7MR10040: Medical Robotics: Theory and Applications
Semester 1

Assignment 7

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Question 1

Haptic displays are interfaces that generate mechanical impedance. In this context, impedance is the force that is exerted unto the user, like the mass of a pencil in the user's hands. Building a haptic interface is challenging and the main problem is building a programmable device that can exhibit such a broad dynamic range of impedances.

In this paper, a study of the problem of the virtual wall has been conducted. This is because the virtual wall is a task representing both very high impedance (contact with the wall) features and very low impedance (no contact with the wall) features. With a wall being an example of a unilateral constraint, which is a common form of kinematic constraint, it is important that its implementation is robust and realistic.

There are three main obstacles in implementing a very stiff virtual environment with a haptic display.

As mentioned above, the first obstacle is robustness. Robustness relies on passivity which states that the coupling of passive systems will form a stable system. Robustness is also required since the human tactic sensory is very sensitive to small forces/vibrations and the human is a dynamic system. Even if a non-passive environment is stable, interaction with a human may cause instability.

The second obstacle is sampled data and inherent dynamics. Both affect the achievable dynamic range. The dynamics of the haptic interface should follow the programmed behaviour (the virtual environment) instead of any inherent dynamics. Any changes in the inherent damping or sampling rate stiffen the system and alter the responsiveness. It is important to tune these parameters so that the system behaves as it would be expected in by the physical laws. Although, as mentioned, adding physical damping makes it easier for the system to follow the physical laws.

The final obstacle is sensor quantisation and velocity filtering. Using encoders, the velocity of the system can be estimated (using differentiation) by measuring the position of the system. The main drawback of differentiation is the amplification of noise. This can lead to higher velocities than required when, in our case, contacting a wall. One way of improving this is to use a slower sampling rate but this goes against the goal of high stiffness. Other ways of improving is to filter the velocity estimate digitally or to use analog sensors. A final way to do this is to use encoders with higher resolutions.

To conclude, the implementation of very stiff virtual environments with a haptic display is a challenging task. The system needs to be accurate and it must "feel good" to the user in both high and low impedances. To achieve this, the implementation must eliminate gross instabilities and eliminate awareness of high frequency oscillations. Furthermore, psychophysical experiments need to be performed in order to tune the virtual environment to match the physical one.

Question 2

With fully automated robotic systems that have a complete view of their environment and understanding of their task still being far off, active constraints/virtual fixtures offer a very adequate and satisfactory “middle” ground.

Active constraints are robot control strategies that can be used to assist humans in certain tasks. They achieve this by guiding the user to a certain area or by restraining them to go in to another. Thus, they improve/augment a human’s capabilities instead of replacing them completely.

The main task of an active constraint controller is to produce a set commands that enforce the appropriate constraint by considering its position and configuration. There are multitudes of methods that have both been proposed and demonstrated within the literature that offer a range of both functional and haptic properties.

These methods can be as simple as point and linear constraints, to point clouds and even Artificial Neural Network constraints that can support even dynamic constraints which will be useful in cases such as the case of a beating heart.

Being simpler to implement, simpler methods are more widespread within the literature and they have demonstrated that they can be useful for a range of tasks but are still not able to cope with more complex/unstructured environments which is where complex methods have proven to be more useful. The main drawback of complex methods is their demand for computational power.

In order to choose the correct active constraint, one must look at whether the device is admittance controlled, impedance controlled or constructed in some other away. An admittance control would only allow the user to move in ways which do not violate the constraint while an impedance control apply a force to counteract the motion which violates the constraint.

Active constraints are a useful concept in robotic systems. Until Strong AI or just more competent AI is developed, active constraints will aid people in tasks which are now very difficult to perform without their assistance. For example, active constraints can help surgeons by restricting them from performing critical mistakes. This will help increase the success rate of surgeries in the best case or just make their success rate consistently the same in the worst. This in turn, would reduce the entry level for surgeons to perform surgeries, as it can turn novice surgeons in to adept surgeons and adept surgeons in to experts and reduce the Bus Factor[1] that is currently present in the field. Furthermore, by keeping a human in the loop, they can help robotics enter the healthcare system more easily than a fully automated system, making them profitable and therefore increasing their effectiveness more quickly.

[1] The risk resulting from information and capabilities not being shared among team members