Momentum Transfer from the Fingers to Object Based on Fluid Dynamics

Baris Ozyer, Ismet Erkmen, Aydan Erkmen

***Abstract*— The initial effect of the impact force patterns on the object for achieving stably grasping is dependent on starting of the movement of a robot hand by taking an optimal preshape. These impact force patterns generated from the changes of the momenta obtained from the fingers lead to motion tendencies of the object. Determining optimal preshape of hand is closely related with the continuum between the initial position of hand preshape and posture of the hand at the contact points on the object. In this paper, we propose a new model for determining continuity momentum of fingers landing on the object based on the fluid dynamics. The commercial computational fluid dynamic (CFD) software package program, Fluent, is used to simulate the compressible fluid flows. The kinematic model of robot fingers and object geometry is created as a preprocessing of fluent. Various scenarios of simple hand preshaping have been applied to the simulation. The experimental results give an idea about how different preshape hand effects to detect the region of contacts while approaching onto an object.**

***Index Terms*—grasping, preshaping, multifingered robot hand, computational fluid dynamics**

I. Introduction

Dexterous manipulation by multi-fingered robot hand initially requires grasping of an object. There have been a number of studies regarding with grasping an object in the literature [1]-[5]. Majority of those is divided the grasping problem into two phases; "reaching to grasp" and "grasping". The investigation of grasping, former phase, are closely related with object properties including size and shape and kinematic redundancies of robot hand. Some of the authors have proposed in detail the force relationship between the fingers and contact points on the surface of the object [6]-[8]. The determining of the appropriate forces with a small number of fingers which can be imparted on the object has been investigated in [9]. There are some researchers conducted on their researches to measure the quality of grasping [10]. Some researchers focus on the analyzing the stability and manipulability formalism for a tactile based redundant robot manipulator [11]. A comprehensive survey for robotic grasping and manipulation can be found in [12]. The latter phase, reaching to grasp, requires initially transport the manipulator to the object location taking with appropriate hand preshaping [1]. The recent studies show that prehasping and transporting are interconnecting each other [13]-[15]. Based on the neuropsychological researches the coordination of transporting and preshaping of hand is dependent on the continuous feedback from the environment such as in [16]. In addition to transporting and hand preshaping of hand, task-object interaction is an important issue that must considered by robotic researchers [17].

Determining appropriate preshaping of hand is necessary to prepare a grasping task for robot [18].The initial effect of impact force patterns generated upon landing of the fingers on the object gives the motion tendencies due to the momentum transfer upon contact [19]. The generated force patterns of the fingers will be changed with time for different hand preshaps because each hand preshapes lands on the objects with different momenta. For that reason, it is important to initialize appropriate hand preshaping before interacting between the fingers and contacts on the object. Therefore, the closing of a preshaped hand should be modeled according to impact force patterns imparted at contacts. However, there are not so many researches related with such an approach in the literature. Many of them deal with the grasp phase after contact occurs.

In our research work, we propose a novel approach to determine the optimal prehshaped hand to generate the motion tendencies of the object upon landing of fingers on the object. The developed approach is based on fluid dynamics that models the momentum transfer from hand preshapes to object contacts. In previous paper [19], we proposed a novel approach for determining continuum between preshaping and grasping based on the Smoothed Particular Hydrodynamics which is a particular based mesh-free computational method for simulating fluid motion. In this study, the developed model is improved by constructing geometric model of the environment and medium occupied by fluid which is divided into meshes. The developed model has been applied to the simulation of various simple robot hand preshaping and objects.

The paper begins with by introducing the problem definition. This is followed by fundamentals of computational fluid dynamics. The geometric model of the environment and meshing procedure is described in the following part. The simulation results are given and discussed in the next section. Finally, conclusion and future work are mentioned in the last section.

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II. Developed Model

A. Problem Definition

In this study, our major goal is to develop a model based on computational fluid dynamics for determining the impact force patterns such as momentum and torques generated from the fingers landing on the object contacts. These force patterns are achieved by mathematically modeling of the medium such as air or water. For this purpose, we propose a model based on the fluid dynamics to compute continuity of grasping behavior of robot hand. The aim is motivated by human like behavior where we preshape and land on object to initiate a certain grasping behavior without losing continuum. The developed model is used to create initial motion tendencies of the object based on the impact forces and torques.

The following assumptions have been made in developing continuum model between the hand preshaped impact and initiation of grasping task.

- Robot fingers, grasped objects and medium are all modeled in fluidic environment.
- Robot fingers and grasped object are modeled as solidified fluid geometry, while the medium is modeled as compressible fluid where volume of fluid is divided into meshes.

