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FUZZY LOGIC CONTROL FOR CAMERA TRACKING SYSTEM

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ABSTRACT :

A concept utilizing fuzzy theory has been developed for a camera tracking system to provide support for proximity operations and traffic management around the Space Station Freedom. Fuzzy sets and fuzzy logic based reasoning are used in a control system which utilizes images from a camera and generates required pan and tilt commands to track and maintain a moving target in the camera's field of view. This control system can be implemented on a fuzzy chip to provide an intelligent sensor for autonomous operations. Capabilities of the control system can be expanded to include approach, handover to other sensors, caution and warning messages.

1. INTRODUCTION

Advanced sensor systems with intelligence and a distributed nature will be required for activities such as proximity operations and traffic control around the Space Station Freedom (SSF). These systems will receive various types of measurements from multiple sensors and perform the necessary data fusion for the Navigation, Guidance and Control systems. The SSF operational requirements necessitate that this system be composed of passive type low power sensors.(Based on the current design, the SSF operations are expected to be power limited and computing resources limited.) An important feature is that the system should be capable of handling imprecise and approximate measurements as well as sensor failures.

A number of theories dealing with approximate reasoning such as fuzzy logic and Dempster-Shafer theory, were considered for this work and fuzzy logic was selected. Since its inception by Lotfi Zadeh [1, 2] in the 1960's, fuzzy logic has been applied to many fields [3, 4, 5], to handle imprecise measurements. Applications of fuzzy logic have also been developed for the star-tracking system of the Space Shuttle [6], the attitude control [7] and a combined translational and rotational control of a spacecraft [8].

The concept development for such an advanced sensor system that can accept measurements from several cameras and laser rangefinders is in progress within the Software Technology Laboratory of the Information Systems Division at the Johnson Space Center. The first phase of this development is a Camera Tracking System based on a fuzzy logic approach that utilizes the object's pixel position and range as inputs and controls the camera gimbal drives to keep this object in the Field Of View (FOV) of the camera. Later phases will involve development of other functions as described in the future activity section.

In this paper, we describe our concept of a fuzzy logic based tracking controller that meets these requirements. A typical proximity operations scenario and the tasks of a tracking system are discussed in section 2. The fuzzy logic approach to the tracking controller and details of the membership functions and rulebase are described in section 3. Advantages of the fuzzy logic approach for such a system are discussed in section 4. Future activities and a summary are given in section 5.

2. OPERATIONS SCENARIO

The proximity operations zone around the SSF is defined as a sphere of about 2000 feet. Within this zone, several activities [9] such as fly-around, final approach and docking will be performed involving other vehicles such as a Space

Shuttle, satellite servicer and other payloads. The zone also includes extravehicular activities performed by the crew in spacesuits or by telerobots to inspect the SSF structure and subsystems and, if necessary, install and/or replace the components. Some of the payloads approaching the SSF will require extensive involvement by the crew. All extra-vehicular activities, trajectories of incoming vehicles and all docking and berthing operations must be closely monitored to avoid collisions.

A typical scenario for proximity and docking operations with the SSF is shown in fig. 1. Assume there is an autonomous satellite approaching the station from about 2000 feet. It first moves to about 200 feet, then performs station keeping at that point for a short period of time. It then completes the necessary information exchange with the SSF, and proceeds to a closer point in such a way that the mobile remote manipulator system moving on the SSF structure can grapple it. This autonomous satellite, if necessary, can also perform a 'fly-around' to observe the SSF from various angles. During all these activities, cameras mounted on the SSF monitor the motion of the satellite and advise the crew in case of malfunction or irregularities. High power sensors like radar and lasers are less desirable when operations are power limited.

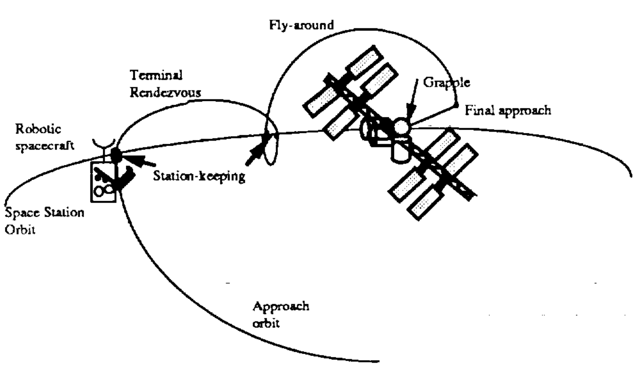

FIG. 1 OPERATIONS SCENARIO FOR TRACKING TASKS

Tracking of an object means aligning the pointing axis of a camera along the object's line-of-sight. vector 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.

