# A Geometric Approach for Partial Liquids' Pouring from a Regular Container by a Robotic Manipulator

Jeeangh Jennessi Reyes-Montiel[a], Antonio Marin-Hernandez[b] and Sergio Hernandez-Mendez[c]
*Artificial Intelligence Research Institute, Universidad Veracruzana, Calle Paseo No. 112, Xalapa, Mexico*

Keywords: Partial Liquids Pouring, Autonomous Mobile Robots, Geometric Control.

Abstract: Partial liquid pouring is a very useful task in many environments; however, it is still a very challenging task for autonomous mobile robots. In this work, is presented a geometric approach to accurately partial pouring by autonomous robots. While diverse approaches propose to deal with this problem measuring liquid's volume at destination container, in this work is analyzed the geometry and initial volume of liquid at pouring container, i.e., liquid's volume and container characteristics are known. Then based on the transversal sections volumes' is proposed to control pouring. Proposed approach computes the cross-section areas formed by liquid in the container when this is tilted an angle $\theta$. The geometric analysis shows that an angle-based linear control does not guarantee a regular flow to perform an accurate liquid control, since cross-sectional volumes have not linear relation with the angle $\theta$ when tilted. As it is show in this work, these volumes increase and decrease according to the tilted angle and the container characteristics. To effectively obtain a regular flow those volumes should be considered in the control phase as here is proposed.

## 1 INTRODUCTION

Many abilities on autonomous mobile robots and particularly on service robots have been implemented and developed over last years. Nowadays, autonomous and service robots can realize diverse tasks on many different environments in a very successful way. Mobile robots can: mapping their environments, determine and execute trajectories, avoid fixed and moving obstacles, detect, recognize, and interact with users or other systems, and manipulate correctly diverse objects; all these very important and required tasks for successful service robots. However, and despite of robots can effectively pour liquids from one container to other, generally this task is done in very controlled environments and pouring the complete or fixed amount of liquid. The pouring of partial and varying quantities of liquids is still a challenging task for service robots.

To successfully perform this task, most approaches require the detection and monitoring liquid's level, process generally done at destination container. The problem lies mainly due to the different geometries of the containers, great variety of liquids and particularly by the intrinsic characteristics of them (Do and Burgard, 2019). This task, generally solved by humans by reinforcement learning, is very important in many human environments; so particularly, robots and service robots should have the ability to deal with it. Moreover, in such environments, humans often don't specifically make precise measurements of the liquids they wish pour; for it, sometimes they use the relation to some containers *e.g.,* a cup or a glass for measure a specific amount of liquid (Schenck and Fox, 2017). Or, on the other hand, people usually use subjective and undefined measures, which are generally mentioned in expressions such as: "pour me a little more than half a cup of coffee" or "just a little bit, please". Humans can deal with language inaccuracies and are sufficiently able to learn complex tasks as partial pouring of fluids.

Solving such a task requires a robust motion control, as well as a very accurate liquids characteristics detection. However, for a robot, it is not easy to carry out this task due to the complexity of fluids dynamics modeling (Schenck and Fox, 2017), (Pan and Manocha, 2016).

In this work, is presented a special case of fluid handling, specifically the problem of pouring a particular quantity of liquid from a known container to

[a] https://orcid.org/0000-0003-3194-914X
[b] https://orcid.org/0000-0002-7697-9118
[c] https://orcid.org/0000-0001-9997-9690



Reyes-Montiel, J., Marin-Hernandez, A. and Hernandez-Mendez, S.
A Geometric Approach for Partial Liquids' Pouring from a Regular Container by a Robotic Manipulator.
DOI: 10.5220/0011321600003271
In *Proceedings of the 19th International Conference on Informatics in Control, Automation and Robotics (ICINCO 2022)*, pages 688-694
ISBN: 978-989-758-585-2; ISSN: 2184-2809

another (unknown). To achieve this task a geometric approach has been developed, which is supported on a simplified hydro-dynamic model. To validate our approach some tests on simulation environments are presented.