B. Fundamentals of computational fluid flows

Computational fluid dynamics (CFD) is a sub-discipline of fluid mechanics that enables to model fluid flows by solving governing equations. These governing equations of fluid dynamics are described by a set of differential Navier-Stoke equations.

$$\frac{1}{\rho}\frac{dp}{dt} + .\nabla u = 0 \qquad (1)$$

$$\frac{du}{dt} = -\frac{1}{\rho}\nabla P + g \qquad (2)$$

where ρ is the density, P the pressure, *u* the velocity, g the gravitational acceleration and ∇ the gradient operator. The first The first differential equation (1), which is the conservation of mass in Lagrangian form, is represented by density of fluid continuum in the control volume. The momentum equation (2) is composed of two force terms; pressure gradient and body forces without considering the viscosity which resist to deformation of fluid flows. The change of acceleration for each particle occurs due to acting external forces (body forces) on the entire of fluid particles. In our case, the external force term is obtained from the closing hand fingers transmitted to the medium.

The important part of the computational fluid dynamics is to convert the continuous differential equation to discretized form because of the numerical simulation requires the continuous differential equations in discrete forms. One of the ways to discretization of the equations is divided the domain into cells (mesh), grid generations, by using finite element methods.

In our case, Fluent, commercial software package program, is used to solve the fundamental equations of fluid flow. Before solving the fundamental equations of fluid

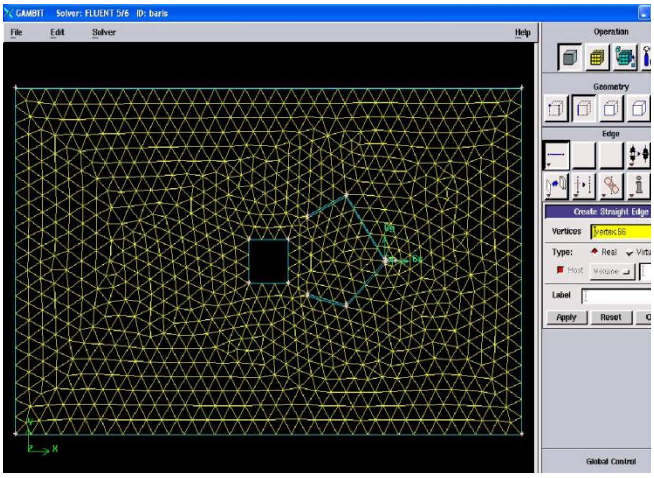

Fig.1 shows the snapshot of the Gambit software package program. The geometric and grid model of the environment are generated by using GAMBIT. Meshes represented as triangles with yellow shows the fluidic medium, blue color edges shows the solid boundaries for robot fingers, rectangular object and environment.

flow by FLUENT, the geometric representation of the environments should be modeled in preprocessing step. The detail information of generating geometric model will introduce in the following part.

C. Geometry and mesh generation

Using GAMBIT software package program, we generate the geometric model of the environment including robot fingers, solid object and medium shown in Fig.1. In this study, both robot fingers and solid object are modeled as solidified structure, which is called wall in the program, while the interior medium is modeled as compressible fluid medium which is called ideal gas. The geometry of the medium was meshed using triangular elements. The geometry generation of the environment depends on complexity of the robot fingers, object and physical constraints.

III. Simulations

In this section, a series of numerical experiments have been tested to demonstrate accuracy of the model. We analyze the momentum transfer from the fingers to fluidic medium on the object surface. The interaction between the fluid flow and solid boundaries has been performed by using dynamic mesh model.

2-D geometric and mesh model used in the experiments is created in Gambit. The total width and height of the fluidic environment is considered as 40x30 units. The mesh spacing is 0.5 units. The initial velocities of the robot fingers are all set zero. A constant laminar viscosity term is used for more stable fluid motion. Unsteady fluid flow analysis has been performed to determine the structure of dynamic mesh generated by finger motion. The governing equations as in (1) and (2) are solved by using pressure based solver of computational fluid dynamics. The compressible fluid such as air is used in the fluidic environment. The viscosity and the thermal conductivity of the air are set to 0.0242 w/m-k and 1.7894e-05 kg/m-s, respectively. The boundary condition of the fingers, object and edges surrounding the environment are set to wall. The interior medium is set as a

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fluid. The time step size for iteration used in the numerical simulation is kept to 0.002 where total number of time step is set to 1000. In order to get the desired converged solution, maximum iteration per time step size is fixed equal to 20.