There are several issues the tracking controller must handle properly while commanding the gimble drives. Since the objects could be fast or slow moving, the controller must keep track of the rotating speed properly. Furthermore, the image could be blurry with a low resolution so that the estimate of the line-of-sight vector is poor. Handover to another camera tracking system may be required because of physical limitations of gimble drives and its mounting geometry. The controller must be aware of its gimble limits and whether the drives are approaching these limits.

There are two methods of commanding these gimble drives: 1) Rotate the gimble by the desired delta angle, and 2) Achieve the desired angular rate for that axis. In the tracking system under development, the gimble drives will be commanded using the second method. The object's line-of-sight vector will be estimated from the position measurements in terms of pixels (as shown in fig. 2) and is input to the control system. There is a laser rangefinder that provides a range measurement for the object in the FOV. This information can be used to properly estimate the effects of the objects speed on the rotation of the line-of-sight vector.

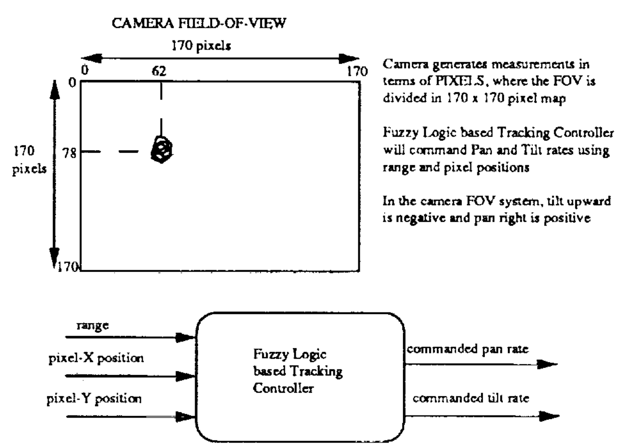

Fig. 2 CONCEPT OF A CAMERA TRACKING SYSTEM

3. FUZZY LOGIC APPROACH TO CONTROL

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. 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. 2. The range of the object is received from the laser rangefinder as a measurement. These three parameter values are input to the controller.

Each of these parameters have their respective membership functions as shown in fig. 3. The range membership functions are Very_Far (VFAR), FAR, NEAR, Very_Near (VNEAR) and Proximity (PROX). The Proximity membership function represents a close proximity threshold within which docking operations can begin. The universe of discourse for range is from 0 to 200 feet. If the spacecraft operations begin at 2000 feet, then this universe of discourse can be extended to that value, however, a large part is then contained in only one membership function, VFAR.

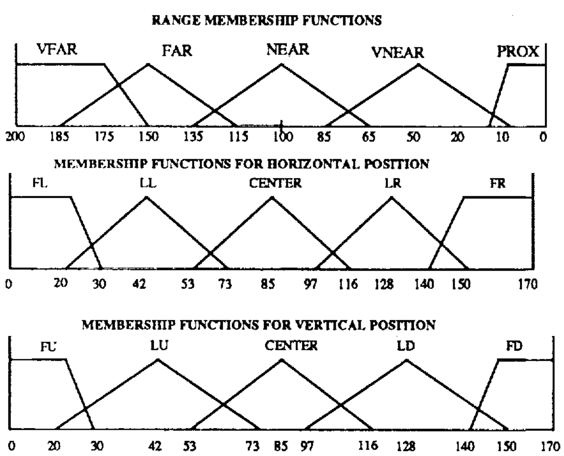

Fig. 3 Membership functions for the input parameters

The horizontal position membership functions are Far_Left (FL), Little_Left (LL), CENTER, Little_Right (LR), and Far_Right (FR). The vertical position membership functions are Far_Up (FU), Little_Up (LU), CENTER, Little_Down (LD), and Far_Down (FD). The universe of discourse for the horizontal and vertical pixel positions is from 0 to 170. The typical FOV is about 45 degrees wide, however, the range of a gimble drive can be from -180 to 180 degrees and thus it should be noted that the FOV range does not represent the gimble drive range.

