Fillables: Everyday Vessels as Tangible Controllers with Adjustable Haptics

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Abstract

We introduce *Fillables*: low-cost and ubiquitous everyday vessels that are appropriated as tangible controllers whose haptics are tuned ad-hoc by filling, e.g., with water. We show how Fillables can assist users in video navigation and drawing tasks with physical controllers whose adjustable output granularity harmonizes with their haptic feedback. As proof of concept, we implemented a drawing application that uses vessels to control a virtual brush whose stroke width corresponds to the filling level. Furthermore, we found that humans can distinguish nine levels of haptic feedback when sliding water-filled paper cups (300 ml capacity) over a wooden surface. This discrimination follows Weber's Law and was facilitated by sloshing of water.

Author Keywords

Tangible User Interfaces; Ubiquitous Computing; Appropriation; Everyday Objects; Up-and-Down Transformed Response (UDTR); Weber's Law

ACM Classification Keywords

H.5.2 [Information Interfaces and Presentation]: User Interfaces – Haptic I/O.

General Terms

Human Factors, Design

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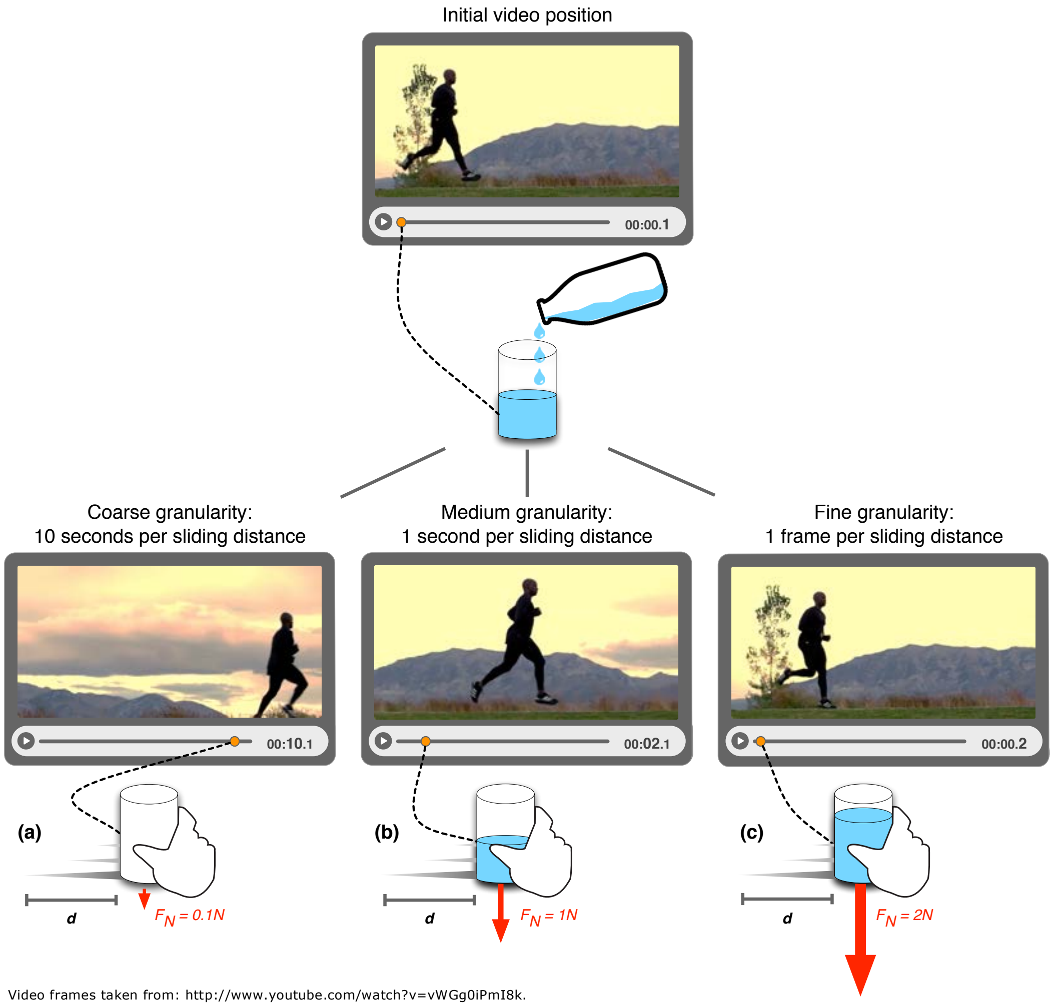

Video frames taken from: http://www.youtube.com/watch?v=vWGg0iPmI8k.

