Momentum Transfer From Preshape to Grasping

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I. INTRODUCTION

The initial effect of contact forces and moments generated upon landing of the fingers onto the object gives the object initial rotation and translation tendencies due to momentum transfer upon impact. This momentum transfer approaches generated from the fingers is related with the hand preshaping to the proper initiation of the grasping task. For that reason, preshaping is an important issue in order to determine the suitable orientation and landing momentum transfer as a continuum from preshaped to grasping. In our work, we aim at triggering a motion on the object by the approaching phase of a preshaped robot hand that will be subsequently suitable to the initiation of a desired manipulation task after grasping. Consequently our specific objective in this paper is to generate a desired moment distribution on an immersed object by the controlled approach of a hand preshape so that the generated moment triggers the desired object rotation and translation to be used as the initialization of the manipulation task of that object by the robot hand.

The literature abounds with works on the different phases of dexterous manipulation: grasp planning, approach, grasping and manipulation [1],[2]. These works generally rely on heavy constraints brought to the grasping problem such as dexterity of the manipulator and object properties and provide solutions within this constrained framework [3]. However, last years have seen few attempts to bridge the everlasting gap between preshaping and landing on an object to grasp and manipulate [4]. Moreover, to the extent of our knowledge, no work has bridge this gap, yet, within the power of a single "preshaping to grasp" model. Our objective is to use fluidics to model momentum transfer phenomena and bridge within the continuum of a single model (namely fluid dynamics), all the phases from 1) preshaping of a multi-fingered hand during the approach of an object, 2) to the initial momentum distribution generation on the object surfaces upon approach, leading to the preparation of the object for motion, 3) to the actual landing of the fingers, initializing the task by the motion tendencies obtained from where the momentum transfer left off the approaching preshape now contacting the object.

Towards this end, we propose in our work, a new model based on computational fluid dynamics, for determining the continuity in momentum transfer from robot hand fingers to the fluid medium, and to the object, until landing on that immersed object. Our experimental results demonstrate how different hand preshapes initiated from different locations in the medium surrounding an object of different cross sections suspended in equilibrium in the fluid, affects its motion tendencies in terms of rotation and translation. Our further contribution, in this paper, includes the modeling of robot fingers and object as fluidic elements which rigidity can be relaxed to induce compliance.

II. METHODOLOGY

Computational fluid dynamics (CFD) is a sub-discipline of fluid mechanics that enables to model fluid flows by solving governing equations which are described by a set of differential widely known Navier-Stoke equations [5]

$$\frac{\partial \rho}{\partial t} + \nabla.(\rho\,\vec{v}) = 0 \tag{1}$$

$$\frac{\partial}{\partial t}(\vec{\rho}\vec{v}\ ) + \nabla.(\rho\vec{v}\vec{v}\ ) = -\nabla P + \nabla(\ \bar{\bar{\tau}}) + \rho\vec{g}\ + \vec{F} \tag{2}$$

where ρ is the density, P the pressure, $\vec{v}$ the fluid velocity vector, ∇ the gradient operator, $\rho\vec{g}$ the gravitational body force, $\vec{F}$ external body force and $(\bar{\bar{\tau}})$ the stress tensor. The first differential equation (1) represents the conservation of mass in Lagrangian form considering density changes in the fluid continuum within the control volume, the mass contained in the control volume remaining constant over time. The momentum equation (2) is composed of pressure gradient and body forces with the stress tensor, detailed as;

$$\bar{\bar{\tau}} = \mu\left[(\nabla\vec{v}\ + \nabla\vec{v}^{T}) - \frac{2}{3}\,\nabla.\vec{v}I\right] \tag{3}$$

where μ is the molecular viscosity and I unit tensor. The equation underline that the changes of momentum occur due to acting external body force on the entire fluid environment and those external body forces, which are relevant with the pressure gradient, effect the fluid motion in the medium. In our case, external body forces are generated by the closing hand fingers, hitting to medium particles. Our perspective of modelling the momentum transfer during the preshaped landing initiating motion tendencies on an object is best demonstrated for grasping a fully immersed object floating suspended in water. Therefore, the fluid environment medium is modeled as incompressible.

The fluid flow governing equations (1,2) are numerically discretized by using finite volume method. The rate of change of the total amount of fluid characterized as momentum in the control volume is represented as mass flux and pressure values at the surfaces of each finite volume of the fluid cells.