This work is organized as follows. In next section some important works related to the spill problem is described in the next section. Subsequently, in section 3 it will be described the proposed geometric approach to solve the spillover problem. Then, in section 4 presents the results obtained from the simulation. Finally, at section 5 the conclusions are presented.

## 2 RELATED WORKS

The problem of precise liquids' pouring has become very important in recent years There are many applications both industries and diverse sectors as: commerce or services.

For example, in metallurgy industry is a very common and important task, where it is required to maintain a constant flow to prevent oxidation, air entrapment and erosion on metals (Noda and Terashima, 2006), (Noda and Terashima, 2007). To deal with such problem in (Castilla et al., 2017) is presented an approach to automate liquids pouring from a tilting ladle. Considering only the tilting ladle in motion, it is proposed to rotate the ladle at an angular speed prescribed by a geometric and dynamic calculation to keep the discharge flow constant. To simplify the geometry ladle is considered as a cylindric recipient with circular weir. The resulting angular velocity was used as input for a set of computational fluid dynamics simulations to later calculate the trajectory of the spilled liquid. In (Sueki and Noda, 2019) it is developed an improved model, initially proposed in (Sueki and Noda, 2018), to pour molten metal in a container by controlling the tilting ladle. The process is achieved using a spill flow feedback control to improve tracking performance. The discharge flow rate is computed by using an extended Kalman filter and controlled using a PID scheme. The proposed approach has been applied at laboratory with a pouring robot.

Other approaches use physical models of simplified dynamics; for example, in (Pan and Manocha, 2016), is presented an approach using intrinsic properties of liquids to transfer them with a robotic manipulator from a container to another avoiding with it, the high-cost solution of Navier-Stokes model. A motion planning algorithm is then used to compute a smooth and collision-free trajectory (Park et al., 2012), (Ratliff et al., 2009), (Pan et al., 2016). The simplified parameter set, and dynamic model is restricted to the task of slow-rate liquid transfer. When the end-effector is moves too fast, the motion described could be far from planned trajectory. This approach pours the complete content of one recipient to another.

To pour partial amounts of liquids, in (Do and Burgard, 2019) it is proposed to control pouring liquid level directly at destination recipient; for which, authors propose, on one side to determine stoppage using depth data from a low cost RGB-D camera and on the other side, adapting pouring speed based on liquid's level at destination. With the use of an infrared light, authors overcome the problem of liquid's level detection for different transparency and refractive index of liquids like water, oil, or milk.

Spilled estimation is very important task when pouring specific quantities. In (Matl et al., 2019) it is proposed a method to pour liquids through haptic sensing. In this work, initially a robot moves a container through a series of tilting movements and observes the twists induced in the manipulator's wrist while the liquid's center of mass scrolls. It is showed that with haptic signals and a physics-based model it can be obtained a high-precision estimate of liquids' mass and volume in a cylindrical container. Additionally, it is provided a framework for estimating fluid viscosity.

The geometric characteristics of the container are also important, for example in (Kennedy et al., 2017) is proposed a method to autonomously dispense a precise amount of liquid using visual feedback. Authors model diverse geometrical containers, showing that, in particular for square base prisms the flow can be controlled by observing the height of the fluid in the receiving container. This approach to pouring control is not smooth and calibration of the target container is required.

Finally, in (Dong et al., 2019) are proposed two approaches to control the movement of a service robot as it accurately pours liquid from one unknown container to another unknown container without the need for external tools. The first proposal focuses on measuring the height of poured liquid in the target container. In this case, the action is controlled using a PD controller, which considers the angular velocity of the pouring vessel as a process variable and the volume poured as a control variable. The second method focuses on the pouring container. The volume poured is calculated using the relationship between the angle of the pour container and discharged volume. The action is controlled with a simple proportional controller that takes the angular velocity of pouring vessel

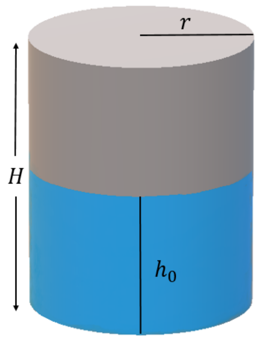



Figure 1: Initial assumptions: a known cylindrical container with a known liquid of initial height $h_0$.

as the process variable and target angle as the control variable. For it, it is only used sensor inputs from an RGB-D camera on the robot's wrist. To perform the tests, both methods are implemented in a double-arm robot system and the results show that accurate pouring is obtained in both methods.

