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Modeling of Flexible Deformable Object for Robotic Manipulation

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***Abstract*—This paper presents an approach to apply the different flexible deformable model for robotic application. This approach is to simulate the different kind of flexible deformable object such as cloth, shirt and pant from specific initial condition through modeling system. The three-dimensional flexible deformable object is modeled as a two-dimensional quadrangular mesh and the particles inside the model are connected with different type of springs. Difference external forces such as handling action and gravity force will applying to the deformable model. The deformation can be estimated by using integration method to compute the change of the particle position in the model and the state of the deformable model can be tracked after simulation. Currently, the developed deformable model is integrated with two robotic arms in the simulation. To test the robustness of the developed deformable model, different handling process such as hanging, spreading and folding are applied to the flexible deformable model. The best possible path can be estimated from the simulation and utilize it in robotic control later. This approach can be used as an assisting tool to estimate the state for a flexible deformable model in vision recognition and also can be extended to path optimization for different unknown flexible deformable object.**

I. Introduction

The research in flexible deformable objects is becoming a new dominant challenge in robotic manipulation. Flexible deformable objects such as rope and clothes are ubiquitous in daily activities. Imbuing robot to handle these kind of objects is a challenging target for researchers since the robot need to understand the nature deformation of these target objects before manipulate them. In robotic manipulation, the configuration of these objects will ease affected although simple action acting into it. The methodology to handle these kind of objects need to plan properly due to its complexity.

Several groups that researching on handling of deformable objects are addressed. Osawa et al. proposed an approach of unfold a garment using template matching by comparing between the current configuration with their templates [1]. Willimon et al. proposed a method using interactive perception to classify the type of clothing and then unfolding it by a single robotic arm [2]. The unfold method based on the repeating step of grasping certain points and estimate the configuration of clothing to flatten the cloth. There also has some research works focus on robotic grasping skills for flexible deformable object [3]. A robotic gripper first grasps one of the corner point of a towel. Another designed inchworm gripper grasps near to that point then trace the edge of towel to the next end point which is second corner of towel. This method is highly depend on the sensor feedback from gripper. Kita et al. proposed a method for garment pose recognition of estimating the configuration of hanging clothes [4]. The current pose of shirt hanging is fitted by the simple deformable model using template matching algorithm, the possible states that closest to the observed shirt is selected then the next grasping point for manipulator can be estimated to unfold the shirt.

When the humanoid robot had seen significant advancement in recent years, Cusumano et al. proposed a clothing recognition and manipulation by using PR2 robot that able to handle the tasks such as folding and unfolding a garment [5]. Doumanoglou et al. proposed an approach to unfold different clothes such as sweater and pants using a dual-arm industrial robot [6]. The autonomy unfolding process is based on the recognition from a set of depth images that using physical garments and then estimate the two grasping key-points for manipulators. Recently, Li et al. proposed a series of laundry works had done using Baxter robot. Firstly, the database is based on simulated deformable model of hung garments and then learned to classify the category and also recognize the pose of garment [7]. Further improvement, Kinect Fusion method also applied to reconstruct a 3D model and then to predict the pose of garment [8].

Flexible deformable objects such as clothes usually considered as two-dimensional surface whereas the thickness is neglected during simulation. Cloth considered as an anisotropic materials that exhibit a complex behavior and difficult to model. Different physically based modeling methods such as finite element models (FEM), finite volume models (FVM) and particle system models had been proposed in computer graphics research. Provot proposed a method using mass-spring model to simulate a cloth [9]. This model is using a set of particles or masses that interconnected with massless spring in the lattice structure and the movement of particles is updating with numerical integration method such as Euler integration. Modeling of deformable object had been widely used as a simulation tool to precompute the deformation of these objects. These techniques had been proposed to improve the level of realism as the computational power enhances rapidly. The deformable models can be constructed and then simulated by considering their mechanical and material parameters respectively. From our previous work [10], we have adopted and focus on the modeling on different flexible deformable object for robotic manipulation as shown in Fig 1.

