Minimising Tremor in a Joystick Controller Using Fuzzy Logic

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Abstract

We have designed and built a fuzzy logic controller which minimises the effect of Multiple Sclerosis (MS) hand tremors. The aim of our project has been to give people with Multiple Sclerosis better control of an electric wheelchair by removing tremors from the joystick signal. The system intercepts the signal from the joystick and then passes it through the fuzzy logic controller. The fuzzy logic rules identify and reduce erratic or unusual movements, employing a history mechanism to determine what "unusual" is. The fuzzy logic then outputs a signal which most closely represents the intent of the user. This paper reports on the latest experiments conducted with our prototype wheelchair, using test volunteers with MS, as well as on the design of a new fuzzy logic controller.

1. Introduction

The main aim of this paper is to report the design and implementation of a controller for minimising tremor in a wheelchair by adding Fuzzy Logic (FL) into the control system.

Conventional wheelchair controllers are composed of a variable potentiometer joystick that increases the voltage proportionally to the displacement from its default centre position. To cater for people with a mild tremor, the controller is installed with a time-delay/damping mechanism to slow down the response time, and then average or filter the input. This approach has the disadvantage of slowing the wheelchair down, sometimes unnecessarily as the person's tremor may vary from time to time. In addition, this delay would affect the ability to navigate safely around objects and through doorways.

The primary method used to cater for more severe cases of tremor is to lock the joystick in one direction, the direction first chosen. This device does not let its user move the joystick to the left or right while moving in the forward direction, for example. The obvious disadvantage of this method is the difficulty in guiding the wheelchair smoothly or consistently. There is no current method for coping with severe tremor or severely limited limb movement. For example, most people with advanced

cases of Multiple Sclerosis (MS) are unable to use an electric wheelchair at all.

Therefore, our tremor-control joystick is a case-in-point for the demonstration of the usefulness of Fuzzy Logic. Our controller is able to handle the tremor peculiar to Multiple Sclerosis. Prior reports describe the simulations and theory behind our work [3], [4], and the design, implementation and initial testing of the fuzzy logic wheelchair controller [1], [5], [6].

Although our tremor-control joystick is used on a wheelchair, the technology can also be applied to other systems, such as a joystick or a mouse for a PC.

The following is an improvement of the system used in the first experiments. Improvements include an embedded PC, updated fuzzy logic, and a more reliable monitoring and data gathering system. A newer design of the fuzzy logic controller is discussed in Section 3. The fuzzy inference engine in this new controller contains just 2 sets of 4 rules each, one set each for the left-right and forward-backward joystick movements, whereas the old fuzzy controller used a total of 8 direction membership functions and 4 speed membership functions, and around 20 rules.

Section 4 gives a look at the results obtained from the latest, more reliable, experiments with people with Multiple Sclerosis, while Section 5 shows simulation results from the controller discussed in Section 3. Finally, Section 6 concludes and looks at the future.

2. System Architecture

2.1 Hardware Module

The hardware module is composed of an electronic wheelchair and an Embedded Personal Computer (EPC) system, and further includes a power supply for the EPC, a wheel movement sensor system and a CCD camera with sender [6].

The EPC is interfaced to the wheelchair via the joystick control signal lines. It intercepts the wheelchair control signals provided by the joystick, and forwards a processed control signal to the wheelchair controller, in place of the original signal. The EPC uses a Pentium 90 processor with 32 Mb memory and a 4 Gb hard disk. A real-time version of Linux is used as the operating system. Also, the EPC contains an added module for A/D, D/A conversion

and a serial interface through which data can be collected from sensors on the wheelchair. An integrated network card provides access to and from the Internet. A separate power supply provides power for the EPC and other added hardware. It converts the 24 V (DC) from the wheelchair batteries to 5 V (DC) for the EPC, which draws about 7 A current [6].

2.2 Software Module

The software module is comprised of a Fuzzy Logic Control System, a Learning and Adaptation System, a Data Logging System, and a Simulator.

The purpose of the Fuzzy Logic Control System is to modify the wheelchair user's erratic joystick movements to control the wheelchair as smoothly and as accurately as possible.

