create control systems which do not require a high degree of **redesign** when system configurations change or operating environments differ? In other words, can adaptivity be achieved through the use of a fuzzy controller in place of a conventional controller ?

2) Can a fuzzy controller be used as a high level controller to function in cooperation with classical controllers in a way a human would ? Specifically, can it be designed to monitor the system, evaluate its performance, and either suggest or force changes to make the system work properly or at least function more efficiently ?

3) How easy or difficult is it to design and implement a fuzzy rule base that will control a complex system as opposed to developing the classical control system to do the same problem ?

4) Another question of interest particularly to NASA is where can hardware implementations be utilized advantageously and how easy or difficult is it to transfer fuzzy rules to hardware? In many cases hardware will be able to take much of the computational burden off the central computing system.

Fuzzy logic based controllers will be valuable in systems that are highly non-linear and having complex environments that are practically impossible to model. Fuzzy controllers work for linear systems also but probably have less justification in this case, unless the problem is best thought of in a rule-based framework. The Japanese researchers and engineers [6,7,8] have demonstrated the usefulness of fuzzy controllers in the last few years with some impressive applications from a engineering viewpoint, such as the Sendai train controller [9], the air conditioning control system, the camera autofocusing system, the television auto contrast and brightness control, the applications to automobile transmission and braking control, and applications to control of jitter in camera imaging which requires the distinguishing between real motion in the image which is desired and motion of the camera which needs to be filtered out.

The role of fuzzy logic in autonomous space operations is discussed first. A short summary of each of the applications of fuzzy logic so far accomplished in the Software Technology Laboratory (STL) at the JSC is provided next. A summary and references conclude this paper.

## ROLE OF FUZZY LOGIC IN AUTONOMOUS SPACE OPERATIONS

The fuzzy logic approach is **simple** to understand and **easy** to implement as a software module. Fuzzy rules provide a framework to implement the **human thinking process** i.e. the rules reflect the human thought process, such as " If the object is Far Left in the FOV then rotate the camera to the left side ". The entire rule base for the controller can be derived as if a human was performing the controlling task. Thus, the knowledge for controlling a process gained through experience can easily be transferred in a software module to achieve the **desired autonomy.**

Fuzzy logic will be useful in proper interpretation of measurements from sensors that are always corrupted by noise and bias. Accuracy of the sensors represent a challenge that is not always surmountable. Fuzzy logic framework can easily handle imprecise measurements, thus helping the integration process. Also sensor systems may perform incorrectly or at least unexpectedly anomalous for a short time. It is necessary to determine this type of behavior and correctly resolve the situation. Processing of uncertain information using **common sense rules** and **natural language** statements is possible in this fuzzy logic framework.

Implementation of fuzzy membership functions, rules and related processing is made easy by tools like the TIL Shell [10] which has a graphics oriented user interface and fuzzy-C compilers [11] that can generate code for the fuzzy chip or C code to integrate with other software modules. There are several commercial products available in the industry that allow easy implementation of knowledge base, rule-base and user interfaces. For autonomous operations, it is easier and useful to implement control decisions through knowledge base and rules so that the **heuristics** and related **experiential knowledge** can be used for a particular situation.