Figure 1. A drinking vessel ("Fillable") mimics a virtual slider knob to scroll through a video at different granularities based on the water level. The same sliding distance *d* navigates the video in (a) ten-seconds, (b) one-second, and (c) one-frame increments. A full vessel is heavier and can be slid with more precision than an empty (lightweight) one. Since the user can feel these differences when sliding the vessel on the table, Fillables make virtual granularity tactile. Weight is given in normal force (F_N).

Introduction

Media professionals frequently use dedicated physical controllers for tasks that require many levels of precision, many repetitions, higher degrees of freedom, or concurrent inputs. An apt example is the Shuttle jog dial (Fig. 2), which allows a cutter to navigate a video at different granularities, e.g., in ten frames per step or frame-by-frame.

However, such special controllers are not at everyone's disposal due to their cost and limited applicability. Consequently, this leaves the amateur to rely on classic mouse and keyboard input, which may be less efficient, e.g., when multiple tangible controllers would be a better fit for the task.

Research has addressed this issue by letting users repurpose objects at hand as temporary controllers [2,7]. However, such tangibles are static in their haptic nature. Therefore, we propose *Fillables*: adjustable tangibles that let users (1) control the haptic feel and (2) adjust the transfer function (e.g., scrolling granularity) between the controller and its output. Everyday vessels can be used to physically instantiate controllers, such as sliders or jog dials. By filling them, e.g., with water, the user can tune these tangibles to satisfy both (1) and (2).

For example, an empty vessel can be slid to mimic coarse time-based video navigation (Fig. 1). After filling the vessel, it becomes heavier, hence harder to push. Consequently, the vessel becomes (1) less susceptible to accidental knocks and (2) feels different in control, therefore conveying a change in the transfer function to the user via the haptic channel, whereas the system detects the filling level via weight and adjusts the

Physical buttons can be used to create shortcuts, e.g., to set a cut mark.

Turn the ring around the knob up to 45° clockwise (counter-clockwise) to navigate at different granularity. The more the knob is turned, the faster the video is forwarded (rewound).

Turn the inner knob clockwise (counter-clockwise) to navigate forward (backward) frame by frame. Detents indicate when the next frame is reached (10 detents per whole turn).

Figure 2. ShuttleXpress jog dial. Turning the jog wheel (center) navigates a video frame by frame. The ring around the dial controls the video at different granularities.

navigation granularity accordingly. This way, Fillables let users create multiple physical controllers that are individually adjustable by filling to make haptics correspond to the granularity of the tool – in short: Fillables make granularity tactile.

This work gives first insight into the vision of Fillables. The contributions are: (1) the concept of Fillables: tangibles made of vessels with adjustable haptics through filling, (2) interaction design for tactile granularity including a prototype, and (3) a preliminary study exploring the human ability to discriminate Fillables of different tactile levels by sliding.

Related Work

Some Tangible User Interfaces (TUIs) [9], such as the Inflatable Mouse [10], Height-Adjustable Tangibles (HATs) [14], and Madgets [18], can change their haptic or visual properties on the fly. However, these tangibles are not readily available until being prototyped. Their fabrication requires special material, time, and know-how. Levesque et al. [12] investigated dynamic haptic feedback via friction for direct finger touch. Yet, their technique requires a special friction display. Opportunistic Controls [7], iCon [2], SketchSpace [8], and Rubber Shark [1] overcome prototyping demands by appropriating existing physical objects as tangibles. Yet, they do not feature customization of haptic properties.

Filling level measurement for cups is addressed by MediaCup [6], iGlassware [4], and SurfaceWare [3], but they do not exploit changes in haptic feedback due to changes in filling. SonicFinder [5] uses aural feedback from filling as a metaphor to indicate the progress of file copying on the Mac OS desktop.