III. EXPERIMENTAL RESULTS

The numerical simulation based on “Fluent” commercial software package runs by solving the continuity and momentum governing equations for momentum transfer generated from the finger motions. The interaction between the fluid and solid boundaries has been performed using dynamic mesh method. The mesh spacing is taken as 0.5 units. A constant laminar viscosity term is used for more stable fluid motion. Unsteady fluid flow analysis has been performed to determine the structure of the dynamic mesh generated by finger motion. The boundary condition of the fingers, object and edges surrounding the environment are particles which connectivity is set as rigid in the result included in

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this section. The time step size for iteration used in the numerical simulation is kept 0.01 where total number of time step is set to 100. In order to get the desired convergent solution, the maximum iteration per time step size is fixed to 20, since this bound is found to be sufficient experimentally. User defined functions (UDF) coded in C are used to generate the finger motion in the fluid medium during the approach of the hand to the object. The DEFINE_CG_MOTION macro is used for creating rotational movement of the finger that lead to transfer momentum to fluid variables.

A. Rotational Motion Tendencies of the square object

Here, the object is left free to rotate. The effect of external forces $\vec{F}_i$ from the fingers to fluidic medium and then from the medium to the object particles are calculated using equation

$$\vec{F}_i = P_i A.\hat{n} \tag{4}$$

where P_i is the center of the cell where pressure is lumped, A is the area of the cell, $\hat{n}$ is the unit normal to the cell. The perimeter of the square object shown to rotate in Fig.1 is composed of 16 cells, each surface partitionned into 4 discrete intervals. The total moment vector around the z-axis is calculated using equation

$$\vec{M} = \sum_i^N \vec{r}_i x \vec{F}_i \tag{5}$$

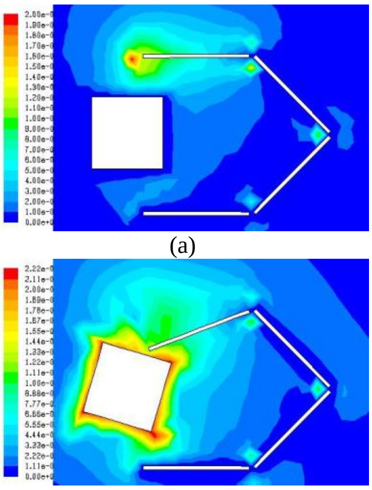
where $\vec{r}_i$ is the level arm of the applied force on a cell, N being the number of the particles. Fig. 1 represents the momentum transfer velocity contours at two consecutive frames, the second one being the landing on the object. The color bar chart in the legend represents the magnitude of velocity of the fluid particles in the medium changing from blue that is the zero velocity to red that is the maximum velocity. The resultant momentum distribution on the square object yields a clockwise rotational motion tendency Fig 1.(b). The clockwise motion is accelerated, as seen for the intensity codes of contour specially due to particle momenta on the upper surface of the object. Table-1 represents the moment distribution on each object surface for each of the 4 surface cells numbered as from left to right and their individual contribution to total momentum vector causing rotation around *z* normal to the surface of the paper, located at the center of gravity.

B. Compliance object modeled as solidified fluid elements

Modeling objects as solidified fluidic elements allows us to relax rigidity for momentum transfer analysis for the case of deformable object towards compliant grasp. Soft boundary particles connected by springs to each other represent the surface cells that partition the object surfaces into small entities. This structure allows object deformation in the virtual environment caused by forces on the object surface generated by rigid fingers approaching the object as shown in Fig. 2. The upper surface is only modeled as deformable fluid particles; the other surfaces are modeled as solidified fluid particles.

IV. CONCLUSION

In this work, a new computational model for investigating the continuum between robot preshapes landing for grasping an object and thus generating the first object motion tendencies to be used in manipulation have been developed. The approach to grasp in a fluid medium has been found to generate the impact force patterns from robot fingers to medium particles and then from these medium particles to the object through analyses based on momentum transfer. We model the continuum of momentum transfer based on fluid dynamics by using finite volume method in order to provide visual simulations.


(a)

(b)

Fig.1 .Contours of velocity for square object at different time during the simulation

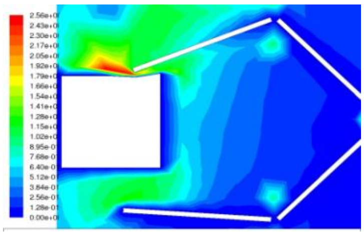


Fig. 2. Object deformation for stiffness constant

Table 1 Moment distribution around the *z*-axis on the square object surface at the center of gravity shown Fig. 1(b)

	Object Surface			
	Top	Bottom	Left	Right
Cell1	3.11	-0.94	0.202	-0.21
Cell2	2.24	-1.17	0.623	-1.16
Cell3	-7.25	-3.38	-1.75	-2.19
Cell4	-11.55	-1.59	-3.59	-3.2
Total	-13.35	-5.08	-3.515	-6.76

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