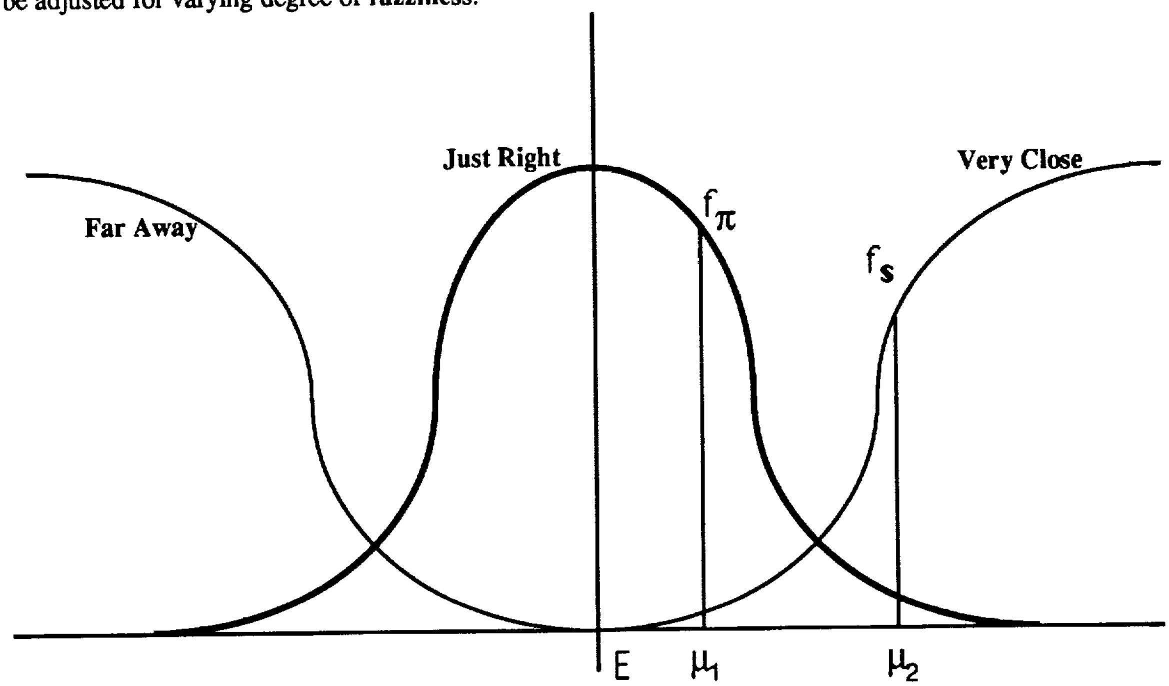
It is also possible to develop and implement a fuzzy controller in the **fuzzy processors**, thus, having a fuzzy hardware controller. There are several commercial fuzzy processors that can process over 30,000 fuzzy rules per second and thus provide high processing power. These fuzzy processors consume low power with a capability to process general purpose instructions and can be mounted in the back plane of a sensor, say, a camera. These processors also provide interfaces to hardware to transfer information and commands to the main Central Processing Unit (CPU). Advanced sensor systems envisioned for space station operations will have such processors embedded as an integral part of the system. Thus, a **distributed processing** function onboard the spacecraft is possible via fuzzy chips.

A camera tracking system described later can be a dedicated sensor with built-in intelligence and speed to perform functions which are normally performed in the main CPU onboard the Space Station Freedom (SSF). With a dedicated fuzzy chip and its processing power, there will be virtually no computational load on the SSF main computers. As a result, the main CPU will be available for other computing requirements such as complex guidance and navigation schemes. Furthermore, the interfaces between the fuzzy chip and the main CPU will be at a command level requiring reasonably low speed data transfer. There will be no need for a high rate data transfer which can increase the cost and decrease the reliability.

A significant application of fuzzy logic is in an advisory role in health monitoring and internal reconfiguration of spacecraft subsystems. These processes require a capability to handle uncertain measurements, estimate possibilities of failures and quickly rearrange flow so that the autonomous operations are not stopped. Techniques have been developed to update the rule base using reinforcement learning [12] in a given environment and adjust the response or behavior of a controller. These are very important for achieving operational efficiency in space operations.

RELATIVE MOTION AND ATTITUDE CONTROLLER

Fuzzy sets have been used in developing a trajectory controller for a spacecraft to maintain proximity operations profiles [13,14]. An automated vehicle controller that interprets the sensor measurements in a manner similar to a human expert has been modeled using fuzzy sets. The control rules were derived from the thinking process used by pilots and were implemented using typical pi- and s-functions (fig. 1) that can be adjusted for varying degree of fuzziness.




For a given value of parameter, m, $f_\pi$ is compared with $f_s$ , and the larger value dictates whether action is taken.

