

Design of Intelligent Filter for Telerobotic System

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Abstract

In this paper, intelligent filtering methodology for masterarm translation signal is proposed. Fidelity and stability are contradicting factors in teleoperation. Human hand trembling filtering is one of the problems in telemanipulation field. During every operation the hand has a certain vibration that can affect the quality of teleoperation, especially in carrying FPD (Flat Panel for Display), nanomanipulation and other precise tasks. It is very important to study the kinesthetic perception of the human and to optimize the teleoperation system accordingly. To cancel out the influence of human's hand vibration the signal from the masterarm should be filtered. One of the feasible solutions is to use an intelligent filter based on fuzzy logic, which is a very flexible instrument. Applying intelligent filtering methodology, we can use some heuristic methods to solve the filtering problem.

Key Words: telerobot, intelligent filtering, FPD.

1. Introduction

From the early 1960s telemanipulators and video cameras were being attached to submarines by the US, USSR, and French navies and used experimentally. Also, from that time the race to the moon began. The early lunar teleoperator called Surveyor demonstrated vividly many control problems of time delay in an actual space mission. By 1970 the interest in teleoperation had turned to undersea applications, for there economic demand for offshore oil [1].

In 1976, robot arms were used on the Viking I and II space probes and landed on Mars. In 1993, the experimental robot, ROTEX, of the German Aerospace Agency (DLR) was flown aboard the space shuttle Columbia and performed a variety of tasks under both teleoperated and sensor-based offline programmed modes. In 2001, the first telesurgery has been performed when surgeons in New York performed a laparoscopic gall bladder removal on a woman in Strasbourg, France. In 2005, ROKVISS (Robotic Component Verification on board the International Space Station), the experimental teleoperated arm built by the German Aerospace Center (DLR), underwent its first tests in space [2].

The main concerns for the design and control of a modern telesurgical system can be summarized as follows:

- 1) fidelity in force-torque feedback;

- 2) stability-fidelity trade-off;

- 3) performance under time delay.

Fidelity and stability are contradicting factors in teleoperation. In conventional teleoperation tasks, involving manipulation of rigid objects for assembly, the interaction with the rigid environment is the main source of this stability problem.

It is also important to study the kinesthetic perception of the human and to optimize the teleoperation system accordingly. The coupling between the master-slave system can be chosen to minimize perceptual distortion rather than seeking an ideal response which is marginally stable and practically impossible to achieve. Also some variables of interaction can be amplified to improve sensation of manipulation for better performance [3].

In many teleoperation and telerobotic systems there is an unavoidable delay in time imposed between the operator's actions and the corresponding feedback. In information-only interactions, a certain amount of delay is natural. In contrast, in energetic interactions, we expect instantaneous response. In telerobotic systems, which can only support information interactions, a certain amount of delay is appropriate, but within teleoperator systems, which support energetic interactions, even a tiny delay (less than 100 ms) between a physical variable and its conjugate variable's response has no correlate in the physical world. Time delay in simulated energetic interaction creates the difficult technical challenge of system stability. But even if the stability problem is solved, it is doubtful that delayed feedback of a conjugate physical variable has any meaning to the human operator [4].

While using commonly applied filters, a certain time-delay is occurred because of complex mathematical operations

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performed by the system. Applying neural networks to real systems is also a very complex task because of the need to "teach" the network to perform required operations and to adjust all the weights. However, in case of using fuzzy logic, we can create a very simple system and reduce the computational burden of our controller, because fuzzy logic has following advantages for applying to the intelligent filter:

- Easy real systems implementation;
- Reduced computation time (time delay);
- Possibility to construct adaptive filter without using mathematical functions and equations.

2. Problem Statement

In every operation, performed by human's hand, a certain amount of hand's trembling occurs, and during variety of such operations which do not require high accuracy (e.g., operating working crane, mobile robot, etc.) we can neglect the influence of these hand's oscillations. But there is a number of highly-precise manipulations including micro- and eye-surgery, microelectronics assembling, etc., where human's hand trembling is extremely undesirable or even intolerable.

