Demonstration of Geppetteau: Enabling haptic perceptions of virtual fluids in various vessel profiles using a string-driven haptic interface

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Figure 1: Geppetteau uses a string-based pulley system to dynamically relocate a vessel's center of gravity, delivering haptic sensations of virtual fluids. Geppetteau can augment everyday vessel profiles, e.g., 4 example vessel shapes shown (left). Users at home or in physical classrooms (middle) can interact with virtual fluids in virtual settings (right).

ABSTRACT

Liquids sloshing around in vessels produce unique unmistakable tactile sensations of handling fluids in daily life, laboratory environments, and industrial contexts. Providing nuanced congruent tactile sensations would enrich interactions of handling fluids in virtual reality (VR). To this end, we introduce Geppetteau, a novel string-driven weight-shifting mechanism capable of providing a continuous spectrum of perceivable tactile sensations of handling virtual liquids in VR vessels. Geppetteau's weight-shifting actuation system can be housed in 3D-printable shells, adapting to varying vessel shapes and sizes. A variety of different fluid behaviors can be felt using our haptic interface. In this work, Geppetteau assumes the shape of conical, spherical, cylindrical, and cuboid flasks, widening the range of augmentable shapes beyond the state-of-the-art of existing mechanical systems.

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UIST '22 Adjunct, October 29-November 2, 2022, Bend, OR, USA

ACM ISBN 978-1-4503-9321-8/22/10.
https://doi.org/10.1145/3526114.3558611

CCS CONCEPTS

• **Human-centered computing → Human computer interaction (HCI)**; *Virtual reality*; Haptic devices.

KEYWORDS

Ungrounded haptic feedback; string-driven actuation; virtual reality; fluid dynamics

ACM Reference Format:
Shahabedin Sagheb*, Frank Wencheng Liu*, Alex Vuong, Shiling Dai, Ryan Wirjadi, Yueming Bao, and Robert LiKamWa. 2022. Demonstration of Geppetteau: Enabling haptic perceptions of virtual fluids in various vessel profiles using a string-driven haptic interface. In *The Adjunct Publication of the 35th Annual ACM Symposium on User Interface Software and Technology (UIST '22 Adjunct), October 29-November 2, 2022, Bend, OR, USA*. ACM, New York, NY, USA, 3 pages. https://doi.org/10.1145/3526114.3558611

1 INTRODUCTION

Upon interacting with a vessel filled with liquid, we gather more information about its material composition using a multitude of senses. For instance, gently swaying a glass of water reveals the nature of the liquid inside the glass, visually, tactically, and sometimes sonically. These interactions create rich sensations of fluidity as we manipulate vessels in our hands. Moreover, these physical sensations give us innate hints about the liquid within, especially its relative volume in the container and its viscosity. The sense of touch is thus a critical aspect of experiences of handling fluid vessels, enabling several application areas, spanning from entertainment to education to workforce upskilling/reskilling.

Custom shaped vessels small enough for one-handed interactions open up a multitude of new experiences in VR. For example, hands-on wet labs can be brought into VR, where students can mix virtual fluids between beakers and Erlenmeyer flasks to cause chemical reactions. Industrial manufacturing training simulations could also be brought into VR, where users can mix epoxy resins together and feel a changing viscosity within the vessel. These experiences need devices that have both the ability to actuate programmable virtual fluids and the ability to accommodate custom vessel containers.

Researchers have developed world-grounded systems capable of providing high-fidelity haptic sensations of handling fluids in a variety of states [2][8][10]. Researchers explored open systems that change their characteristics by adding or removing physical matter, such as liquid [6] and changing air flow rate [3]. While these systems provide high-fidelity haptic feedback, their mechanical complexity does not allow for straightforward integration into a wider range of physical vessel profiles to create intuitive user interfaces. Previous work SWISH [7] has shown that an actively shifting weight that moves with the virtual liquid's center of gravity can give the tactile sensation of virtual fluids in vessels; however, the actuation mechanism is not adaptable to different vessel shapes and the size of the device is too large for smaller scale VR use cases.

We introduce Geppetteau, a novel haptic device that affords users with a wide range of tactile sensations related to handling virtual liquids in VR. Figure 1 illustrates an overview of the system. Geppetteau revolves around a string-driven apparatus inside of a swappable 3D printable vessel enclosure; as a user interacts with a vessel, the system actively pulls the location of an active mass inside the vessel (red sphere) to dynamically follow the center of gravity (CoG) of the simulated liquid in the vessel.

Geppetteau offers adaptability for different vessels unlike previous rack-and-pinion systems, e.g., SWISH [7]. It's string-driven nature of the system allows Geppetteau's weight-shifting mechanism to integrate inside a wider range of 3D-printed vessel shapes with convex hulls, including conical, cylindrical, spherical and cuboid shapes. Additionally Geppetteau offers one-handed interactions with the vessel shapes as Geppetteau's size is a significant 83.5% decrease in volume when comparing Geppetteau's cylindrical vessel to that of SWISH's[7].

2 GEPPETTEAU DEVICE

Our Geppetteau system is designed to provide haptic compliance for fluid sensations, an adaptive design to fit familiar vessel shapes and recomposable software/hardware integration. Researchers have explored tensioning cables to provide haptic kinematic forces [9] [4] [5]; however, to the best of our knowledge we are the first to use string-driven actuation to provide haptic sensations of virtual fluids. The main contribution of this work is to use a string-driven mechanism to move an active mass around inside a vessel profile.

In response to our design needs, we design the Geppetteau system. Geppetteau's string-driven mechanism is made up of 3 motors

Figure 2: Geppetteau provides sensations of handling virtual liquids in various vessels. (Left to Right) Conical, Cylindrical, Spherical, Cuboid.

with spool shaft attachments to draw the active mass along axial (one motor at the top) and radial dimensions (two motors attached to a rotary base) while a fourth DC motor rotates the rotary base. The string-driven nature of the system allows Geppetteau to be integrated inside in a range of vessel shape profiles, including conical, cylindrical, spherical and cuboid shapes, augmented with Geppetteau's actuation mechanism. Additionally, Geppetteau leverages the inherent slack of the string in combination of gravity to have the active mass reach locations within the vessel.

We construct software interfaces to integrate Geppetteau vessels into virtual environments through game engines, e.g., Unity/Unreal, enabling the fluid simulation in such engines to drive the center of gravity of the simulated liquid, as shown in Figure 2. Altogether, this provides the force feedback sensations necessary to simulate virtual fluids in the handheld vessel.

3 APPLICATIONS

We envision our device integrated into virtual experiences in education (such as chemistry experiments[1]), training and entertainment scenarios to provide the tactile feedback of handling virtual fluids. Our Geppetteau device is not only able to actuate different fluid behavior but also fluid chemical reactions such as changing viscosity and bubbling. Even when the gravity of the virtual world is changed, our device can simulate the fluid behavior in the new environment.

We aim to expand the possibilities for fluid interactions in VR. With Geppetteau, we demonstrate a novel haptic device which affords users a wide range of tactile sensations for handling virtual fluids in VR. Geppetteau uses striven-driven actuation to move an active mass to follow the center of gravity of the virtual fluid. It can also actuate different fluid behaviors for a variety of vessel profiles.

ACKNOWLEDGMENTS

We would like to thank the National Science Foundation for supporting this work under Grant No. 1917912. We'd also like to thank the School of Arts, Media and Engineering (AME) at ASU for Fabrication Lab support.

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