**Fig. 1 Control Strategy for Range Parameter**

The controller has been implemented into a multi-vehicle dynamical simulator known as the Orbital Operations Simulator (OOS) [15], complete with all environment and sensor models. A small part of this control simulation was demonstrated via tele-video links [16], to the International Fuzzy Systems Association (IFSA) Workshop that was held in Iizuka, Fukuoka, Japan in August 88. In this simulation, the automated fuzzy controller was used to control the closing rates and relative positions of the shuttle with respect to the solar max satellite. The scenario required it to perform operations including approach to target, fly around and stationkeeping.

Many different scenarios have been run with this automated fuzzy controller to evaluate the performance with respect to flight profiles and delta-v requirements. Comparisons of delta-v requirements for a man-in-the-loop versus the automated controller have shown that the automated controller always uses less delta-v.

For a test case involving stationkeeping at 150 feet for 30 minutes, the automated controller required 0.1 ft/sec delta-v whereas 0.54 ft/sec was used in the man-in-the-loop simulation. For v-bar approach from 500 feet to 40 feet within a 25 minute time interval, the automated controller used 2.12 ft/sec vs. 2.99 ft/sec for the man-in-the-loop simulation.

To complement this translational control, it was decided to implement the rotational control via fuzzy membership functions and the rules based on the conventional phase plane. It was obvious that such an implementation would provide a direct performance comparison with the conventional control system, thus leading to further insight into understanding the relative merits of fuzzy control systems. Furthermore, an integrated six Degree Of Freedom (DOF) controller can be developed by combining these two control systems.

The rotational control system is based on the phase plane construct used in the attitude control system. The angle and rate errors, PHI and PHI_DOT, are input and torque is the output for this rotational controller. The input variables have seven membership functions defined over the universe of discourse while the output variable torque has five membership functions (fig. 2). The membership functions are piece-wise linearly defined and have graphs that form mostly triangular or trapezoidal shapes. There are 25 rules defined for reducing the PHI and PHI_DOT errors to within their zero (ZO) range.