This work focuses on pouring specific quantities of liquids, through the analysis of the geometry of pouring container particularly cylindrical containers. Physical properties of liquids, such as laminar flow is also considered. In such a way that smooth control be achieved when pouring liquids. In next section, analysis of the geometric model will be described.

## 3 GEOMETRIC MODELING

In this section, the geometrical approach to model and control partial pouring is presented. Following assumptions are considered:

1. A cylindrical container of height $H$ and radius $r$.
2. The initial liquid's height inside the container is $h_0$.
3. Liquid's density is considered known.

Therefore, the following statements can be stablished. The robot always uses a known pouring container. Initial volume of the liquid in the container can be determined and this is considered known, e.g., water, milk or sirup. Additionally, robot is requested to pour specific quantities of liquid, e.g., beginning with $200ml$ and then $50ml$. And finally, to be able to compute precisely liquid poured, the pouring process must ensure a laminar flow, in other words, the robot should not do sudden motions to avoid turbulences.

### 3.1 Spilling Angles

Initial and final pouring angles can be easily determined by the problems geometry.

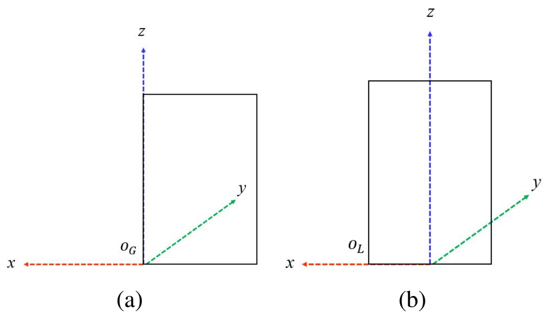



Figure 2: References frames. a) Global reference frame and b) local reference frame.

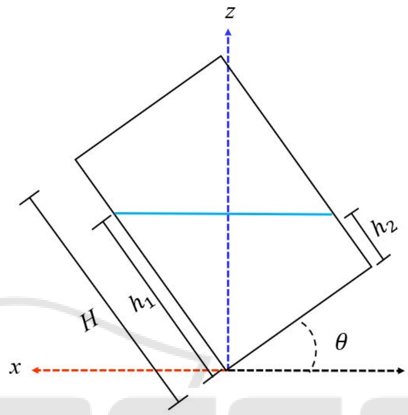



Figure 3: Cylinder with an inclination θ.

The total volume of the container is given by: $V_T = \pi r^2 H$,

and similarly, the initial volume of the liquid is given by: $V_{init} = \pi r^2 h_0$.

As showed on Figure 2, two reference frames are considered: a) the global reference frame, which by simplicity is placed at the tilting corner of the container and denoted by $O_G$, and b) the local reference frame placed at the bottom center of the container and denoted by $O_L$.

To find the spill angle $\theta_s$, it is necessary to analyze the geometry and rotation around $O_G$.

When container slopes an angle $\theta$ and the liquid inside changes its shape (Figure 3), it can be verified that:

1. Liquid's height in the local reference frame $O_L$ is composed by the average of two heights $h_1$ and $h_2$, corresponding to both sides of the cylindrical container, where $dh$ is the difference between them.
2. The form of liquid's surface goes from a circle at $\theta = 0$ to an ellipse with major axis $2a$ at $\theta > 0$.