Fillables combine *appropriation of everyday objects* with *filling* as a manipulation technique. By using ubiquitous vessels as physical controllers, the process of hardware prototyping is shortened. Physical properties of such repurposed tangibles can be altered ad-hoc by means of filling: A material is used to modify filling height and weight of a vessel, which subsequently alters visual and haptic perception.

Fillables

Interaction with Fillables requires (1) a *vessel* to store physical content, (2) a *filling material* to adjust weight and filling height of the vessel, (3) a technique to sense updates in filling, and (4) *physical manipulation* to sense the haptic feedback generated by a filled vessel.

By sliding, rotating, or lifting the vessel, the user perceives differences in inertia, friction, or weight depending on the filling. Liquids of different viscosity (e.g., water, oil, honey), granules of different size (e.g., sand, salt, M&M's™), or various small objects (e.g., paper clips, pens) could be used. Their different mass densities affect the vessel weight differently.

Using filling as an adjustable parameter to tune the haptics of these appropriated tangible controllers opens new ways for interaction design. Subsequently, we present two exemplary usage scenarios in which the filling level is mapped to the granularity of input. We show how Fillables convey such input granularity via the haptic channel to the user.

Interaction Design: Tactile Granularity

We envision Fillables to act as tangible controllers with adjustable granularity of output through filling. Therefore, Fillables could assist a user with haptic feedback for tasks that require frequent switching of tools, each of which have a certain level of detail or precision. Fillables make each such level tactile by mapping a filling level to a level of precision or granularity. Subsequently, we illustrate two application scenarios in which Fillables act as tangible controllers that transform input granularity to the user via the haptic channel.

Video Navigation

Setting frame-precise cut marks in a video is a repetitive task that requires a coarse-to-fine navigation strategy. Think of an amateur who wants to cut commercial breaks out of a recorded TV show. First, the user roughly skims the video to a scene that is succeeded by a commercial break. Second, she advances within that scene by iteratively increasing precision in navigation until the last frame right before the beginning of the break is identified. To set the next cut mark at the end of the commercial break, all steps must be repeated, such that the user repetitively switches between different levels of navigation precision to set all cut marks. Typically, a GUI would provide multiple widgets (one widget per precision level), e.g., sliders, or a selection tool or technique that lets the user adjust the level of granularity per widget. However, this change in granularity is only conveyed visually to the user. Using a mouse to drag the slider knob always feels the same – no matter what granularity/resolution the virtual slider corresponds to.

Using Fillables as tangible controllers tackles this inconsistency between virtual state and physical feel. Each vessel could represent a physical slider knob that the user drags over a table to browse the video akin to the virtual counterpart (Fig. 1). Depending on the filling level, however, the precision of the slider changes: An empty, lightweight vessel can be slid easily and roughly, thus suitable for *skimming* the video stream. By adding filling material to the vessel, the *Fillable* becomes heavier and therefore harder to push. As a consequence, the user can handle it with more *precision* since that heavier cup is less susceptible to jitter or accidental overshoots that can occur when the user applies too much force. Hence, a filled vessel could be appropriated to navigate the video frame-by-frame. The transfer function used in this scenario would automatically adapt the number of frames to be skimmed for a given sliding distance based on how much water a vessel contains.

Although the Shuttle jog dial can be tuned via software to modify the granularity per turn, the haptics of the device do not change. Fillables, however, do. Adding weight to the vessel not only alters granularity of the input device; it also *feels* different when using it.

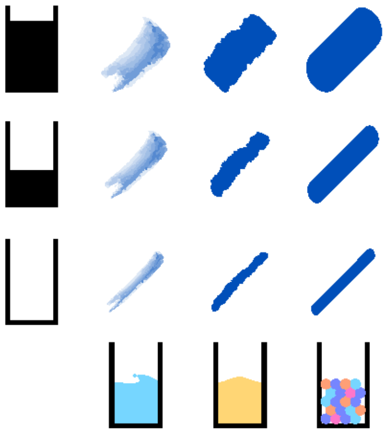

Figure 3. Different levels or types of filling material (water, sand, marbles) can be used to select and to provide corresponding haptics of different brush parameters.

