Solving liquids by discarding Fluid Dynamics

Predicting force feedback of liquids for haptic bilateral teleoperation

Teleoperation

It refers to the remote control of a remote machine by a human, with applications in:

- **Medicine** – for performing surgeries over distance
- **Disaster Relief** - aiding rescues in harsh terrain
- **Expertise over distance** - it allows people to perform tasks all around the globe as if they were there.

Figure 1 - Novint Falcon[1] is a device used to produce haptic feedback. This allows the user to actually feel his environment and make their actions more accurate

Yet, with distances, there come delays. One of the best ways to deal with them is through environment models *[1]*.

Camera & Model

For full immersion, the simulations usually entail complex visualizations. For liquids, particles, cutting and so many more, these are easier said than done.

However, if we replace this with a live camera feed, we can only focus on the haptic feedback. Our research focused on modelling this force feedback for liquids.

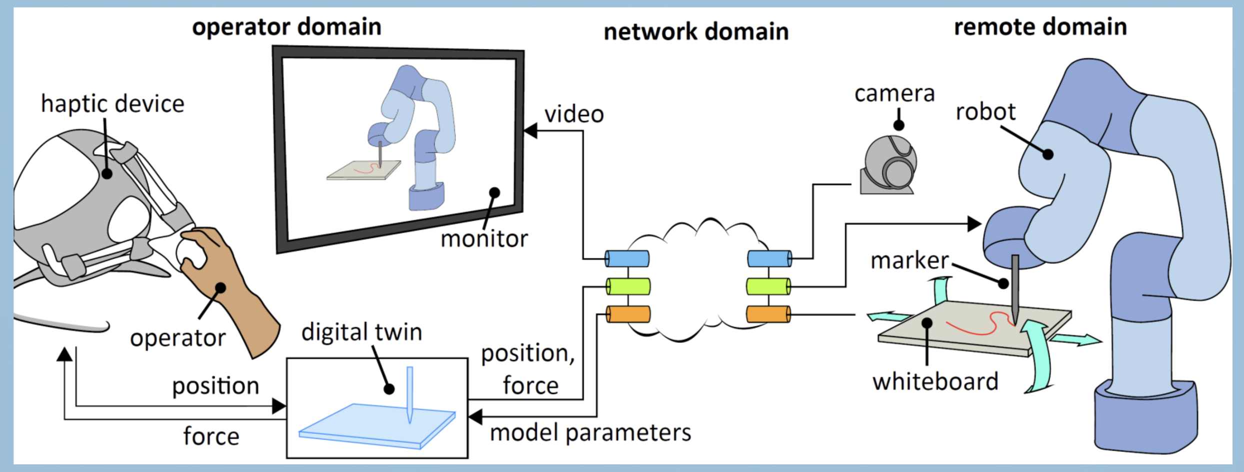

Figure 2 - Overview of the system[2]. Our solution resided in the Operator Domain and modelled the "digital" liquids.

How to handle liquids?

Modern fluid models are accurate, but costly to run. Far too slow for real time simulations. Luckily, we do not need all the complex flow values, but just the force.

$$F_d = \frac{1}{2}\rho u^2 C_d A$$

The drag equation, while simple, allows us to easily model viscous fluids like honey.

To simulate more liquids, that might be turbulent such as water, we need other improvements.

But what about water?

To achieve this, we are still using the drag equation, but complementing it with a novel *position tail*. It approximates the liquid's turbulence and acts as its velocity. While it cannot match complex simulations in accuracy, it runs in real time and attempts to make a good enough estimate.

Furthermore, we can adjust the tail's parameters to tweak its length, speed of decay or max force. This can be used to model liquids like water, but also many others such as oil or slime.

Approach

To devise and fine tune the model we went through several steps:

1. **Simulations** - the initial tests were performed using repeatable simulated paths. These provided insights into the produced haptic forces.

2. **Researcher tests** – afterwards the Novint Falcon was used to check if the feedback was accurate enough to fool humans.

3. **User Study** - in the end, we performed a limited user study to check whether people could actually believe they were interacting with a liquid.

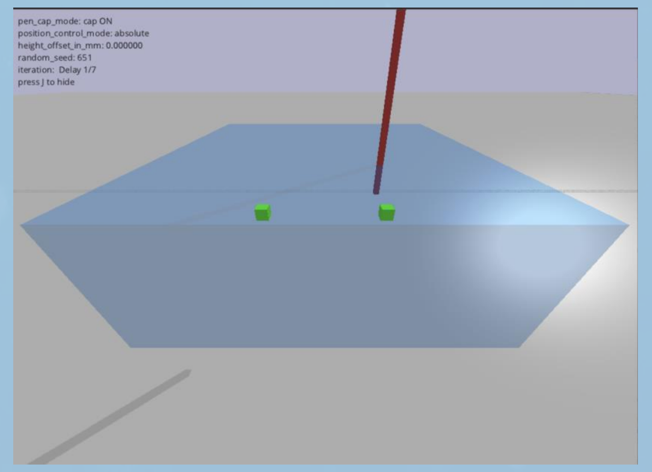

Figure 3 – An example task from the user study. Users were asked to label an unknown liquid by haptic feedback alone

