

A NOVEL AND FAST VIRTUAL SURGICAL SYSTEM USING FUZZY LOGIC

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ABSTRACT

Virtual Reality (VR) and associated technologies are experiencing growing importance in medicine and surgery. VR demands fast and real time simulations. Finite element analysis can be used for cutting simulation; however, finite element analysis is computationally intensive and is unsuitable for real time applications involving cutting of a large amount of tissue. We have developed a fuzzy logic based system which involves significantly reduced computational times and provides real time simulations of cutting. The user-exerted forces on a simulated cutting tool held by the user are dynamically measured and fed to the fuzzy logic system. The user-exerted forces and the stiffness of the element are first fuzzified and fed to a fuzzy rule base to provide the output membership values. These output membership values are then defuzzified using the centroid defuzzification technique to provide a crisp output of the cutting depth. The technique has been implemented in real time. Experiments with human users have shown consistent results.

KEYWORDS

Surgical Simulation, Fuzzy Logic, Virtual Reality, Tissue Cutting.

1. INTRODUCTION

Virtual Reality (VR) is gaining its importance in every major discipline, including medicine and surgery [1-2,5-12,15]. Potential applications of VR technologies in medicine and surgery include rehabilitation exercises in VR space, surgical simulation and planning, functional anatomy education, etc. Surgical simulation in VR environment can be used in medical education and training. Moreover, such systems can be used to investigate new procedures or determine the optimal surgical procedure for a given patient. VR is a pseudo-

space that creates an illusion, but can give a realistic result that looks, feels, sounds, and even smells real. Song and Reddy [12] have developed a technique for VR surgical simulation using real time finite element models controlled by user-exerted forces. The finite element analysis, although accurate, is computationally intensive and requires large computing power as VR demands real time processing [1,5,6-8]. We have designed a novel, fast, real time simulation process using a fuzzy logic [3] subsystem which enables us to build a complete real time virtual surgery simulation system. The purpose of this paper is to illustrate the role of the fuzzy logic subsystem. The design of a complete virtual surgery simulation system, using such subsystems is presented elsewhere [16].

2. FUZZY LOGIC SUBSYSTEM DESIGN

VR surgical simulation systems are complex and involve integration of user inputs, model simulation and display. The user-exerted forces (force and angle) are dynamically measured and used to control the cutting process. Cutting depends on two parameters: the instantaneous value of the multi directional cutting force on the virtual tool held by the user, and the stiffness of the tissue at the tool tip location. These parameters are first fuzzified to obtain the membership values corresponding to the measured parameter values [3-4, 13]. Then, these membership values are fed to a fuzzy rule base to obtain output membership values for the depth of cut (magnitude and angle). These output membership values are converted to a crisp output value for the depth of cut using an output membership function together with the centroid defuzzification technique [14]. The overall scheme is shown in Figure 1.

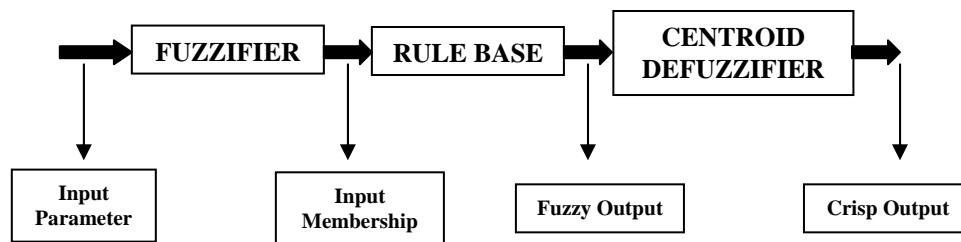


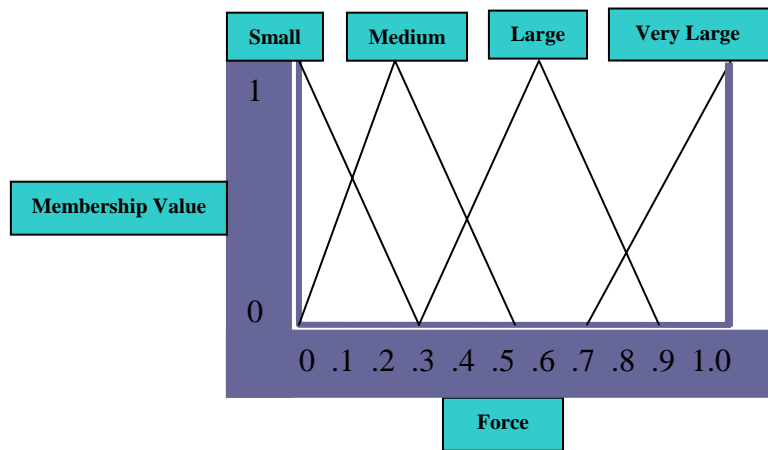
Figure 1. A block diagram of Virtual Surgery Fuzzy Control System.