Then, when $h_1 = H$ liquids begins to spill and then $\theta_s$ can be determined by:

$$tan\theta_s = \frac{H - h_0}{r}. \tag{1}$$

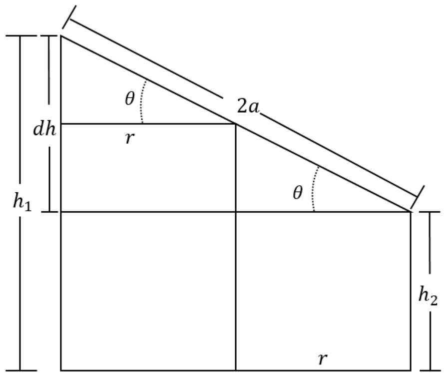



Figure 4: Geometric analysis of the shape acquired by liquid when tilted at an angle θ.

Figure 5: Liquid surface visualization (surface ellipses formation).

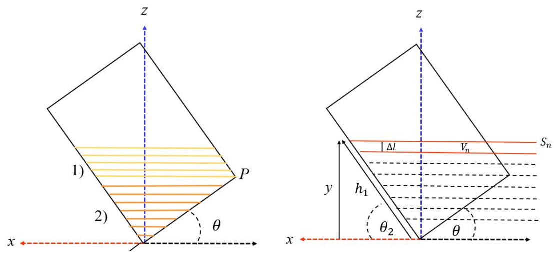
Similarly, to obtain the final spill angle $\theta_f$, it can be determined considering the difference $dV$ between the liquid's initial volume $V_{init}$ and poured volume $V_P$, then computing the corresponding height $h_{dV}$, the angle is given by:

$$tan\theta_f = \frac{H - h_{dV}}{r}. \quad (2)$$

## 3.2 Transversal Sections Volumes

As described previously, in order to compute accurately poured liquid's volume is very important to get to make a smooth control to avoid a turbulent flow.

It can be observed that the surface of the liquid forms ellipses when it is inclined at an angle $\theta \neq 0$. And as showed in figure 6, two regions can be distinguished; the first region above the point P, in which it can be seen that, ellipses formed are complete, and a second region, below the point P, where it can be seen that the ellipses are trimmed.




(a) (b)

Figure 6: Geometry considerations. a) Region 1 in yellow and region 2 in orange, and in (b) Volume discretization.

### 3.2.1 Determination of the Transversal Volumes at First Region

Being $S_n$ as the area of liquids' surface as described in Figure 6b, and considering a height discretization into $n$ similar intervals of height $\Delta l$ in the global reference frame, then it can be considered the volume of a transversal section as:

$$V_n = S_n \Delta l \quad (3)$$

where $\Delta l$ is related with liquid's viscosity.

The total volume will be the sum of all transversal volumes, as follows:

$$V_T = \sum_{i=1}^{n} V_i(\theta) = \sum S_i \Delta l = S_i \Delta l n. \quad (4)$$

It is important to note that, the volume of each segment is a function of tilting angle, as following:

$$V_n(\theta) = \frac{\pi r^2 \Delta h}{cos\theta}. \quad (5)$$

### 3.2.2 Determination of the Volume at Second Region.

Below point P and due to geometry of tilted container, surfaces ellipses are incomplete as described in Fig. 8. Moreover, to determined transversal volumes below point P, it is important to note there are two subregions. One above $O_L$ and the other one below $O_l$

Remembering that, the last complete ellipse formed will be at $h_2 = 0$ (this point is referenced as $P$) as showed in Figure 7, then below this point, all ellipses formed will be cut in relation to the semi-major axis, as shown in figure 8.