Drawing

Drawing applications often provide adjustable properties, such as line width or brush type. Typically, such properties are re-used, e.g., once when drawing a rough sketch, and again later when adding details. Drawing with Fillables allows users to perceive haptics corresponding to the current brush parameters as shown in Figure 3. The filling level may represent line thickness — fill more material for a thicker line. Similarly, the type of filling material may represent the brush type: fill the cup with water to use watercolor, or fill it with candies for solid strokes. The different tactile feeling may encourage different artistic expression, just as drawing with a brush feels different from drawing with chalk. We envision the user to prepare all vessels before drawing. This way the user can quickly re-grasp a Fillable when needed, such that no (re-) filling is required while drawing.

Since both scenarios exploit sliding Fillables to make granularity tactile, we were interested in how many different levels of granularity humans can discriminate when sliding filled vessels. Therefore, we conducted a user study on haptic perception with Fillables.

Base[ml]	Comparison [ml]			
0	5	10	...	60
50	55	60	...	110
150	155	160	...	210

Table 1. Filling levels [ml] used for bases and comparisons in the UDTR experiment.

Study: Haptic Discrimination of Fillables

In order to understand whether Fillables can assist humans in controlling a user interface, we must investigate human precision in (1) discriminating levels of feedback gained from variably filled vessels, and (2) the process of filling. In this work, we investigated (1) in a small user study.

Two typical ways of manipulating a vessel are (a) sliding and (b) rotating. Lifting is also an option, but can be tedious for the user after some time. Therefore, to exploit *haptic* feedback of Fillables, we were interested in how well humans can discriminate cups by simply sliding or rotating them on a table without looking at them. We hypothesized that the intensity of perceived haptic feedback based on the water volume would conform to Weber's Law [17]. To obtain just noticeable differences[1] (JND) we conducted a preliminary user study based on the 1-*Up-and-2-Down Transformed Response* (1-2-UDTR) [19]. We assumed that (a) causes more sloshing of water than (b) and that sloshing facilitates discrimination.

Setup, Participants, and Procedure

UDTR lets users compare two intensities of a stimulus, one fixed (*base*) and one adjusted based on the user's performance (*comparison*). We used standard coffee paper mugs (designated capacity: 300 ml, weight: 14g with lid) and filled them with water ahead of the study, such that we had three bases and twelve comparisons per base in 5 ml steps as shown in Table 1. A user had to perform six UDTR tests: {sliding, rotating} × {3 bases}, in randomized order.

We asked 12 users (11 males), aged 21–31 (*M* = 25.83, *SD* = 2.69) to participate. A session took less than one hour. Each test consisted of various trials. The user was sitting in front of a table. Each time the user was presented the base and a comparison (sequence randomized), starting with the highest difference, i.e., I_i + 60 ml. The user had to slide (rotate) one cup after another on the table[2] (once, in two opposite directions) and had to identify the cup that contained more water. If she judged right, the same pair of vessels was

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[1] difference required between two stimuli to be discriminable