During most operations human operates the working instrument directly, therefore, the influence of this hand's trembling (or vibration) can not be canceled. However, applying teleoperation provides us with an opportunity to minimize or even eliminate the influence of undesired oscillations. Since master arm, operated by human directly, and slave arm are not rigidly connected to each other, we are able to filter the translation of the master robot first and only then feed a clean position signal to a slave robot's controller. Therefore, we need a fast and not complex filter to bring down the magnitude of vibration to a suitable value. In addition, this filter must be very flexible and easily adjustable to meet the needs of different human operators since the hand's trembling of each of them has its own unique parameters.

Human's hand vibration in terms of stability can be represented as some disturbance added to the dynamical equation. It has a certain influence on a master's behavior, and the oscillation damping is very critical sometimes, especially in tasks where high precision is required.

Sometimes the position response is not required to be identical. For example, in nanomanipulation or in telesurgery, it is required to reduce the position response of the slave robot [5]. In this case, scaling can be very useful since it is much easier for a human to work in usual-scale space then in mini- or even micro-scale.

3. Intelligent Filter

Fuzzy logic as an intelligent algorithm has some advantages, which are ease of design of the control rules (straight out of an operator's manual), the lack of dependence on accurate process models, the "understandable" nature of the resulting control strategies by plant operators and other practitioners, and the inherit nonlinear nature of the fuzzy logic-based systems [6].

In the ordinary structure of a telerobotic system, the masterarm translation signal is fed directly to the slave robot, and force feedback is applied from slave to master. In our case, we implement the intelligent filter to filter the oscillations of the human hand:

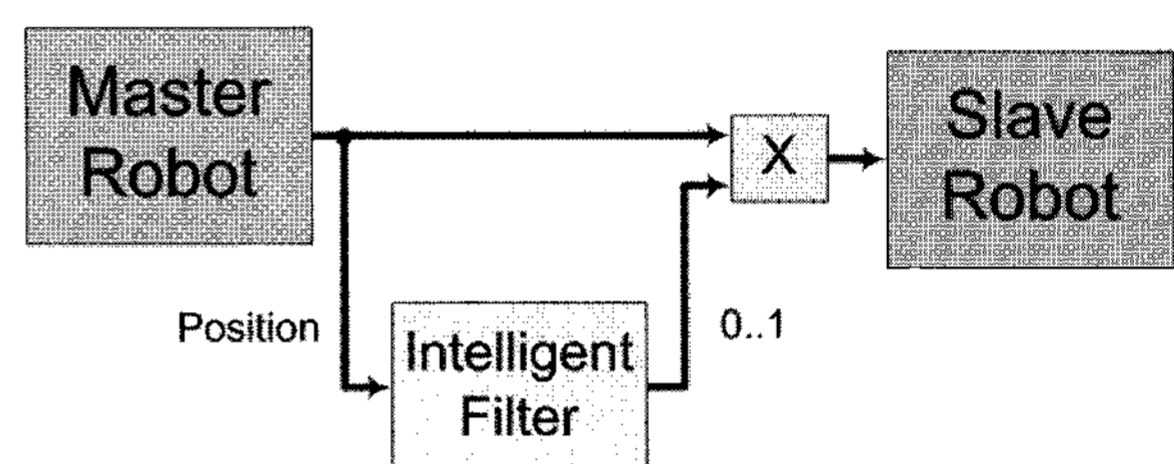


Figure 1: Telerobot system with intelligent filtration

According to this structure, the signal from the masterarm is not fed directly to the slave robot controller, but is being analyzed by intelligent filter. If the input signal is a certain vibration, the output of the filter will be nil and no information will proceed to the slave robot after multiplication of nil and input signal; therefore, current value of signal will be equal to the previous one achieved during the previous filtering sample. But if the vibration magnitude lies within accepted limits the intelligent filter will let the signal from the masterarm pass through to the slave robot controller.