It is required to find the parameter $a_c$ that determines the cuts of these ellipses. Since $a_c$ cuts reduce ellipses according to the semi-major axis, this value will have a constant of proportionality being $a_c = \alpha$, where $\alpha$ is:

$$\alpha = \frac{y}{y_p(\theta)} = \frac{y}{rsin\theta} \quad (6)$$

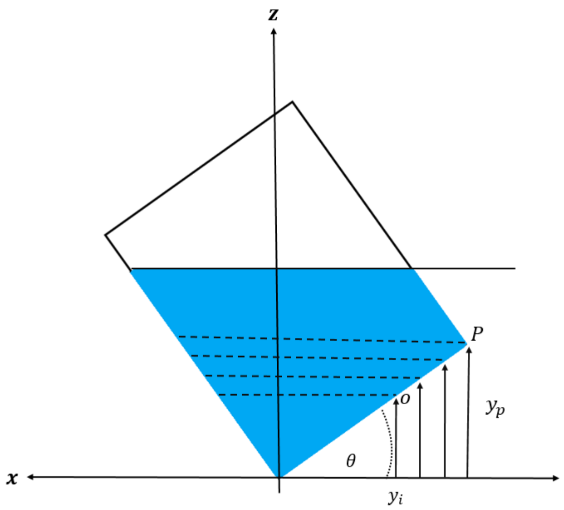


Figure 7: Ellipses cut below point P ($o \rightarrow r$).

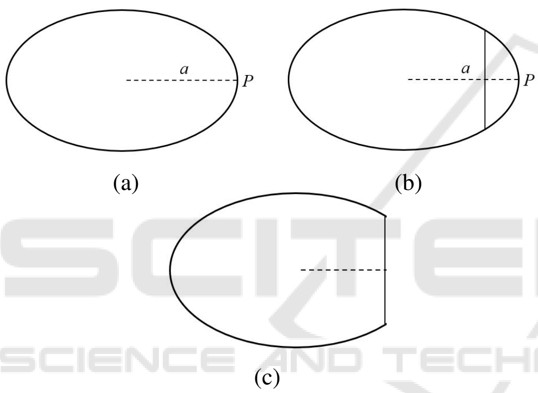


Figure 8: Geometry cut: a) Complete ellipse, b) section to cut and c) final area.

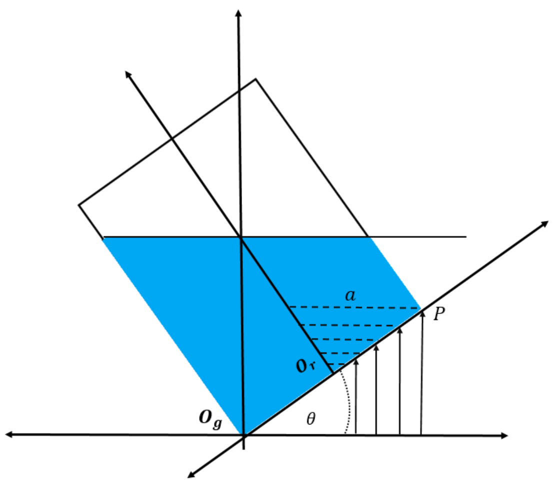


Figure 9: Geometry of the tilted container at the region $r \rightarrow 0$.

where $y$ is the height of the container from the base of $O_L$ frame to an angle θ and assuming the following

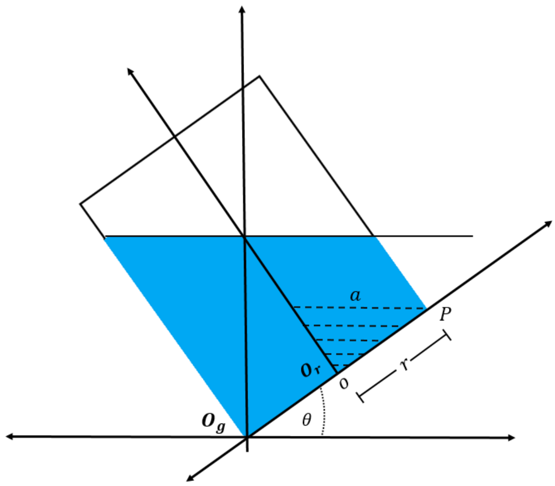


Figure 10: Intervals from 0 to r.

condition $y \leq r sin\theta$.

Below point $P$, ellipses formed are not only cut, but also deformed. This is due, particularly by the implicit geometry of this section. At this stage of the work, this subregion is not considered. So, a hard constraint is considered, and is that nor the initial liquid volume nor the final volume is inferior to $h < r$.