[2] sliding friction coefficient (paper cup vs. wooden table): μ_k=0.2

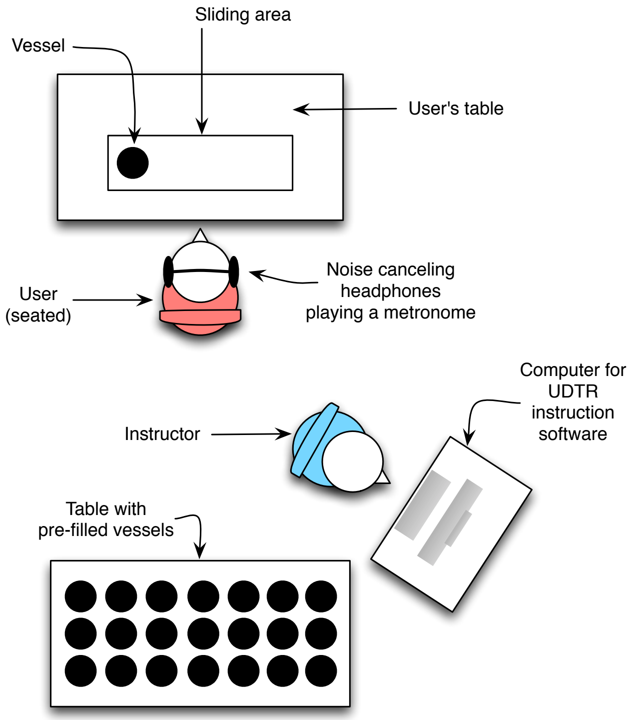

Figure 4. User study setup. The user was facing a wall and wearing noise-canceling headphones while manipulating the vessel. A software guided the instructor which vessel to pass to the user next.

presented to her again, demanding for a renewed judgment to avoid guessing the answer. If she was still correct after the second trial, the comparison was decreased by one step (technically called “2-down”). A wrong answer caused the comparison to be increased (“1-up”) [19]. To save trials, renewed judgment was not started until the user gave the first incorrect response. Judgment exclusively involved the haptic sense: The filling level was neither visible (opaque cups with lids) nor audible while the cups were moved (noise canceling headphones playing a metronome). Figure 4 shows the study setup. A test was completed after six reversals in the UDTR plot (Fig. 5). For each test and user, the JND was calculated by averaging the peaks and valleys from the plot (*Wetherill Estimate*, [19]).

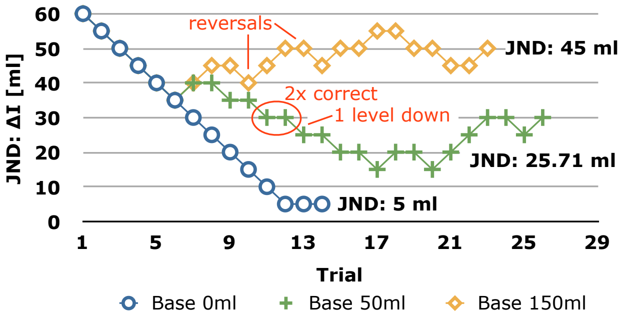

Figure 5. UDTR plot for horizontal sliding (Sample from one user. On average, results were worse.). The user could discriminate paper cups filled with 5 ml vs. 0 ml, 75.71 ml vs. 50 ml, and 195 ml vs. 150 ml.

Step size and range for the comparisons, adequate sliding distance (0.5m), rotation angle (≈180°, rotated from top), and execution speed (48bpm) were determined in a pilot study (five users). Markers on the table and a metronome assisted the testers in maintaining distance and pace to obtain comparable data.

Results

Table 2 summarizes the JNDs and derived thresholds. The results are visualized in Figure 6.

Base [ml]	Sliding JND	Rotation JND
0	16.73 [10.11, 23.87]	17.84 [11.38, 24.29]
50	29.94 [23.87, 36.01]	50.06 [45.47, 54.65]
150	48.27 [46.02, 50.53]	(imperceptible difference)
K_W	21%	64%
θ	17.88ml	–

Table 2. Just noticeable difference (JND) results from the experiment (Mean & 95% CI). Weber Fraction (K_W) and absolute threshold (θ) for discrimination in sliding and rotation were calculated from the linear regression in Figure 6.

(a) Sliding: We calculated a linear regression from the relationship between JNDs and base volumes:

$$\Delta I = 0.21 \cdot I + 17.88 \text{ ml} \qquad (1)$$

The regression had a high correlation (R^2=0.99) indicating Weber's Law [18] behavior. The slope of the regression (Weber Fraction, K_W, here: 0.21) is the ratio between discrimination threshold of a stimulus (ΔI) and base intensity (I). The intercept of the regression (the absolute threshold, θ, here: 17.88) is the additional amount of water to be added such that the user can perceive the difference. Figure 7 summarizes the result: in sliding, the next discriminable cup needs 21% more water from the current cup plus an additional 17.88 ml.