One input of the suggested intelligent filter is the velocity of the actuator of the master robot. During vibration the velocity is relatively high within small translations. Thus, let's consider that if velocity is small (lies within some fixed limits) it means that the input signal is good and we need it; comparatively high velocity means that input signal contains vibration and we must not let it pass through. But we need at least one more input to distinguish the useful signal and vibration. Let consider this input to be the frequency of input (master arm) signal. If the frequency of the incoming signal gathered by the sensors is greater than some fixed value we set as a limit, it means that the operator's hand is trembling, the signal contains unavoidable oscillations and needed to be filtered somehow.

The proposed structure of the filter looks the following way:

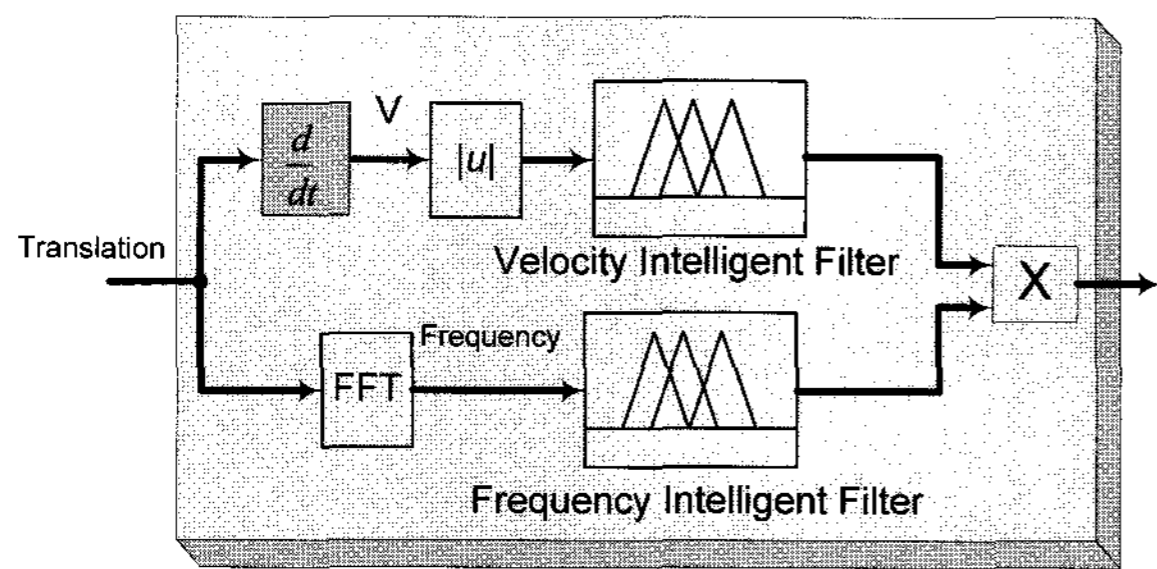


Figure 2: Internal structure of intelligent filter

This system works the following way: an input signal (let us assume that it is the translation or position of the master-arm actuator) is being differentiated, and the absolute value of the evaluated velocity is fed to the velocity intelligent filter. At the same time, input signal without any changes is fed to the frequency intelligent filter. After performing filtering, the output of the filter (in this case, of the both velocity and frequency filters) is being multiplied by the input signal.

To perform experiments, the data of hand trembling was gathered. The average frequency of an operator's free hand oscillations lies between 4 and 5 Hz depending on age, hand's weight, etc.; however, when a human holds any object (e.g., the end-effector of the master manipulator), this frequency is decreased due to increased mass of the hand-end-effectors couple and therefore do not exceed a 3.75 Hz. Nevertheless, a certain high-frequency noise always occurs, especially in highly-precise micromanipulations; this noise is caused by vibration provided by the electrical motors and a variety of other possible reasons. Therefore, the overall teleoperation in terms of operator's hand motion can be modeled as a 3.25-3.75 Hz noise, representing hand's trembling, and a high-frequency noise, representing a vibration of any kind (e.g., a motor's vibration caused by its unbalanced shaft, robot's basement vibration, etc.), added to desired (or "clear") translation - "useful" signal. In many cases, to avoid undesirable high-frequency vibration, the robot is mounted on a floating table or other vibration-isolated basement; in this case, if the angular speed of the motors is relatively low, we can completely bring down the influence of the vibration on system's behaviour.