From analysis of transversal sections, it can be seeing that volumes increase until $h_2 = 0$, then volumes of transversal sections decrease. Then, to get a soft pouring it is required a function of these transversal sections in order to get a regular flow and then estimate accurately poured volume.

## 4 PRELIMINARY RESULTS

The proposed approach has been validated by performing some tests over simulation environments, as showed in Figure 11. As it can be seen, from figures (b) to (f), at the first region, as it has been described in section 3.2.1, the transversal section area increases in function of the tilted angle. However, this relation is not linear, thus the change in volume of corresponding section is neither.

Moreover, at region two, the ellipses formed are cut as it has been described previously; decreasing the transversal section area while tilted angle increases, thus volumes of corresponding sections also decrease.

Therefore, and considering a close relation between the volume of the cross section and the viscosity, to get a regular flow, it is necessary to control pouring according to volumes' change of mentioned sections.

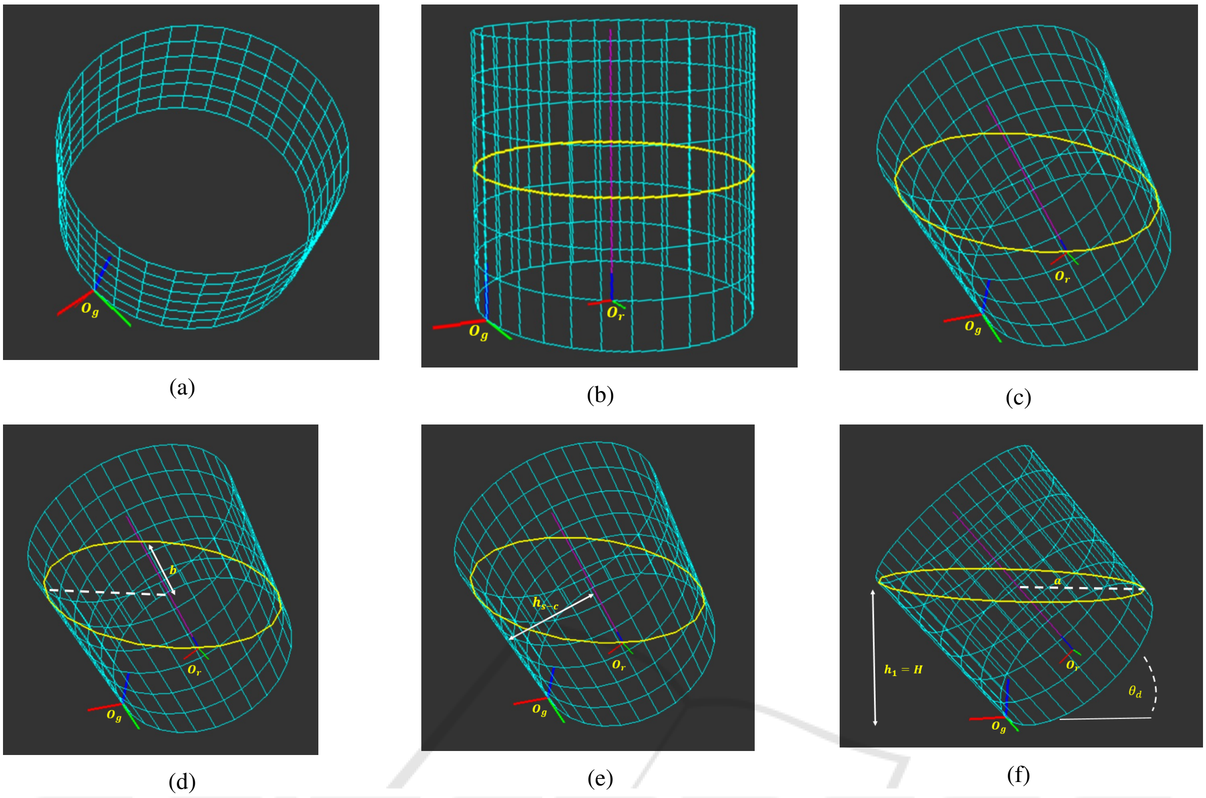



Figure 11: Simulation environments: a) cylindrical container, b) reference frames, c) elliptical liquid surface, d) semi-minor and major axis at ellipse, e) height of the liquid, and f) initial pouring point.