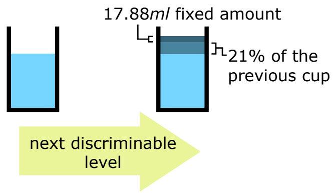

Figure 7. A breakdown of the amount of water needed to create a next discriminable level

From Equation 1, we can derive a recursive function to express the relationship between the volumes of water in two adjacent levels:

$$V_{i+1} = 1.21V_i + 17.88 \text{ ml} \qquad (2)$$

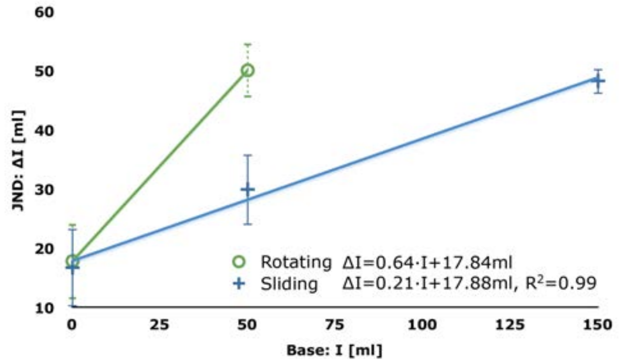

Figure 6. Discrimination results for sliding vs. rotating. Sliding shows Weber's Law behavior. For rotation, 150ml could not be reliably distinguished from 210ml. (Mean & 95% CI)

Using our setup and Equation 2, when starting with an empty cup, V_0 = 0 ml, we can create nine discriminable levels: 0, 18, 39, …, and 302 ml.

(b) Rotation: Discrimination by rotation was worse compared to sliding. For the 150 ml base, 7 out of 12 users were unable to sense the maximum difference of 60 ml. Based on the two bases (0 and 50 ml*)*, we calculated K_W = 64% for rotation. This is worse compared to vertical rotary controls (K_W = 10–20%, [11]). Therefore, with our setup, users can discriminate much fewer levels of cups in rotation than in sliding.

Discussion

Users stated that *"it's hard to tell differences apart only by rotating"* and that *"horizontal movement felt better for judgment"*, as confirmed by the results of the UDTR tests (Fig. 6). This was due to sloshing of water inside the cups, which was perceived more intensely when sliding (*M* = 3.67 vs. *M* = 2.25, 5 is best) compared to rotating: *"Sloshing helped my judgment when sliding* *the cup backwards".* Friction force was also exploited for judgment: "Cups with more water feel harder to push or rotate because of the perceived resistance."

Users' comments and UDTR results show that — unlike sliding — rotation did not allow participants to reliably detect different intensities of haptic feedback for the vessels used in our setup.

Verification

To verify whether our Weber function also holds for bases >150 ml, we asked 10 users (9 males) aged 21–32 (M = 25.50, SD = 2.95) to arrange nine cups in order of ascending filling level by sliding the cups across the table. Eight users arranged all cups correctly. One user mixed up the 236 and 181 ml cup and another user mistook the 135 ml vessel for the 97 ml vessel. Hence, 80% of the participants managed to put cups in ascending order just by sliding them over the table in pairs. This confirms our UDTR study, which had revealed that users can discriminate nine levels correctly at least 70.71% of the time (tested correctness for 1-2-UDTR tests [19]).

Prototype: Drawing with Fillables

Inspired by the second application scenario and as proof of concept, we created a drawing application that repurposes cups as physical pencils. Based on the amount of filling, the virtual line width changes. In an informal user study, we tested two different mappings (line thickness increases vs. decreases with rising fill level) whose results we will report below.

We used paper cups with paper fiducials on their lids to track cup position by camera and to map it to the tip of a pen on a virtual canvas. Whenever the user held a modifier key on the keyboard and moved the cup, the same trajectory was drawn on screen. We filled five cups with water ahead of the study (0–300 ml, equidistant step size of 75 ml) and put them all on a USB-powered postal scale[3] (Fig. 7). When a cup was lifted off the scale and put on the desk for drawing, the total weight on the scale decreased, which was used to infer the fill level of the cup. However, in this preliminary study, we tested five discrete levels with pre-filled vessels. We tested two different mapping directions: (a) 5pt → lowest filling level, …, 25pt → highest filling level, (b) 5pt → highest filling level, …, 25pt → lowest filling level. Remaining line thicknesses were mapped ascending (a) or descending (b). We let ten users draw in both conditions without mentioning the mappings. The testers were free to play around with the "pens" and draw images. Before a different cup was used, the previous one had to be put back on the scale.