Following membership functions have been used for the inputs (velocity and frequency, respectively):

Velocity:

(0 - 0.8) cm/sec – the signal is clear (doesn't need filtration);

(0.8 - 0.9) cm/sec – fuzzy zone (we are not sure if the input signal contains any sufficient vibration part or not);

> 0.9 cm/sec – input signal is vibration.

Frequency:

(0 - 3.25) Hz – the signal is clear;

(3.25 - 3.75) Hz – fuzzy zone;

> 3.75 Hz – the signal is vibration.

The output of the filter is calculated basing on Mamdani's rule.

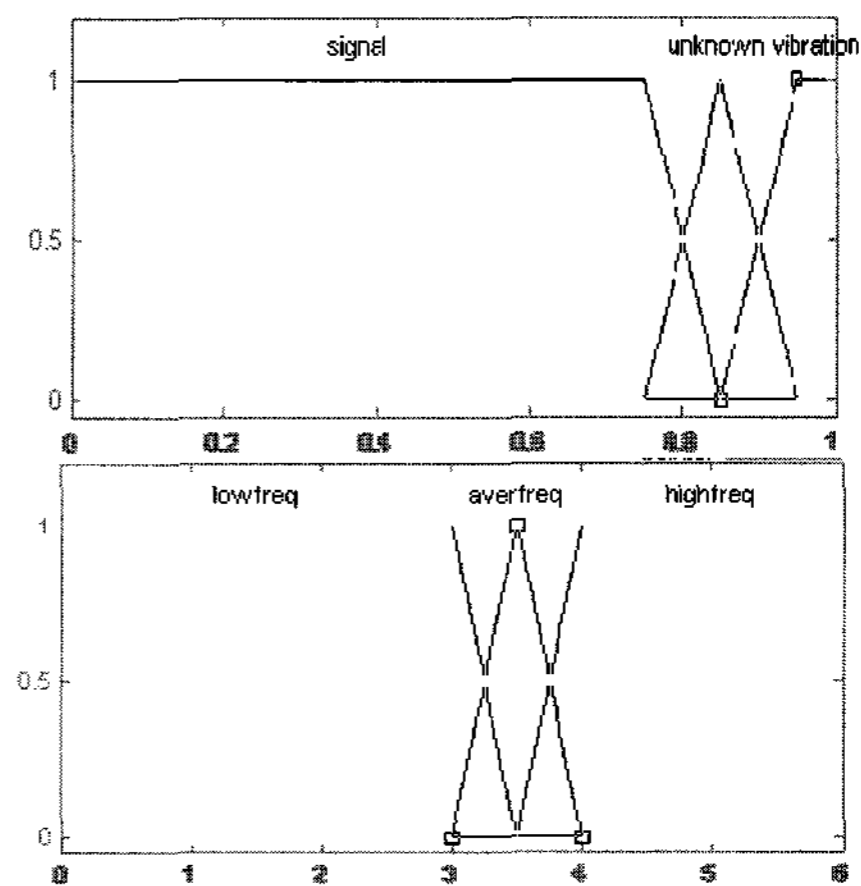


Figure 3: Membership functions for velocity and frequency inputs.