2.1 Defining Membership Functions

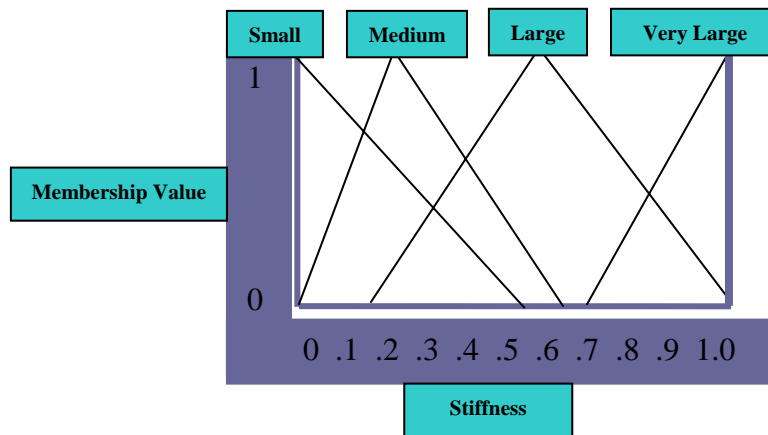
Fuzzy control systems are modeled based on expert experience of real people. The membership functions for inputs and outputs have to be defined by expert experience. The membership function defines the fuzzy sets in each input and output variable. In our virtual surgery system, the membership functions have been defined for input variable (Force and Stiffness) and output variable (Depth) as illustrated in Figure 2. Each membership function is divided into several fuzzy regions (small, medium, etc.). The x-axis in Figure 2(a) represents the normalized input force and the y-axis quantifies the partial membership values of a given force in each fuzzy region. The x-axis in Figure 2(b) represents the normalized stiffness of the soft tissue while the y-axis gauges the partial membership values of a given stiffness in each fuzzy region.

2.2 Constructing Fuzzy Rule Base

The fuzzy rule base transforms the given input functions into outputs. In order to construct the rule base, a lookup table is defined. The lookup table defines the corresponding action to be taken for each combination of input fuzzy sets. In order to achieve this, a three dimensional table is constructed. The input functions are represented in the X and Y axes. The output function is represented in the Z axis. In virtual surgery system, the input function Force is represented in X axis and Stiffness in Y axis. The output function Depth is represented in Z axis. The lookup table for the present virtual surgery fuzzy system is given in Table 1.



(a)



(b)

Figure 2. Membership functions for force (a) and stiffness (b).

The rules are written in “AS THEN” format. The rule base is then used to calculate the outputs. The “AS THEN” format makes the control system work fuzzy.

2.3 Applying Fuzzy Logic

The membership value of each fuzzy set in the input functions is determined. This is calculated from the membership function definition. For each combination of input membership values, the conjunction fuzzy set is determined based on fuzzy math. This is because the rules we have written are AND rules. All values corresponding to each output membership category are collected and added up.

De-fuzzification is achieved by taking moments about the origin including all the output membership values. This method is popularly called as the centroid method of de-fuzzification [14].

3. RESULTS

The fuzzy virtual surgery system was used to perform tissue cutting (Figure 3) based on the force exerted by the user and the material properties. Experiments have been conducted to estimate the validity of the fuzzy control system. The experimental process was divided into two phases, the training phase and the testing phase. In the training phase, a trainee was first explained on how to use the virtual tool to perform tissue

cutting. The trainee then exerted forces on an instrumented scalpel. Sensors attached to the scalpel measured the forces and sent them to the simulation system, which in turn computed the direction and depth of the cut based on the user exerted force. The final results were animated on the computer screen. The training phase helped the trainee to acquire a feel of the cutting tool and allowed the trainee to be familiar with the system. After a stipulated training period, a pre-defined path was designated to each trainee and the trainee had to follow the path to perform the cut. The experiments demonstrate that the system can simulate and display the tissue cutting process in real time. Further experiments are being conducted to verify the accuracy of the fuzzy logic model by cutting real animal soft tissue.

Table 1. Fuzzy rules.

Force Stiffness	Small	Medium	Large	Very Large
Small	No Cut	Small	Medium	Large
Medium	No Cut	No Cut	Small	Medium
Large	No Cut	No Cut	No Cut	Small
Very Large	No Cut	No Cut	No Cut	No Cut

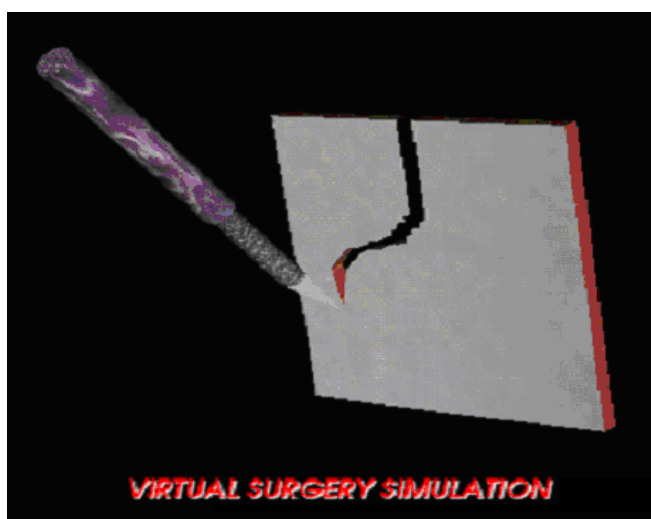


Figure 3. Visualization of simulated tissue cutting.

4. CONCLUSION

A new and novel technique of cutting simulation has been developed using fuzzy logic. In addition, the present paper represents the first investigation of the application of fuzzy logic to cutting in VR environments. Preliminary results, with several users, are encouraging and are consistent with other techniques of VR simulations requiring large computing delays. The fuzzy logic based system developed in this study significantly reduces the simulation time which allows us to simulate virtual surgery in real time. Moreover, expert surgeons' knowledge can be incorporated into the system to make the tissue cutting more realistic. The fuzzy logic based technique developed in this study offers a powerful tool for VR surgical simulations.

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