The Learning and Adaptation System is designed to modify the membership functions of the fuzzy logic control system to optimise the controller for the tremor characteristics of a specific user at a specific time of the day. The tremors can vary greatly between users and a single user can have different types of tremor from day to day or even during one day. Also, the Learning System will detect slight deviations ("biased movements") by switching to a mode with a set of fixed output directions instead of a continuous output domain. The Adaptation part will then accommodate for the bias by shifting the appropriate membership functions. Because our tests so far were limited in duration, the Learning and Adaptation System has not yet been tested in practice.

The Simulator has been implemented on a separate desktop computer, which can be connected to the EPC through a normal Internet connection. This system provides a graphical display of the position of the joystick, both before and after the fuzzy logic is applied. It has been helpful already in the design and improvement of the fuzzy logic controller.

3. The New Fuzzy Logic Controller

3.1 Introduction

The system gathers information from the joystick controller at a rate of 100 Hz and modifies the system's state of belief accordingly on each iteration. Fuzzy logic techniques are used to convert the information into a fuzzy domain where an inference engine determines the current state of belief. The state of belief is then used to determine the resulting control state for the wheelchair.

In the design stage of the FL system for the wheelchair, the importance of the encoding, or fuzzification, of the input signals soon became clear. The first design of the fuzzy controller mapped the input signals to directional and velocity membership functions. The fuzzy controller's behaviour was quite similar to the existing (optional) damping mechanism that comes with the wheelchair joystick. Real-world tests with this fuzzy controller have already proven to enhance the wheelchair driving control [1], although

not all of the test volunteers had benefit from this first fuzzy controller. After computer simulations, a completely new FL controller was designed. The fuzzy inference engine in the new controller contains just 2 sets of 4 rules each, one set each for the left-right and forward-backward joystick movements. The old fuzzy controller used a total of 8 direction membership functions and 4 speed membership functions, and around 20 rules [5], [6].

3.2 Fuzzification

A conventional fuzzy logic system basically maps each input to the corresponding output, and the same input should always produce the same output. Now if the input is in error, then the output will also be in error. So, if the system is going to perform under uncertain input, then some modifications are necessary in order to allow the fuzzy system to deal with this uncertainty. From this point of view, it is less effective to consider each input sample independently, so in order to make more reasonable decisions, some kind of input history is useful.

We convert a time series of the input signal into indicators for the *change* in the signal as well as for the *rate of change*. As we want to prevent a delay in the controller output for more direct user control, we need to calculate these indicators in real-time. Existing methods for tremor control use averaging filters and integration techniques, which cause a notable drag in the system's response to the user's input (see Figure 2 for an example). Such a system was also integrated in the existing joystick controller.

The indicator for *change* is based on the derivative of the input signal, averaged over an adjustable (short) period of time to rule out noise effects. The indicator for the *rate of change* is based on the second derivative of the input signal, again averaged over an adjustable (short) period of time to rule out noise effects. The membership functions for the left-right joystick movements are shown in Figure 1. Similar membership functions exist for the forward-backward movements.

3.3 Fuzzy Inference Engine

After fuzzification, the 2×4 input memberships are used in an equal number of fuzzy rules to determine 2×4 output memberships. The output membership functions are currently just spike functions, but after real-world experiments these will probably be replaced by triangular functions. The four rules for the left-right (*x*) signals are as follows:

1. if *small* and *sudden* change in input,
then *zero* change in output;
2. if *small* and *smooth* change in input,
then *small* change in output;
3. if *large* and *sudden* change in input,
then *moderate* change in output;
4. if *large* and *smooth* change in input,
then *large* change in output.

Figure 1. Fuzzy membership functions for the left-right (x) joystick input movements

A similar set of rules applies to the forward-backward (y) movements. The respective fuzzy inference rules for left-right movements can be interpreted as:

1. a *small* and *sudden* change in the input is very likely to be noise, which should be removed;
2. a *small* and *smooth* change in the input could be a small change in direction, either on purpose or involuntarily (a reported characteristic of MS tremor movements [2]): we should wait for more evidence of a desired change in direction, or ignore it;
3. a *large* and *sudden* change in the input could be a strong tremor, or a left or right turn; this is very hard to distinguish, and is different per user: for users prone to large tremors, the weight of *moderate* should be decreased (see Section 3.4);
4. a *large* and *smooth* change in the input is very likely to be a desired change in direction, so the wheelchair should move accordingly.