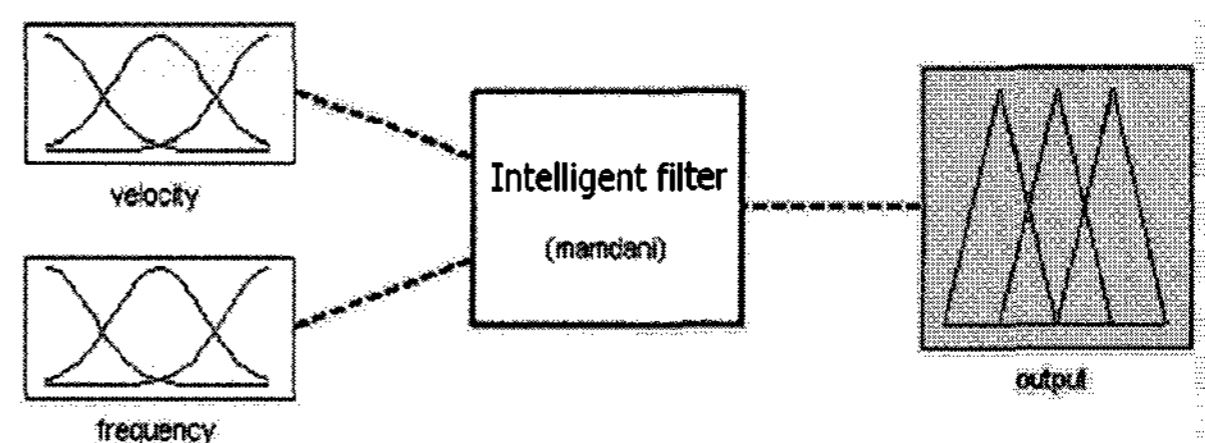


Figure 4: Internal structure of the intelligent filter.

The membership functions for output signal look the following way:

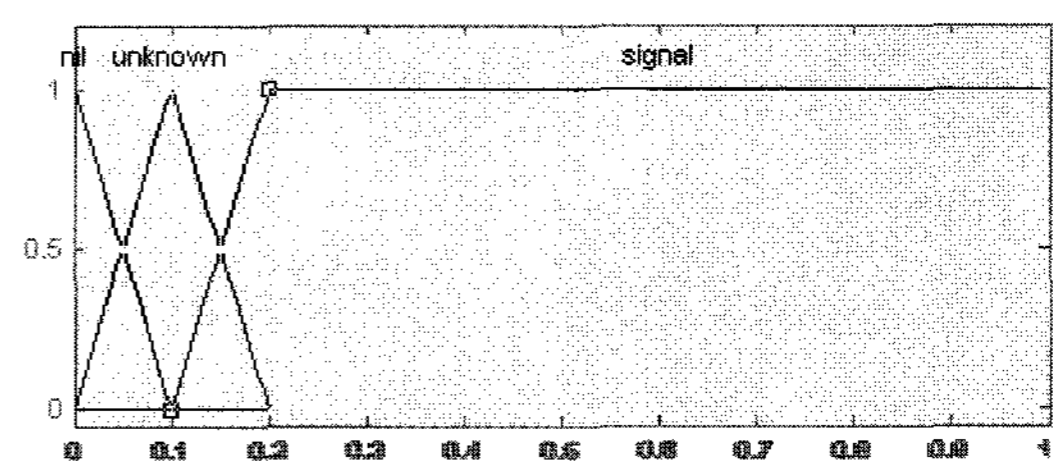


Fig. 5. Membership functions for the output signal of the filter.

Therefore, at each time sample following desired translation is evaluated:

$$Xout_i = Xout_{i-1} + Xin_i \cdot VIFout \cdot FIFout \quad (1)$$

where $Xout_i$ denotes the output signal (desired slave robot position) at current evaluation sample, $Xout_{i-1}$ denotes the output signal of the system at previous sample, Xin_i is input signal fed to the filter, and $VIFout$ and $FIFout$ represent the output signals of velocity and frequency intelligent filters, respectively. Therefore, if output of intelligent filter is nil it doesn't necessarily mean that the resulting output of the system (desired slave robot position) will be nil as well; it just means that previous position ($Xout_{i-1}$) should not be changed.

4. Experimental Results

The following experiments were performed: at first, an input signal was a noisy circle – a signal contained a sufficient part of unavoidable oscillations.