At the beginning of the simulation, pressure and the velocity in x and y directions of robot fingers are set to zero. The initial position of the object is centered at position (25, 15) and robot fingers are located at (35, 15) which is the intersection point of two fingers shown in Fig.2a. In Fig.2b, fingers start to navigate from right hand side to left hand side. The velocity of the finger zone is changing in time as in (3) and (4).

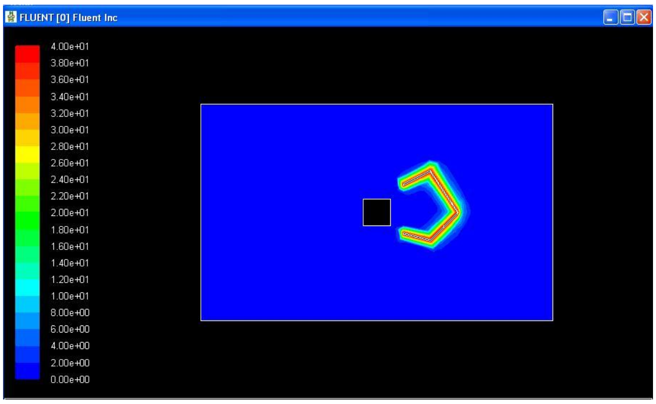
$$v_x = -\alpha.\cos(10t) \qquad (3)$$

$$v_y = 0 \qquad (4)$$

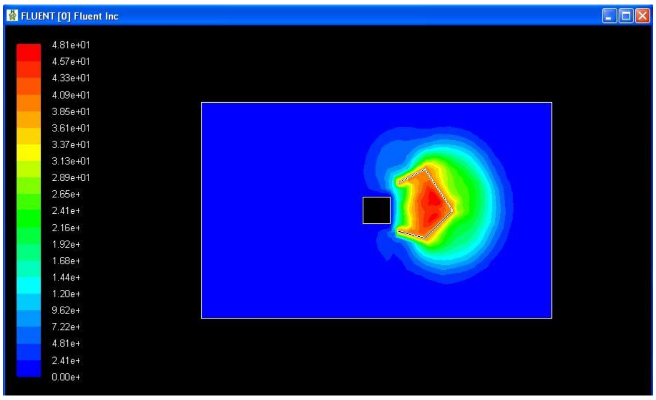
where v_x and v_y represent the velocity of fingers in x and y direction respectively, α is a constant value and t represents the time. The momentum transfer from the fingers to fluidic environment is achieved by the fingers movement in the impacted fluid medium. The position of the fingers moves to the left hand side for the initialization of grasp. Preshape of the fingers landing on the object does not change during the simulation. Moreover, the robot finger velocity versus at time decreases just like human behavior while approaching on the object because of the equation (1) and (2) by incrementing the time step. At the end of the simulation the magnitude and the direction around solid object is displayed in Fig. 2c and Fig.2d, respectively.

The first experiment shown in Fig.2 represents at different step of iteration in time. The contour of velocity magnitude during the simulation are shown in Fig.2a, b and c, respectively, at time t=0.0001, 0.001 and 0.035 s. From the Fig2a, it is shown that finger velocities are changed very rapidly at the moment of starting of the movement. No interactions between the object and fingers exist yet in the figure. The maximum velocity changes occur between the fingers shown in Fig.2b. The interaction between the object and medium momentum generated from the fingers is shown in Fig.2c. The magnitude of momentum changes of fingertip on upper side of object is higher than the bottom side detected by observing color at the fingertip. Resultant momentum of this distribution of the particles generates motion tendencies to the object. Fig.2d gives the vector representation of Fig2c.

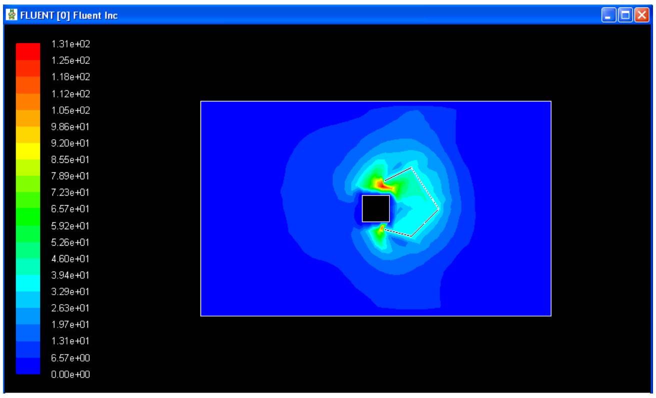
Two different scenarios for different preshape of hand and object shown in Fig. 3 and Fig. 4 are implemented based on the momentum transfer from the fingers to the medium in the simulation. Robot fingers approach through to the left hand side of the object in both cases. A circle object, which is comparatively greater than the rectangular object in Fig.4, is tested to demonstrate momentum distribution of medium around the object in Fig.3. A circle is located symmetrically relative to intersection point of the fingers according to y-axis. The maximum velocity changes occurred at the fingertip shows the region of possible contacts on the object to be initially imparted force patterns generated from that preshaped of hand.