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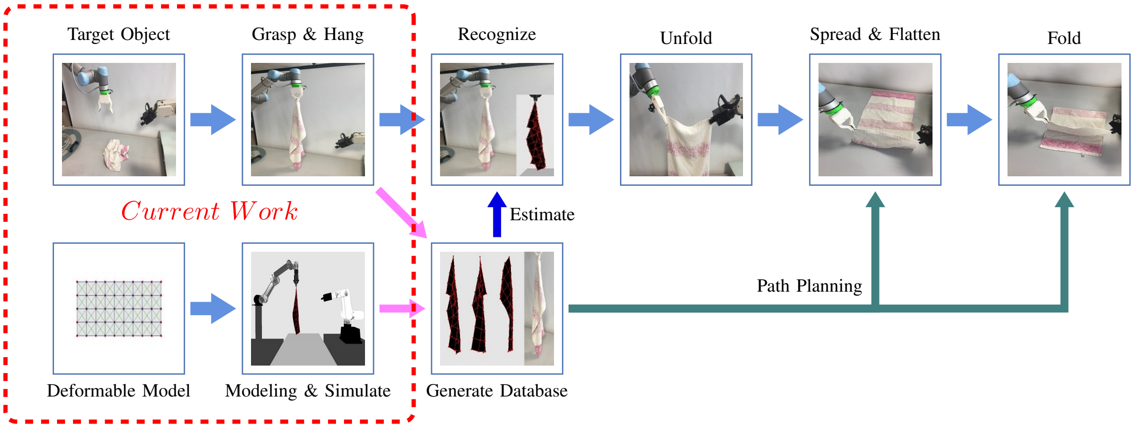


Fig. 1: Overview for manipulation of deformable objects by robot

II. Flexible Deformable Object Model

To model a flexible deformable object such as clothes, these objects are usually categorized as a three-dimensional object but model as two-dimensional mesh structure and its thickness is neglected in computer simulation. By applying mass-spring modeling technique, the target object is represented as rectangular or triangular mesh in lattice structure which are constructed by a mesh of particles as shown in Fig.2 and each particle has its own mechanical properties such as force, mass, position, velocity and acceleration. Then the massless spring are connected each particle to its neighbour particles and these spring forces will determine the type and deformation of the cloth model. Commonly, three different types of springs are applied into our cloth model: (i) Structural springs - they connect each particle together with its vertical and horizontal adjacent neighbours which serve to resist planar stretching and compression deformation in order to keep the cloth model in its natural rectangular size in warp and weft directions. (ii) Shear springs - they connect each particle with diagonal adjacent neighbours which serve to resist shearing deformation in order to prevent the model from collapsing. (iii) Bending springs - they connect each particle with its neighbours in every second row in warp and weft directions which serve to resist bending deformation in order to avoid the cloth model to bend excessively out of its original position in mesh lattice.

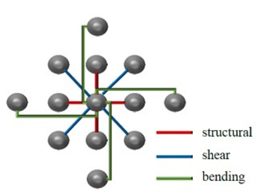


Fig. 2: Structure of mass-spring model

The cloth model under study is a mesh lattice consisted of n particles, the movement of each particle is governed by Newton's law of motion: $f_n = m_n a_n$, where m_n is the mass of the particle, P_n and a_n is its acceleration caused by the force, f_n. These force f_n is divided into external and internal forces. The external forces adopted into the model are mainly from the environment such as wind, gravity and air damping ratio. The internal forces are spring forces for each particles link to its neightbours and can be described as below.

$$f_{internal} = \sum f_{structural} + \sum f_{shear} + \sum f_{bending} \quad (1)$$

By applying the Hookes law, the extension and compression of each spring can be defined as:

$$f_n = -\left[k_s(|l_n| - l_o) + k_d v_n \frac{l_n}{|l_n|} \right] \left(\frac{l_n}{|l_n|} \right) \quad (2)$$

where l_o is the original length of the spring, l_n is the length of the spring after deformation, k_s is the coefficient of spring , k_d is the damping ratio, v_n is the velocity difference between endpoints of spring. After the completion setup of cloth model, the numerical integration method such as explicit Euler integration method is applied to simulate the deformation over time and the configuration of cloth model can be predicted after simulation finished. The equation of external Euler method can be simply defined as:

$$\begin{aligned} f_i^t &= m a_i^t \\ v_i^{t+1} &= v_i^t + f_i^t \frac{dt}{m} \\ x_i^{t+1} &= x_i^t + v_i^{t+1} dt \end{aligned} \quad (3)$$

where x_i^t represents position of particle, v_i^t represents velocity of particle, a_i^t represents acceleration of particle, m represents mass of particle, dt represent time-step in numerical integration, and f_i^t represents total force acting on a particle. In addition, the inverse dynamics correction is applied into the flexible deformable model in order to avoid the over elongation of spring during the deformation process. This adjustment will correct the two particles along their axis and preserve the position each time if the spring between them is overstretched. Collision detection and response method also considered in the flexible deformable model to prevent the penetration of target model with itself. By using mass-spring system, different type of flexible deformable model can be designed as shown in Fig.3

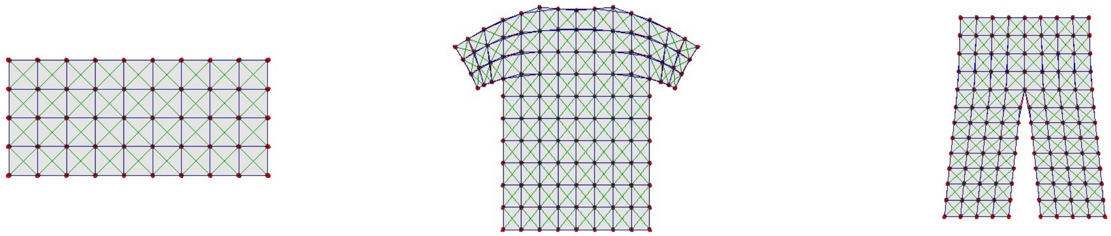
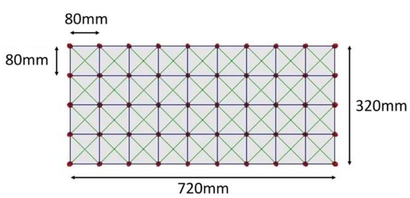


Fig. 3: Flexible deformable model designed using mass-spring system: towel (left), shirt (middle) and pant (right)

III. Experiment Setup

In the experiment setup, the workspace is composed of a Kinect depth camera, two robotic manipulator which are RVM1 and UR5. A set of calibration points consisting of 3D world coordinates (in mm) and corresponding 2D image coordinates (in unit) are provided and then this calibration data set by imaging a cloth consisting of known 3D world object point in camera is retrieved and the reflected image coordinates of these points is calculated. The cloth consists of 10×5 points and each point is placed at distance of $80mm$ from each another shown in Fig.4. Then cloth is placed on the workspace as shown in Fig.5.

(a) Cloth object ($720mm \times 320mm$)



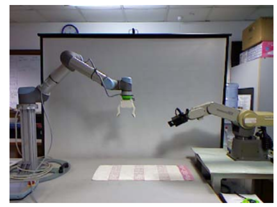
(b) Cloth model (10×5 particles)

Fig. 4: Calibrate flexible deformable object in experiment and simulation

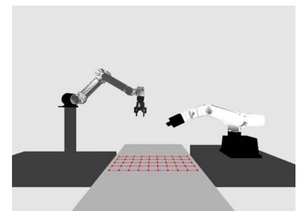
IV. Methodology for Handling Flexible Deformable Object

The hanging action is applied into cloth model in order to validate the practicable of this developed model in robotic manipulation. The necessary steps for manipulate the flexible deformable object are:

1) Locating a target object on the working platform as shown in Fig.5a with same location of the deformable model in the simulation environment before start the handling process as shown in Fig.5b.
2) Some configuration properties such as interest points and silhouette of target object in the simulation environment can be determined initially by obtaining the position of these particles used in its model. Thus, the properties of deformable model in the simulation can be related with the target object in experiment later.
3) The manipulator velocity is applying to the particle of deformable model where the location is similar to the robotic manipulator grasping to the target object. Simulate the deformable model and estimate the final configuration of target object after the simulation as shown in Fig. 6a.
4) Step 1 to 3 is repeated by changing different grasping point of deformable model in the simulation system until the handling process is complete successfully.
5) Observe and verify the handling task for the actual target object in real world experiment.
6) The step 1 to step 5 is repeated using different flexible deformable object.