## 5 CONCLUSION

In this work, a geometrical approach to pouring specific quantities of liquid was presented. The proposed approach considers the variation of cross-sectional areas formed by the tilted container to control pouring. Based on the geometry analysis exposed, it has been showed that a linear angular control does not assure a regular flow. Therefore, to get a regular flow it is required to consider the two regions described, when areas and corresponding volumes increase, at region one, and when they decrease, at region two. It is important to note, that both regions occurs while $\theta$ angle is increasing, proving that linear angular control is not enough to get a regular flow.

In future works, experiments on real autonomous robots will be done, considering different liquid's viscosity, quantities and diverse shape containers.

## REFERENCES

Castilla, R., Gamez-Montero, P. J., Raush, G., Khamashta, M., and Codina, E. (2017). Numerical study of impingement location of liquid jet poured from a tilting ladle with lip spout. *Metallurgical and Materials Transactions B*, 48(2):1390–1399.

Do, C. and Burgard, W. (2019). Accurate pouring with an autonomous robot using an rgb-d camera. In Strand, M., Dillmann, R., Menegatti, E., and Ghidoni, S., editors, *Intelligent Autonomous Systems 15*, pages 210–221, Cham. Springer International Publishing.

Dong, C., Takizawa, M., Kudoh, S., and Suehiro, T. (2019). Precision pouring into unknown containers by service robots. In *2019 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, pages 5875–5882.

Kennedy, M., Queen, K., Thakur, D., Daniilidis, K., and Kumar, V. (2017). Precise dispensing of liquids using visual feedback. In *2017 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, pages 1260–1266.

Matl, C., Matthew, R., and Bajcsy, R. (2019). Haptic perception of liquids enclosed in containers. In *2019 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, pages 7142–7149.

Noda, Y. and Terashima, K. (2006). Nonlinear modeling with hydrodynamics and flow control using inverse pouring dynamics of tilting-ladle-type automatic pouring process. In *Proceedings of the 67th World Foundry Congress*, volume 207, pages 1–10.

Noda, Y. and Terashima, K. (2007). Falling position control of outflow liquid for automatic pouring system with tilting-type ladle. *IFAC Proceedings Volumes*, 40(11):53–58. 12th IFAC Symposium on Automation in Mining, Mineral and Metal Processing.

Pan, Z. and Manocha, D. (2016). Motion planning for fluid manipulation using simplified dynamics. In *2016 IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, pages 4224–4231.

Pan, Z., Park, C., and Manocha, D. (2016). Robot motion planning for pouring liquids. In *ICAPS*, pages 518–526.

Park, C., Pan, J., and Manocha, D. (2012). Itomp: Incremental trajectory optimization for real-time replanning in dynamic environments. In *ICAPS*.

Ratliff, N., Zucker, M., Bagnell, J. A., and Srinivasa, S. (2009). Chomp: Gradient optimization techniques for efficient motion planning. In *2009 IEEE International Conference on Robotics and Automation*, pages 489–494.

Schenck, C. and Fox, D. (2017). Visual closed-loop control for pouring liquids. In *2017 IEEE International Conference on Robotics and Automation (ICRA)*, pages 2629–2636.

Sueki, Y. and Noda, Y. (2018). Operational assistance system with direct manipulation of flow rate and falling position of outflow liquid in tilting-ladle-type pouring machine. In *Proceedings of the 73rd World Foundry Congress, Cracow, Poland*, pages 23–27.

Sueki, Y. and Noda, Y. (2019). Development of flow rate feedback control in tilting-ladle-type pouring robot with direct manipulation of pouring flow rate. In *ICINCO*.