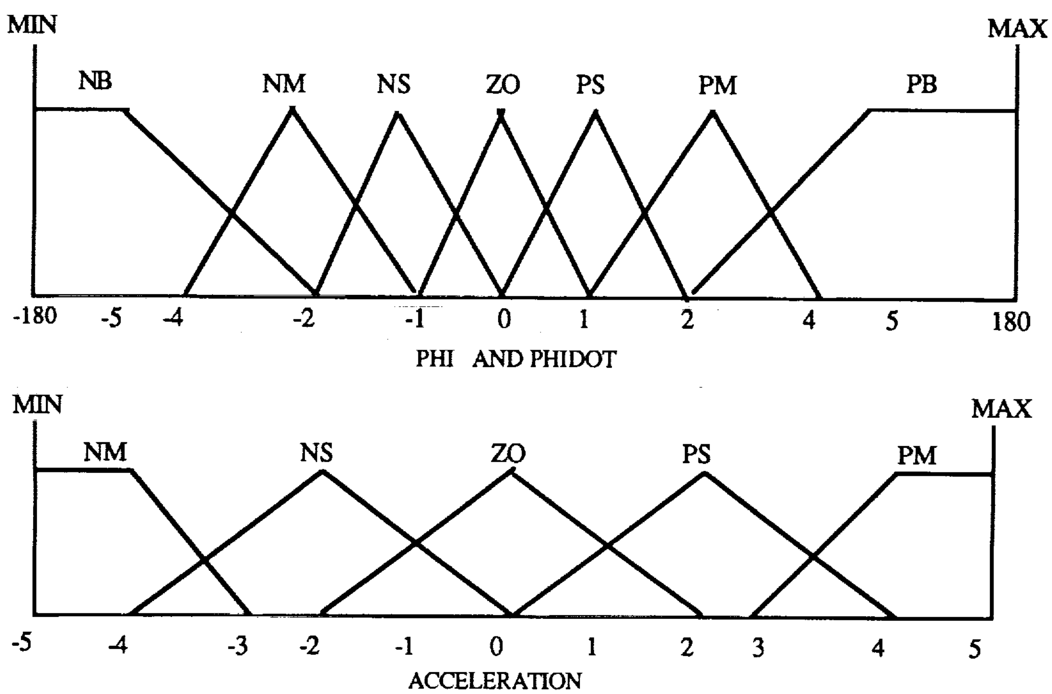



**Fig. 2 Membership functions for input and output variables for attitude controller**

Single axis rotational equations were implemented for the pitch axis of the shuttle. The pitch moment of inertia and the positive and negative pitch torques provided by jets were used in this simple simulation to test the fuzzy controller rules. The shuttle jets provide a larger acceleration for positive pitch as compared to the negative pitch. The simulation was set up to provide a constant torque during a cycle time of 80 milliseconds. The pitch attitude and the rate are propagated at this cycle time. When the fuzzy controller asks for a torque greater than 0.5, the constant torque is provided in that direction, otherwise no torque is provided. This simulates the jet on and off activity at the appropriate time. Testing for the pitch axis has shown very satisfactory results. With several starting states, meaning initial angle and rate, the system has converged on the commanded value, and manifested relatively smooth limit cycles around the deadband. The control system response in all cases has been as expected, including overshoot behavior in cases where initial rate error is very large. Tests were performed with some rules turned off or deactivated to observe the performance with a limited ruleset. The objective was to reduce the number of rules to a minimum.

Performance of the fuzzy controller with 25 rules (see Table 1.) was more than adequate for a single axis, and gave us confidence to expand it to three axes case. There is an automatic attitude control system called the Digital Auto Pilot (DAP) for the space shuttle. This onorbit DAP is implemented in OOS for shuttle on-orbit operations. There is a module called Phase Plane which is replaced by this rotational fuzzy controller with all other interfaces maintained intact. The integration process was completed with only minor modifications to the interfaces. The simulation testing included three axes attitude hold and single axis maneuvers. In a three axes attitude hold case, the fuzzy logic based controller used only 30 % of the fuel used by the DAP, while for an attitude maneuvers case, the fuzzy controller used around 60 % of the fuel used by the DAP. In both cases, the fuzzy controller has shown comparable performance for maintaining attitude and body rates. Further testing and analysis is planned to include other maneuver modes and different parameters sets.

**Table 1. Rule base for attitude controller**

| | phi | | | | | | |
|---|---|---|---|---|---|---|---|
| phi_dot | NB | NM | NS | ZO | PS | PM | PB |
| NB | PM | PM | PS | | | | |
| NM | PM | PM | PS | | | | |
| NS | PS | PS | PS | | | | |
| ZO | PS | PS | ZO | ZO | ZO | NS | NS |
| PS | | | | | NS | NS | NS |
| PM | | | | | NS | NM | NM |
| PB | | | | | NS | NM | NM |

The integration approach adopted for combining translational and rotational control systems is simple, straight forward and involves extensive testing. The translational fuzzy control system will be used by the autosequencer to generate proper hand controller commands so that the desired range and range rate are maintained during proximity operations. Typically, a shuttle pilot provides these inputs and controls the relative trajectory. Thus the autosequencer will simulate the crew input via the translational fuzzy control system. The rotational fuzzy control system as described earlier will generate commands for jet-select to fire jets for attitude control. Existing interfaces with the Phase Plane module will be maintained intact for the overall integrity of the system. When both fuzzy control systems are used together, it will provide a total 6 DOF controller for proximity operations.

A preliminary test plan has been put together to test the 6 DOF controller. It includes test cases for stationkeeping with a fixed attitude, stationkeeping with attitude changes, line of sight approach on the V-bar, line of sight approach on the R-bar, fly around at a constant distance with constant relative attitude, and final approach for docking. Details of these test cases such as initial conditions, commanded attitude maneuvers, etc. are being defined to finalize the test plan.