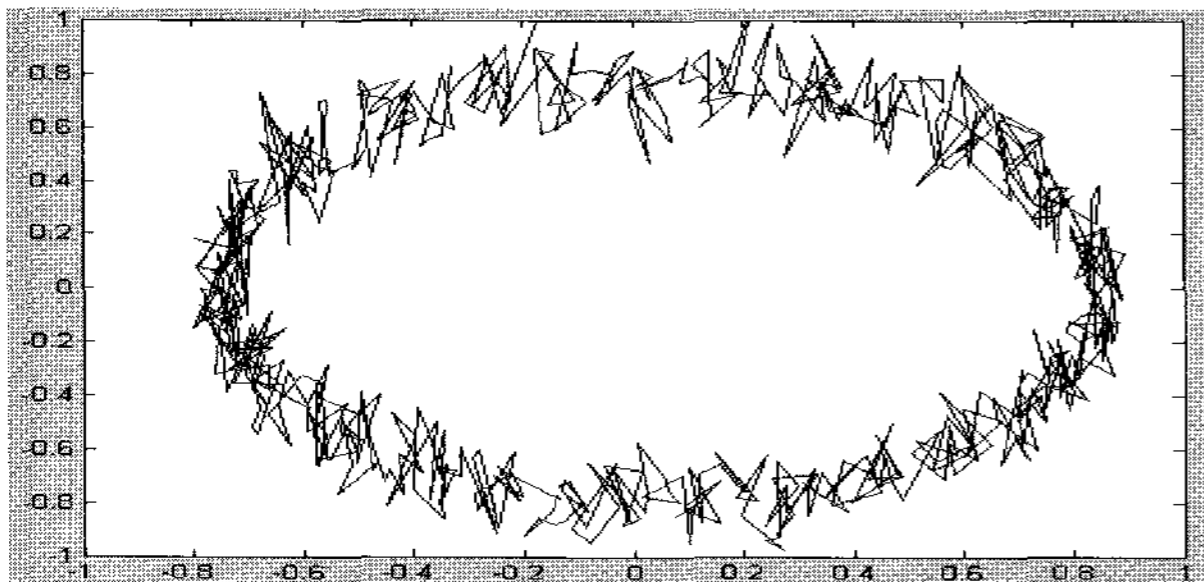


Figure 6: An input signal during first experiment (noisy circle)

In the input signal, vibration part was modeled as a random signal with the magnitude equal 35 % from the "useful" signal magnitude.

After applying intelligent filtration, we achieved such an output signal:

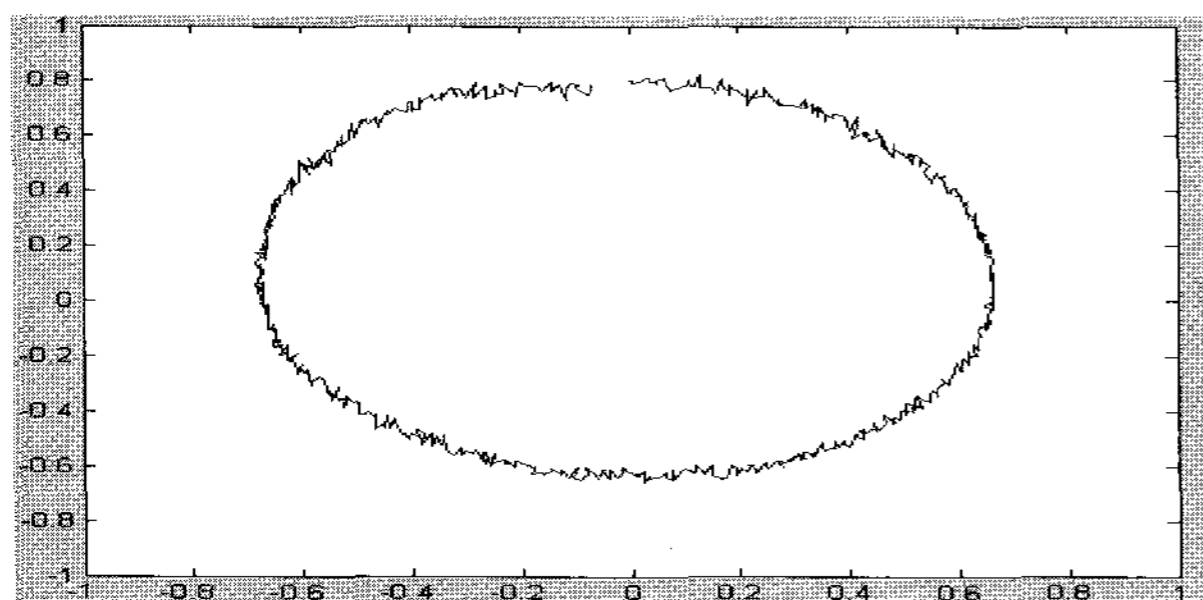


Figure 7: An output signal during first experiment (noisy circle)

As you can see, the signal became much smoother after filtration: the oscillations part came down to 7.3 % instead of 35 % within the signal from the master arm.

During next experiment, the input signal represented the capital "A" character. Before filtration it looked the following way:

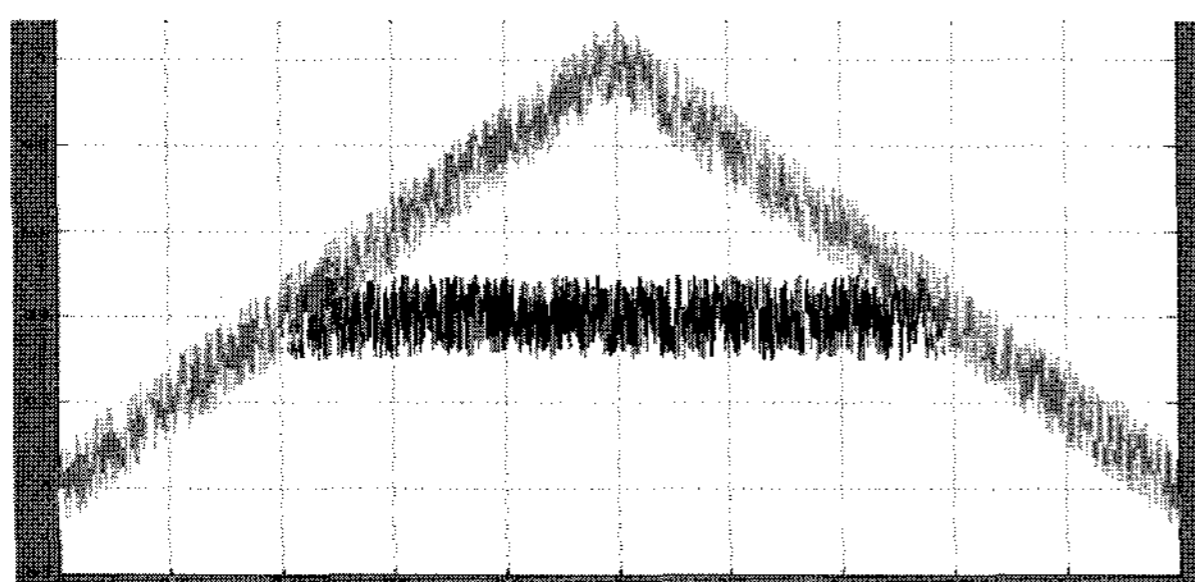


Figure 8: An input signal during second experiment (capital "A" character)

The vibration magnitude was set to the 10 % of the pure signal.