The membership functions shown in fig. 4 for the pan and tilt rates are the same with a universe of discourse from -6.0 to 6.0 degrees per second implying that the maximum rate that can be achieved by gimble drives is 6.0 degrees per second in one direction. Membership functions are Fast Negative (FN), Slow Negative (SN), Zero (ZR), Slow Positive (SP) and Fast Positive (FP). To properly handle the different ranges and effects of the velocity of objects in the FOV, there is a need to generate a scale factor. If the objects range is very far, then, with a typical approach velocity, its line-of-sight vector is not going to rotate fast. Thus, the pointing vector rotation can be managed with a low rate. If the object is very near or in the proximity range, then the approach velocity may rotate the line-of-sight vector with a high rate. In that case, the object may go out of the FOV quickly. In order to keep up with high angular rate of line-of-sight vector, the controller will need a high rate. The scale factor membership functions, shown in fig. 4, provide the capability to change the response based on the range measurements. All membership functions are triangular shaped for simplicity in implementation.

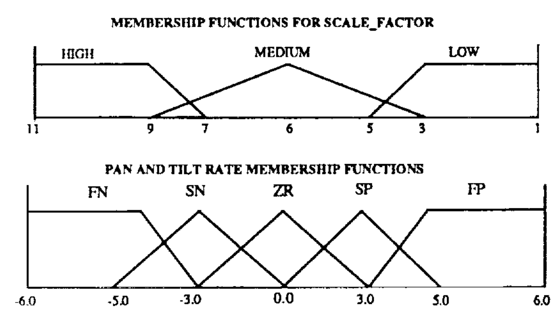

Fig. 4 Membership functions for the output parameters

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 rulebase shown in Table I. First the range measurement is fuzzified and the value of the scale factor is determined based on the scale_factor rules. The necessary defuzzification processing is performed to compute the crisp value of the scale factor. Then, the crisp 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 I. 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

KEY : VFAR - Very Far, VNEAR - Very Near, PROX - Proxomity zone
FL - Far Left, LL - Little Left, LR - Little Right, FR - Far Right
FU - Far Up, LU - Little Up, LD - Little Down, FD - Far Down
FN - Fast Negative, SN - Slow Negative, ZR - Zero,
FP - Fast Positive, SP - Slow Positive

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 time requirements for the following functions: 1) determine pixel positions, 2) obtain a range measurement, 3) rotate the gimble drives at a desired rate, and 4) the requirements to track the object within a certain performance envelope. Typical cycle time ranges between 0.1 to 1.0 second.

4. ADVANTAGES OF FUZZY LOGIC APPROACH

There are several advantages of our approach that utilizes fuzzy logic in a camera tracking system. 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 then rotate the camera to the left side ". The entire rule base is derived as if a human was performing the tracking task.

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 the C code to integrate with other software modules. There are several commercial products available in the industry.

It is also possible to develop and implement the fuzzy controller in the 'fuzzy processors', thus, having a fuzzy hardware controller. There are several commercial fuzzy processors [12, 13, 14] that can process over 30,000 fuzzy rules per second and thus provide a high speed 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 camera. These processors also provide interfaces to hardware to transfer information and commands. Advanced sensor system envisioned for space station operations will have such processors embedded as an integral part of the system.

The camera tracking system described here can be built as an intelligent sensor with built-in intelligence and speed to perform functions which are normally performed in the distributed processing network of approximately 20 computers (the actual number of computers may change with requirements) onboard SSF. Because of a dedicated fuzzy chip and its processing power, there is virtually no computational load to the SSF computing network. As a result, the SSF computers will be available for other computing requirements such as complex guidance and navigation schemes. Furthermore, the interfaces between the fuzzy chip and the computing network 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.

This system will involve low power sensors as compared to an active sensor e.g. Radar in 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 system in comparison with active sensor system. 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 a distributed intelligent sensor system.

5. FUTURE ACTIVITIES AND SUMMARY

Our future activities include testing of the concept in software and hardware simulations. The software testing will help fine tune the rule base and the membership functions, while the hardware testing will help to identify and solve integration issues. Both types of testing are required in order to make the system operational and useful. All interface problems need to be resolved to implement the controller on a fuzzy hardware chip. Performance of the controller must be evaluated in light of real-time response, accuracy and imprecise measurements.

In later phases of the development, it is planned to expand the concept and fuzzy logic approach from tracking to : 1) identifying potential sensor failures and notifying the crew 2) handover techniques for switching to a different type of sensor measurement, 3) identifying one or more objects appearing in the camera's FOV (object extraction and identification algorithms), and 4) traffic management guidance. For configurations where the camera is mounted on a movable platform or on an end-effector of a robotic arm, this concept will be expanded to perform tasks such as the approach towards the docking fixture of the object, and grappling and rigidizing operations (similar to the operations performed by the crew). The concept can also be expanded to incorporate sensor data fusion required for the debris avoidance task.

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