## INTELLIGENT SENSOR SYSTEM

Advanced sensor systems with intelligence and a distributed nature will be required for activities like proximity operations and traffic control around the SSF. There will be several sensors of different types providing various measurements simultaneously as inputs for processing to such a system. The conceptual development of such a system where several cameras, laser range finders and radar can be used as independent components is in progress within the Software Technology Laboratory of the Information Technology Division at the Johnson Space Center. The first phase of this development is the camera tracking system based on the fuzzy logic approach that utilizes the object's pixel position as inputs and controls the gimble drives to keep this object in the Field Of View (FOV) of the camera.

Tracking of an object means aligning the pointing axis of a camera along the object's line of sight. The monitoring camera is typically mounted on the pan and tilt gimble drives which are capable of rotating the pointing axis within a certain range. The task of the tracking controller is to command these gimble drives so that the pointing axis of the camera is along the line of sight vector which is estimated from the measurements.

For the fuzzy logic based tracking controller, the inputs are range and line of sight vector, and the outputs are the commanded pan and tilt rates (fig. 3). The line of sight vector is input in terms of pixel position in the camera FOV. When an image is received, it is processed to determine the location of the object in the camera frame which has the vertical, horizontal and pointing vectors as three axes. Usually an image, particularly for complex objects, spans over many pixels. Using a suitable technique, the centroid of the image is computed as the current location in the viewing plane which is like a Cartesian coordinate plane having vertical and horizontal axes. The size of the viewing plane is 170 x 170 pixels, and the origin is at the upper left corner as shown in fig. 3. The range of the object is received from the laser range finder as a measurement. These three parameter values are input to the controller. There are five membership functions for horizontal and vertical positions as well as range input [17].