All users identified the mappings correctly by themselves. Mapping (a) was preferred over (b) (9 vs. 1) and considered more intuitive: *"Heavier cups cause more pressure on the table. Like in real drawing, putting more pressure on the brush causes bigger footprints."*, one user commented. The user who preferred (b) associated a thin line thickness with precision in drawing, which was better with a heavy cup since it is less prone to accidental knocking than a lighter cup.

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[3] Although we could have used different fiducials to statically identify the pre-filled vessels, the scale allows us to detect any filling level, which could be useful for future experiments.

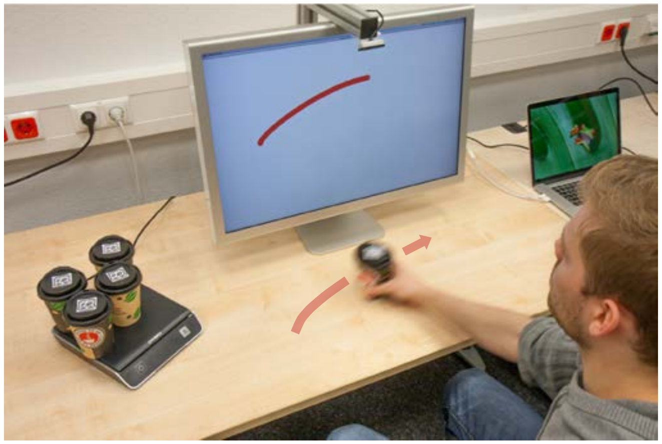

Figure 7. Drawing with Fillables. Paper cups with fiducials attached to the lids were tracked by a camera to draw on screen. Based on the amount of water in the cup, the line stroke varied. After drawing, a cup were placed back on the scale (left), which was used to identify fill levels via weight. The scale display was not visible to the user.

Conclusion

We introduced *Fillables*, a ubiquitous, low-cost way of providing users with tangible controllers whose contents and fill levels the user can change ad-hoc such that output granularity of the physical controller harmonizes with its haptic feedback. We presented two application scenarios in which the user could benefit from the tactile granularity perceived by sliding: Video navigation and drawing. In this context, we conducted a user study to understand how many levels humans can discriminate eyes-free by sliding based on the amount of water in a paper cup (designated capacity 300 ml). Discrimination followed Weber's Law. Users were able to detect nine different levels of haptic feedback, exploiting the additional effect of water sloshing inside the cups while sliding. As proof of concept we created a drawing application that uses vessels as pens whose stroke width corresponds to the fill level of the cup. The prototype and the user study showed that everyday vessels can be used as low-cost tangibles to convey virtual granularity to the user via the haptic channel. Weber's Law behavior for the discrimination of filled vessels used in our setup gives grounds for hoping that the law also applies to other combinations of vessels, filling materials, and surfaces.

Limitations and Future Work

After these initial explorations, we intend to study the act of filling tangibles in depth. While filling needs time, it is a one-time process: Once prepared for a task, the user can re-grab Fillables whenever needed. Yet, manual filling is not trivial: the weight differences a user creates may not be big enough to be discriminable by sliding. This inconsistency might confuse the user. To overcome these issues, we will look into controlled filling/draining aids that help filling/emptying the vessels and minimizing spillage. This mechanism will also allow actuating Fillables.

Although fillable vessels and their modification are ubiquitous, the local sensing of the vessel and its weight as well as the connection of Fillables to an interface are still dependent on a specific setup, such as USB scales or optical tracking technology. However, integrating force sensors (e.g., [15, 16]) into desk pads could provide a ubiquitous solution to sensing both cup position and weight. In addition, we will investigate an end-user programming approach to map Fillables to standard GUI widgets of any application.

Furthermore, we planned to compare human sliding precision between Fillables, a finger on a touchscreen, a stylus, and a mouse. This will shed light on the quality of input and the fluency of user experience, e.g., in drawing tasks, and opportunities in future interaction designs for Fillables.

Acknowledgements

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