Results

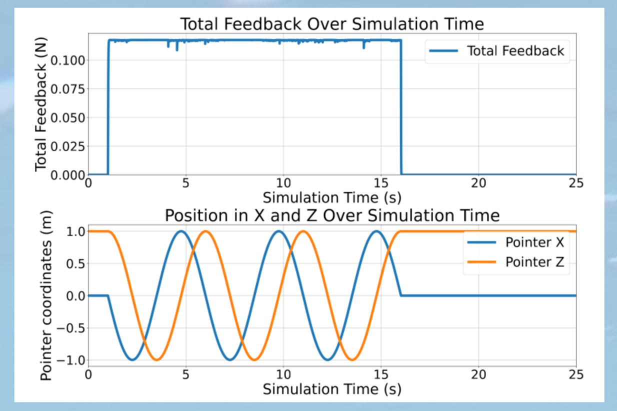

Figure 4 – force feedback in a honey

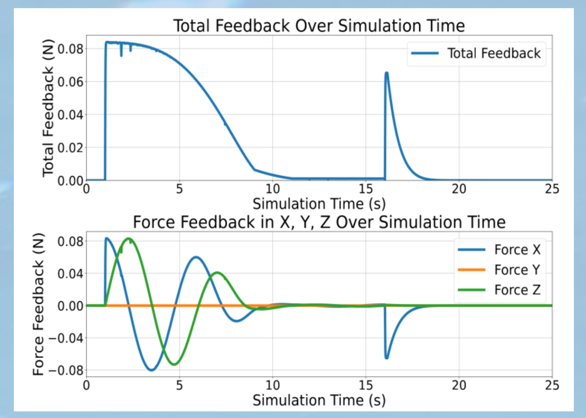

Figure 5 – force feedback in water

Figures 4 and 5 show example motions of objects in water and honey. We can see a constant force in viscous honey and a whirlpool in turbulent water.

As shown in figure 6, participants felt immersed by the simulations. They were usually able to correctly label honey and water by haptics alone. The worse results of oil suggest fine tuning of parameters is required.

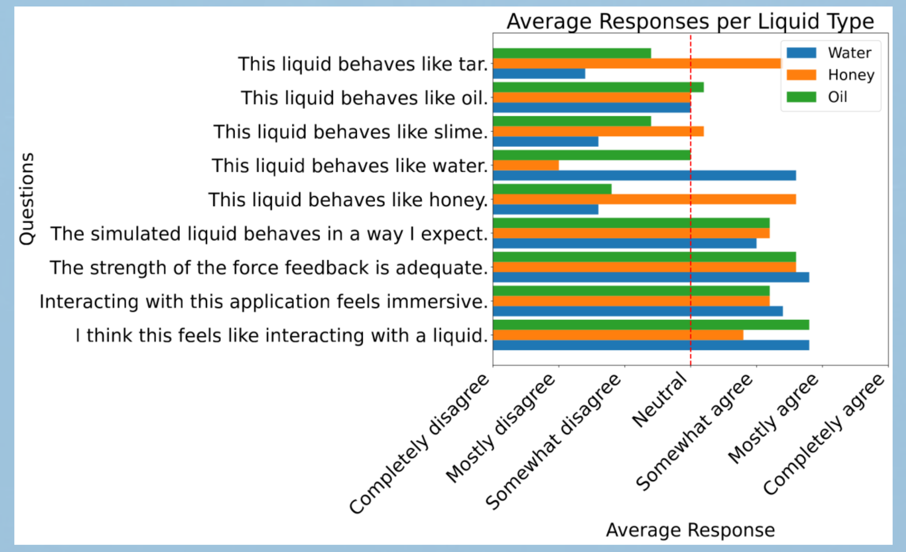

Figure 6 – user study results

Conclusion

To summarize, we were able to create a simplified liquid model that was able to correctly simulate the force feedback of liquids. It is not perfect, and remains a proof-of-concept with much improvement possible. Nonetheless, once completed it promises to provide an immmersive teleoperation experience with liquids.

References:

1. *Mitra, Probal, and Günter Niemeyer. "Model-mediated telemanipulation." The International Journal of Robotics Research 27.2 (2008): 253-262.*

Footnotes:

1. *More information about the Novint can be found on the TU Delft Haptics Lab website -* https://delfthapticslab.nl/device/novint-falcon/
2. *The image was provided by Kees Kroep and the system is part of his research.*

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