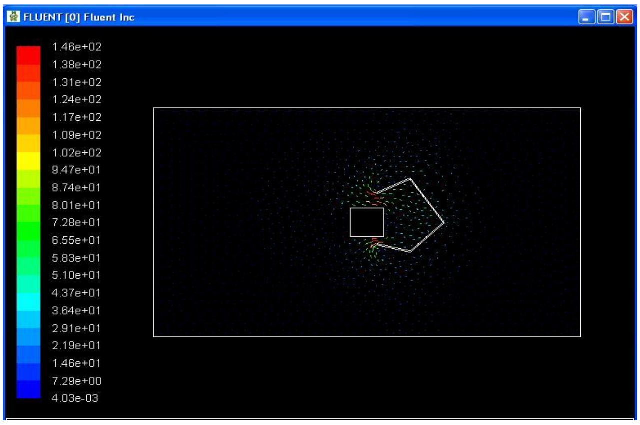
(a) time =0.0001s



(b) time =0.001s



(c) time =0.035s



(d) time =0.035s

Fig.2 shows the snapshots of the movement of the fingers in fluidic environment. Color legend bar shows the correspondence values between the color and velocity magnitude. (a), (b) and (c) shows counter plot of velocity magnitude (d) shows magnitude of the velocity vector.

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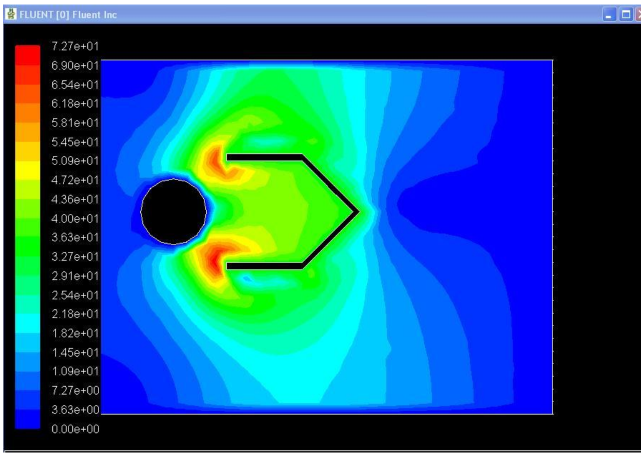

Fig.3 shows counter plot of velocity magnitude of medium while different preshape fingers are landing on the circle object.

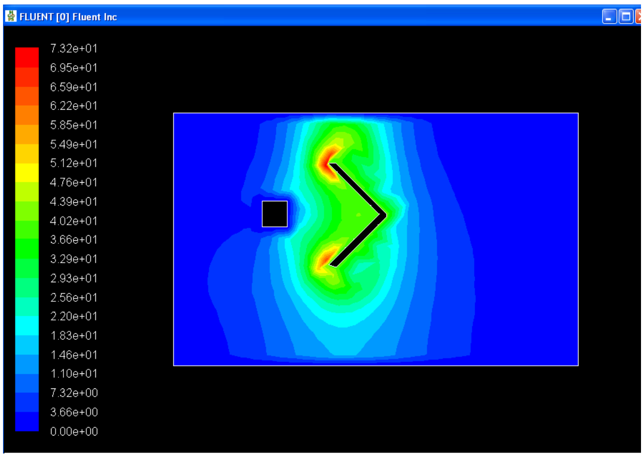

Fig.4 shows counter plot of velocity magnitude of rectagular object and simple gripper in fluid medium. Rectangular object is used in the simulation.

IV. CONCLUSION

In this report, we have presented the results of analysis of the initial effect of the impact force patterns generated from the fingers landing onto an object. For that purpose, we have proposed a new model based on the computational fluid dynamics to determine continuum between preshaping and grasping. We have especially focused on the study momentum transfer from robot fingers to the object in fluidic environment. From the result of the simulation, it is observed that the distribution of the velocity around the object is affected by continuum of finger motion and different hand preshaping.

The momentum distribution around the object should be transformed into the momemtum with respect to object center of gravity. The momentum distribution at the center of gravity of object leads to determine the direction of motion tendencies to the object.

For future work is to propose a control methodology in order to determine the optimal preshape of hand for a given task based on the momentum distribution at the center of gravity of object. Then, proposed method will be expanded for three dimensional workspaces.

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