(a) Target object on working platform



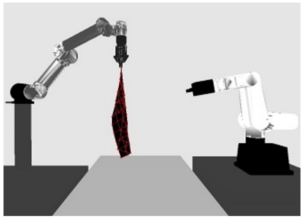
(b) Deformable model in simulation

Fig. 5: Setup flexible deformable object on working platform

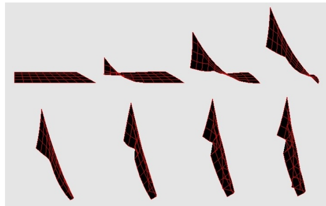
V. Results and Discussion

TABLE I: Parameter sets used in cloth model

Parameter	Symbol	Value
Structural spring, kgs^{-2}	$k_{structural}$	0.3
Shear spring, kgs^{-2}	k_{shear}	0.03
Bend spring, kgs^{-2}	$k_{bending}$	0.003
Structural damping, kgs^{-1}	$d_{structural}$	0.01
Shear damping, kgs^{-1}	d_{shear}	0.001
Bending damping, kgs^{-1}	$d_{bending}$	0.0001
Gravity, ms^{-2}	g	9.81



(a) Cloth hanging by robot



(b) The deformation sequence in simulation

Fig. 6: Cloth handling in simulation process

This experimental setup consists of a working platform with two robotic manipulators which are Mitsubishi Movemaster RV-M1 and Universal Robots UR5 respectively. At this current stage, only one robotic arm is utilized to the developed model in hanging action. In real world experiment, the coordinate of the cloth on the working platform is adjusted by end-effector manually then tracking by using Kinect sensor. The hanging action is chosen in this experiment because of its simplicity and normally as a first step in clothes handling process as shown in Fig. 1. In Fig.4b, total of 50 particles which are linked with springs are using in the cloth model. The parameters of cloth model used is tabulated in Table. I. The deformation sequence of deformable model in simulation is depicted as shown in Fig. 6b. The final configuration of the deformation model is based on the deformation of mass-spring model after simulation finished. Since the path of hanging the cloth is similar in experiment and simulation, both results can be compared in order to prove the validity and the dissimilarity obtained is 16.36% from Fig 7. Thus, more simulated models can be generated from this approach in order to obtain more accurate results and a database of the deformable model which different patterns can be generated from the collection of these simulation results.

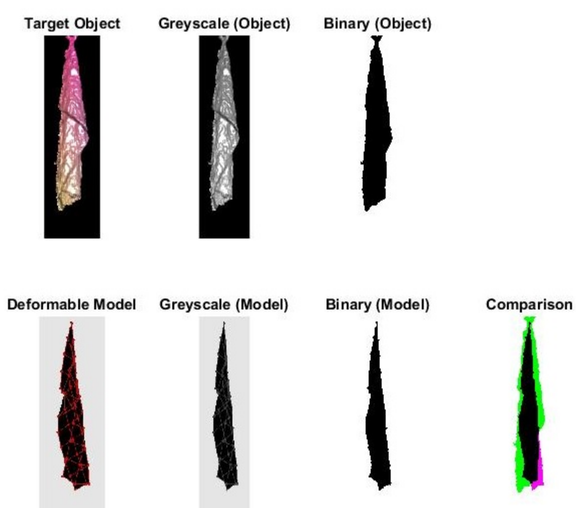


Fig. 7: Comparison result between target object and deformable model

VI. Conclusion

A method to model the different flexible deformable object in robotic control is presented. Firstly, the deformation characteristics of flexible deformable object is represented by two dimensional mass-spring model is created in three dimensional environment simulation and the thickness of these object is neglected. In this research period, the mechanical properties of target object in simulation is based on approximation. There are two robotic manipulators and one flexible deformable model modules in the simulation which used to simulate the deformable model in robotic manipulation system. However, only one robotic manipulator is fully utilized in hanging process at this current stage. The results is obtained from the simulation and validated through experiment. In conclusion, it is acceptable since the results shown are promising. Thus, the deformation and configuration of target objects can be estimated by the developed model from simulation to real world robotic manipulation. Specific handling processes such as unfolding, spreading and folding will adopted to the flexible deformable object in research later.

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