3.4 Defuzzification

The 2×4 output memberships are used to calculate two 'crisp' values that are sent to the wheelchair motors controller. As the output membership functions are currently just spike functions, the defuzzification is nothing more than taking a weighted average of the output memberships. Typical weights are: *zero* = 0, *small* = 0.2, *moderate* = 0.7, and *large* = 1. In the future, these values will automatically be adjusted by the learning and adaptation module. The crisp defuzzification results

are multiplied by the original input changes to obtain the new control values for the motors. In a later stage, when the output membership functions are triangular functions, defuzzification may involve a different method, e.g., the centre-of-mass method.

4. Real-World Experiments

In order to test (a modification of) the old fuzzy controller, experiments were conducted with Multiple Sclerosis volunteers.

In a large room (appr. $8 \times 25 \text{ m}^2$), a track was laid out on the floor. Previous tests showed that following a single line pattern could cause over-correction problems for some of the volunteers [1]. To avoid over-correction, we now used a test track more similar to the real world situation. The test subjects were asked to guide the chair through lanes drawn on the floor. The test track included a variety of real-world situations, such as straight lanes, wider and narrower curves to both left and right, turning around a right angle corner, and wider and narrower U-turns.

Typically, we would ask the volunteers to complete the whole test track four times: first in normal operation mode, then twice in fuzzy logic control mode, and finally once more in normal operation mode. The test subjects did not know what mode the chair would be in during a particular trial.

Our test subjects were eleven people with MS selected with assistance from the National MS Society of Australia. Between these volunteers, the tremors varied from mild to severe. Some of them were using a wheelchair already (some powered, some not), others used a cane or a walking frame.

4.1 Results

As can be seen from Figure 2, the old fuzzy logic software reduced the tremors significantly, and this made the chair ride more smoothly. In general, the volunteers with severe tremors felt more improvement in the fuzzy logic control than those with only mild tremors.

5. Simulations

The real-world experiments with the old controller have supplied us with a large collection of electronically recorded joystick input signals with tremors. The raw input signals were processed through a simulation of the new fuzzy logic controller, so that the results can be compared with the output signals that were recorded from the existing controller during the experiments. Figure 2 shows an example of an input signal with tremors, with the actual output of the existing controller, and Figure 3 shows them with the simulation results for the new fuzzy logic controller.

From these figures, it should be clear that the new controller is filtering out the tremors well, and has a much quicker response than the controller currently present on the wheelchair.

Figure 2. Example of a joystick input signal (thin lines) with tremors, together with the recorded output signal from the old controller (thick lines); the top lines are the forward(+)-backward(-) signals, the bottom lines are the right(+)-left(-) signals. The graph shows the test subject making a sharp left turn, then correcting to get back into the lane.

Figure 3. The same input signals (thin lines) as in Figure 2, but now with the simulated outputs from the fuzzy logic controller (thick lines). The fuzzy logic controller has not been fine-tuned for the specific tremor characteristics of this user, hence the imperfections, e.g. at $t = 23.4$ s.

6. Conclusions

For most test volunteers, the old fuzzy logic wheelchair controller improved driving behaviour, but for some, the effect was opposite. The latter was in particular the case for those volunteers that use an electric wheelchair already.

It appears that the FL controller is particularly useful for people with more severe MS tremors, but less useful for people who have only light tremors. The latter group might still benefit from the system after adjustment of parameters in the fuzzy logic and history mechanism, or when they are having a 'bad day.' Tremor behaviour in people with MS can differ widely from day to day and usually worsens during the day as well. In future tests, the Learning and Adaptation Module will take control of parameter adjustment.

At the time of publishing, we hope to already have installed the new fuzzy logic controller and to have conducted real-world tests with the new controller.

First steps have already been made to integrate an Assisted Navigation System into the wheelchair controller, but this still needs to be tested in practice. An Assisted Navigation System is similar to an Obstacle Avoidance System, but leaves the user in more control, which can be useful for purposely nearing an obstacle (e.g., a wall, a door, a desk), which is not possible with an Obstacle Avoidance System.

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