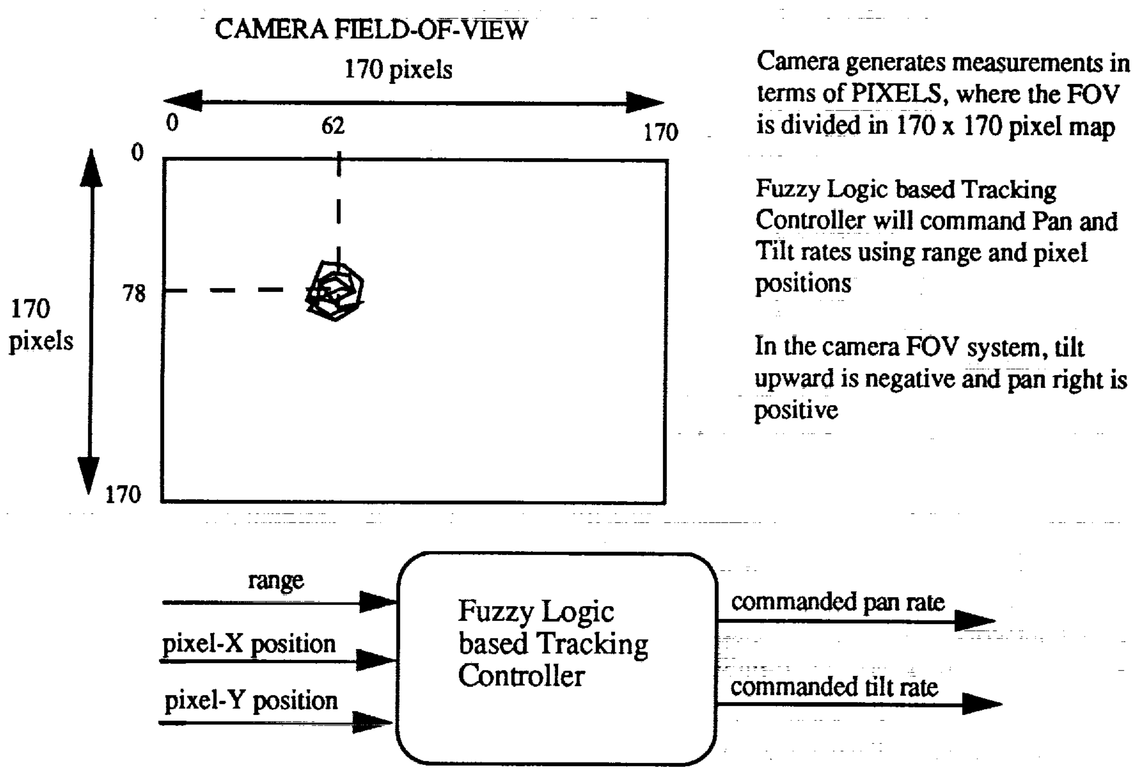



**Fig. 3 CONCEPT OF A CAMERA TRACKING SYSTEM**

The desired image location is the center of the viewing plane, which is at (85,85). If the current location is close to the center, then rotation of the pointing axis is not required. If the location is to the left of center then a left rotation is necessary. Similarly, if the image is down from the horizontal line then a downward rotation is required. These rotations are determined using the position and range measurements and the rule base shown in Table 2. First the range measurement is fuzzified and the value of the scale factor is determined based on the scale_factor rules. Necessary defuzzification processing is performed to compute the crisp value of the scale factor. Then, the scale factor and the position measurements are provided to the next set of rules to determine the rate at which the gimble drives should be rotated. There are 30 rules that determine both pan and tilt rates. Again, the necessary defuzzification processing is performed to compute the crisp values of the pan and tilt rates which can be sent to the gimble drives as command values.

**Table 2. Rule base for the tracking task**

| | Distance Membership Functions | | | | |
|---|---|---|---|---|---|
| | VFAR | FAR | NEAR | VNEAR | PROX |
| Scale_Factor | LOW | LOW | MED | HIGH | HIGH |

| Scale_Factor | Horizontal Position Membership Functions | | | | |
|---|---|---|---|---|---|
| | FL | LL | CENTER | LR | FR |
| LOW | FN | SN | ZR | SP | FP |
| MED | SN | SN | ZR | SP | SP |
| HIGH | SN | ZR | ZR | ZR | SP |
| | Pan_Rate Membership Functions | | | | |

| Scale_Factor | Vertical Position Membership Functions | | | | |
|---|---|---|---|---|---|
| | FD | LD | CENTER | LU | FU |
| LOW | FP | SP | ZR | SN | FN |
| MED | SP | SP | ZR | SN | SN |
| HIGH | SP | ZR | ZR | ZR | SN |
| | Tilt_Rate Membership Functions | | | | |

Note - Negative Tilt_rate means the pointing axis going upward in FOV

The camera is moved based on these commands within the limits of its gimble rates and angles. New measurements in the camera FOV are obtained for the next cycle and the processing is repeated. The cycle time is based on the processing time required for the following functions : 1) determining pixel positions, 2) obtaining a range measurement, 3) rotating the gimble drives at a desired rate, and 4) the requirements to track the object within a certain accuracy. Typical cycle time ranges between 0.1 to 1.0 second.

There are several advantages of our approach that utilizes fuzzy logic in a camera tracking system. This system will be a low power sensor as compared to an active sensor e.g. Radar in the Ku band range, or LADAR using laser frequency. Typically, the active sensor radiates a power pulse towards a target and receives back a reflected pulse. Based on the power transmitted, power received and time between these pulses, parameters like range and range rates are calculated. Since the camera tracking system will not be radiating power, it will be a low power sensor in comparison with an active sensor. Since there is already a shortage of power, an important consumable, onboard the SSF, availability of low power sensors is very important for continuous operations. The SSF can afford to keep this type of a sensor working around the clock without having much impact on the power management or other computational load on the main computers.

Capabilities of the tracking controller can be expanded to perform other functions such as approach toward the object, grapple, object identification, traffic management, and caution and warning to the crew. Fast moving objects can be identified easily via prediction of position and thus collision avoidance can also be achieved. Since the system can work as a stand-alone system at the command level and will interrupt the operations flow only if necessary, it can become a node in the distributed sensor system.

Current plans include testing of the concept in software simulations in the STL and in the hardware laboratories in Engineering Directorate at JSC. The software testing will refine the Rule Base and the Membership Functions, while the hardware testing will identify all interface problems, real-time performance evaluation, and the controller behavior in light of actual measurements which will be noisy and imprecise. Both type of testing is required in order to make the system operational and useful. Development of pattern recognition and object identification algorithms is underway in the STL [18].