After applying filtration, the following signal has been achieved (as a result, we have a signal with a 2.4 % vibration part):

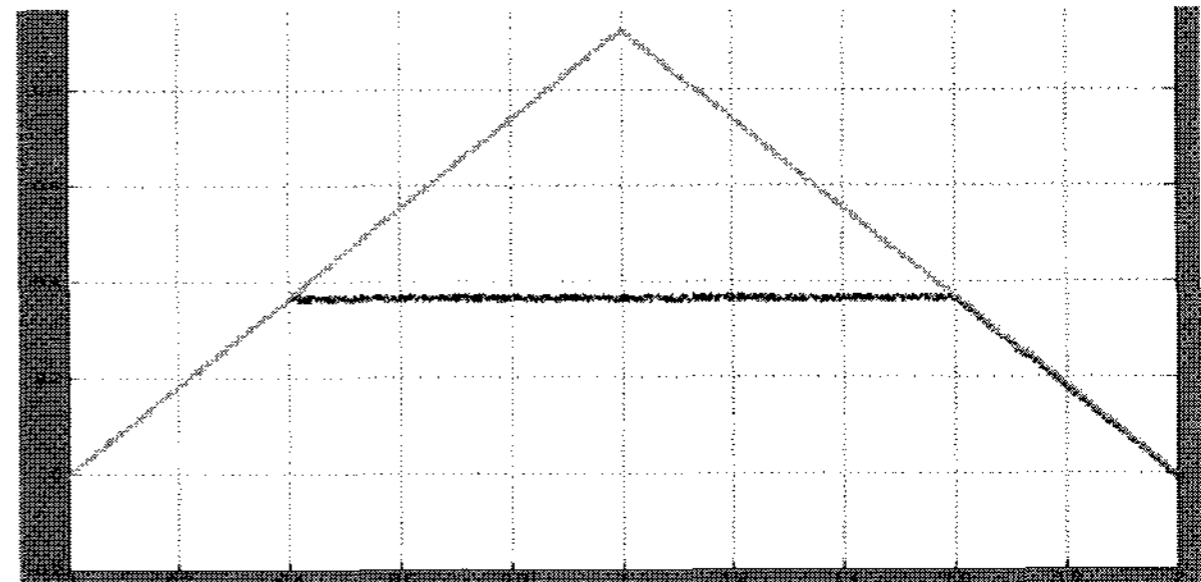


Figure 9: An output signal during second experiment (capital "A" character)

5. Conclusions

In this report, the concept of intelligent filtration methodology is suggested for human's hand trembling filtering. This kind of filtering may be applied in different fields where the noise reduction is recommended or required. Using fuzzy logic for both velocity and frequency filtering, we can design a really precise and flexible filter suitable for many applications. All the fuzzy membership functions within the internal structure of the filter can be made more complex and accurate or even new inputs can be added depending on the experimental data or any additional requirements. The borders of existing membership functions can also be adjusted to increase the precision of the filter and the smoothness of the outgoing signal, but even using these inputs and membership functions we achieved a much smoother signal that it was before the filtration.

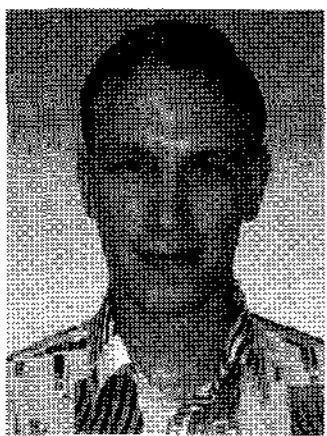
In the future, it is planned to gather more experimental data of the human's hand trembling and the influence of different factors on vibration magnitude and frequency. Acquiring such data can help us to adjust the intelligent more precisely according to each operator's hand.

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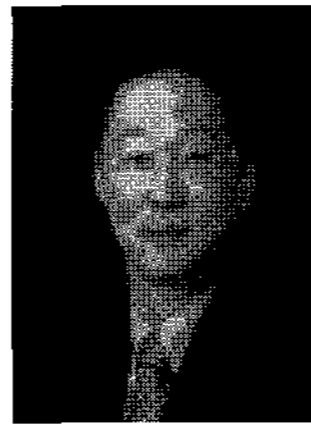
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