## MARS ROVER TRAJECTORY CONTROL AND PLANNING

While collecting soil samples and surveying the Mars surface, the Mars rover will be moving from one point to another among obstacles which cannot be identified prior to the mission. In order to complete the collection task, the rover must interpret imprecise sensor measurements of obstacle size and distance to determine which obstacles present a hazard and must be avoided and plan a trajectory to avoid these unforeseen obstacles. In addition, worst case round trip communications time between Earth and Mars will require 20 minutes. Earth-based tele-robotic control of the Mars rover will be extremely difficult and time consuming and could seriously endanger the success of the mission. Fuzzy trajectory planning and control provides robust real-time control capable of adapting the trajectory profile to avoid unforeseen hazards. The fuzzy logic approach eliminates communications travel time, allows the rover to avoid obstacles which may be unavoidable due to tele-robotic reaction time, and provides adaptable control which will extend the rover performance envelope.

A fuzzy logic approach to trajectory control has been developed which allows the rover to avoid these hazards during the sample collection process. The fuzzy trajectory controller receives the goal or target point from the planner and uses X and Y position errors as well as Orientation (Yaw) error in the control system frame and commands the rover in terms of steering angle and velocity. The fuzzy rule-base containing 112 rules for the controller has been designed to drive the rover towards the X-axis of control error frame. As the rover approaches this axis, the rover is commanded to the correct orientation error and then slowly drive towards the target point.

The X and Y position error variables were modeled as a shouldered [11] membership set of 5 piece-wise linear functions with a universe of discourse ranging from -100 to 100 meters. The orientation or yaw error variable was modeled as an unshouldered membership set of 7 functions with a universe of discourse ranging from -180 to 180 degrees. The steering variable was modeled as an unshouldered membership set of 5 functions with a universe of discourse ranging from -30 to 30 degrees. Finally, the velocity variable was modeled as an unshouldered membership set of 7 functions with a universe of discourse ranging from -5 to 5 meters/second.

A fuzzy trajectory controller for a Mars rover has been tested on several cases. Preliminary results have shown that the trajectory controller can reach the target position and attitude within 0.0005 meters on the x-error axis, 0.25 meters on the y-error axis, and 0.45 degrees yaw error. It is believed that these accuracies can be reduced by altering the membership function sets for the inputs and outputs. Further testing will facilitate the tailoring of the membership functions to the fuzzy rule set. The fuzzy approach provides a control system which can be easily modified and tested.

## CONCEPT FOR LUNAR/MARS CREW QUARTERS CONTROL

Continuous monitoring of the Environment and Life Support System (ELSS) for Lunar/Mars crew quarters will be required for two reasons; 1) the safety of the crew, and 2) an efficient usage and management of available resources. The system dynamics model ( typically known as the 'plant' in conventional control theory ) that represents the behavior of the system becomes increasingly complex and non-linear as the volume of the crew quarters increases significantly. Multiple sensor measurements distributed over the entire volume are required to derive accurate state information for the system so that a nominal operational state can be maintained. In such a case, applying conventional control theory will be very difficult, if not impossible. A concept of a fuzzy logic based monitoring and diagnosis technique is under development to moving objects can be identified easily via prediction of position and thus collision avoidance can also be achieved. Since the system can work as a stand-alone system at the command level and will interrupt the operations flow only if necessary, it can become a node in the distributed sensor system.

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| Scale_Factor | Horizontal Position Membership Functions: FL | LL | CENTER | LR | FR |
|---|---|---|---|---|---|
| LOW | FN | SN | ZR | SP | FP |
| MED | SN | SN | ZR | SP | SP |
| HIGH | SN | ZR | ZR | ZR | SP |
| | Pan_Rate Membership Functions | | | | |

| Scale_Factor | Vertical Position Membership Functions: FD | LD | CENTER | LU | FU |
|---|---|---|---|---|---|
| LOW | FP | SP | ZR | SN | FN |
| MED | SP | SP | ZR | SN | SN |
| HIGH | SP | ZR | ZR | ZR | SN |
| | Tilt_Rate Membership Functions | | | | |

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Capabilities of the tracking controller can be expanded to perform other functions such as approach toward the object, grapple, object identification, traffic management, and caution and warning to the crew. Fast combine several measurements from different types of sensors and maintain a desired state of this non-linear system. The concept can easily be expanded to detect potential component failures and generate immediate advisory messages for corrective actions. Suitability of currently available fuzzy hardware for real-time monitoring and diagnosis is also being investigated.

## SUMMARY

Applications of fuzzy logic in autonomous orbital operations are described in this paper with past accomplishments at JSC. Current ongoing as well as future activities planned are also described. The main objective of all these activities is to **increase autonomy** in orbital operations and thus achieve a higher level of **operational efficiency** desired for future space operations. The approach is to develop modular control that can be upscaled for greater autonomy in an integrated environment. The initial step is to develop a software controller and then to integrate it with hardware at the appropriate level. As the activities progress, detail testing is performed to check out implementation and integration of components. Our preliminary results promise a very successful utilization of fuzzy logic in autonomous orbital operations.

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# GENETIC ALGORITHMS

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## ABSTRACT

Genetic algorithms are highly parallel, mathematical, adaptive search procedures (i.e., problem-solving methods) based loosely on the processes of natural genetics and Darwinian survival of the fittest. This paper introduces basic genetic algorithm concepts, discusses genetic algorithm applications, and presents results from a project to develop a software tool that will enable the widespread use of genetic algorithm technology.

## INTRODUCTION

### Background

Genetic algorithms (GAs) were pioneered by John Holland in his research on adaptation in natural and artificial systems (1). This research outlined a logical theory of adaptive systems. In essence, biological adaptive systems strive to optimize single individuals or entire species for specific environments to increase the chance of survival. Holland simulated the methods used when biological systems adapt to their environment in computer software models–the genetic algorithms–to solve optimization and machine learning problems. The following paragraphs briefly discuss two types of adaptation strategies which are observed in many biological systems and inspired the basic framework of genetic algorithms.

Adaptation. One form of adaptation pertains to the way an individual changes within its environment to promote survival. Examples include the development of antibodies specific to certain diseases, or the enlargement of muscles needed for daily activities. The way we learn, and the neural changes that accompany learning, is another example of how an individual adapts within its environment. The effects of this form of adaptation are not imprinted on the genome (the genetic makeup of a species); that is, they are not passed on from generation to generation. On the other hand, *individual* adaptation does promote the survival of the individual within an environment–*survival of the fittest*–and enhances that individual's net reproductive advantage through a *natural selection* where *fitter* members of a population are more likely to reproduce.

All species have used adaptive search for millions of years, through an evolutionary search process, to improve the way a species lives and survives within its environment. Therefore, adaptation also refers to evolution and modification of an entire species to fit its environment. This is the process of making a species environmentally *fit*. An appropriate example can be seen in the way many plant species have evolved their flower to resemble a female bee or wasp that attracts the male counterpart and promotes pollination. This evolutionary or *species* adaptation is imprinted on the genome and is passed on to subsequent generations.

Thus natural, biological systems continuously use adaptive search to improve genomes–that is, to improve the species–and to promote the survival of *fitter* individuals and genomes through natural selection.

Genetic Algorithms. Genetic algorithms are highly parallel, mathematical, adaptive search procedures (i.e., problem-solving methods) based loosely on the processes of natural genetics and Darwinian survival of the fittest. These algorithms apply genetically-inspired operators to populations of potential solutions in an iterative fashion, creating new populations while searching for an optimal (or near-optimal) solution to the problem at hand. Population is a key word here: the fact that many points in the space are searched in parallel sets genetic algorithms apart from other search operators. Another important characteristic of genetic algorithms is the fact that they are very effective when searching (e.g., optimizing) function spaces that are not smooth or