# GRASPING SPHERICAL DEFORMABLE OBJECTS USING PARALLEL GRIPPER WITH PLANAR OR CONCAVE JAWS

Marius IONESCU, Dan N. DUMITRIU, Cristian RUGINA, Ligia MUNTEANU

*Abstract*. The goal is to demonstrate that spherical concave jaws of a parallel gripper induce smaller indentation displacements and smaller contact pressures to spherical deformable objects, compared to planar concave jaws. A Festo electric parallel gripper type HGPLE-14-60 is used here to grasp spherical deformable objects with gripping forces from 0 to 50 N. It is equipped with two types of parallel almost rigid jaws: planar jaws, *versus* spherical concave jaws with spherical concavities of radii –75 mm and –50 mm. The advantage of using spherical concave jaws rather than planar jaws is proved analytically for a purely Hertzian theoretical spherical object, and experimentally for two spherical objects with nonlinear viscoelasticity: a tennis ball and a small deformable water ball. So, the obtained results show clearly that indentation displacements and contact pressures are smaller when using the spherical concave jaws and quantify this reduction. Further publication will concern the experimental grasping of apples and oranges using spherical concave jaws versus planar jaws.

*Key words:* parallel gripper, spherical concave jaws, planar jaws, grasping, tennis ball, deformable water ball, smaller indentation, contact pressure.

## 1. INTRODUCTION TO GRASPING SPHERICAL DEFORMABLE OBJECTS

Grasping deformable objects by robotic end-effectors is based on contact mechanics and friction principles [1]. Current robotic end-effectors are versatile and can adapt to various shapes of objects, using flexible fingers based on various techniques, *e.g.*, Rad *et al.* [2] propose PneuNets bending actuators for soft grasping of fragile objects with different sizes and shapes. In the manipulation tasks of deformable objects and in other applications, the goal is to reduce the contact pressures so that to keep the grasped object as much as possible in the

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Institute of Solid Mechanics of the Romanian Academy, Bucharest
E-mails: mariusionescu@yahoo.com, dan.dumitriu@imsar.ro, dumitriu.dan.n@gmail.com, rugina.cristian@gmail.com, ligia_munteanu@hotmail.com

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viscoelastic behavior domain and to avoid plastic deformation. Dharbaneshwer *et al.* [3] use FEM simulations to generate contact pressures maps, this grasp experience database being able to improve real-time grasp of robots on fruits and fluid-filled bottles. An interesting idea for robotic grasping is to take its source of inspiration from human hand grasping behavior, thus Hokari *et al.* [4] use FEM simulations to study contact pressure distribution during hand grasping of cylindrical object, with the goal of proposing new shapes with improved gripping comfort.

Our study is not focused on robotic grippers with increased complexity, but on the improvement of the simple normal contact between a spherical deformable object and the parallel jaws of a simple parallel gripper. It is not forgotten that the human hand grasps a spherical object with several fingers of quasi-cylindrical shape (convex shape), but the idea here was to compare planar jaws with spherical concave jaws.

This type of grasping by contact between a sphere and a spherical concave surface is less studied in the literature. On the other hand, sphere-on-sphere contact or the contact between a sphere and an inner cylinder are studied intensively in specialized literature. Bearings are the most common technological application. For example, Anoopnath *et al.* [5] studied analytically and numerically the Hertz contact stress between the deep groove ball bearing and inner race. An interesting sphere on spheres multiple-contact FEM simulation was performed by Iarovici *et al.* [6], studying the load transfer mechanism in a total hip prothesis with a layer of rolling balls.

Fang *et al.* [7] studied the contact between a sphere and a spherical cavity by using a new hemi-analytical and hemi-numerical model, called Fang contact model. This new Fang contact model can be used to analyze the contact pressure of the spherical fixed ring journal bearing, He *et al.* concluding that [8]: "The smaller radius clearance value of journal bearing is, the corresponding contact pressure will be higher". This journal bearing issue is conceptually similar to our proposition to reduce the contact pressure for a spherical deformable object grasping task, through a judicious choice of a spherical concavity (cavity) grasping jaw.

Dumitriu *et al.* [9] have recently presented at the Annual Symposium of the Institute of Solid Mechanics SISOM 2024 some results preliminary to this paper, without any extended publication.

## 2. GRASPING SPHERICAL OBJECTS WITH PARALLEL GRIPPER

The grasping of spherical deformable objects is studied here using a parallel gripper with two types of almost rigid jaws: planar jaws versus spherical concave jaws. The logical expectation is that grasping with spherical concave jaws produces smaller indentation displacements of the grasped spherical deformable object and smaller contact pressures, compared with the case of using planar jaws. The gripping force is the same in both cases. A simple normal contact is considered in this study. Figure 1 illustrates in cross-sectional view the concepts used here about grasping of a spherical deformable object of radius $R_1$. The planar jaws are shown in Figs. 1a and 1b, while the spherical concave jaws with negative spherical concavity of radius $|R_2| > R_1$ are shown in Fig. 1c. The indentation displacement represents the displacement produced by the applied normal force *P* over the spherical deformable object, in the central point where the maximum deformation occurs. For the planar jaws case, this displacement is illustrated between the state in Fig. 1b where the homogenous symmetrical spherical object is deformed under the action of force *P* and the undeformed state from Fig. 1a.

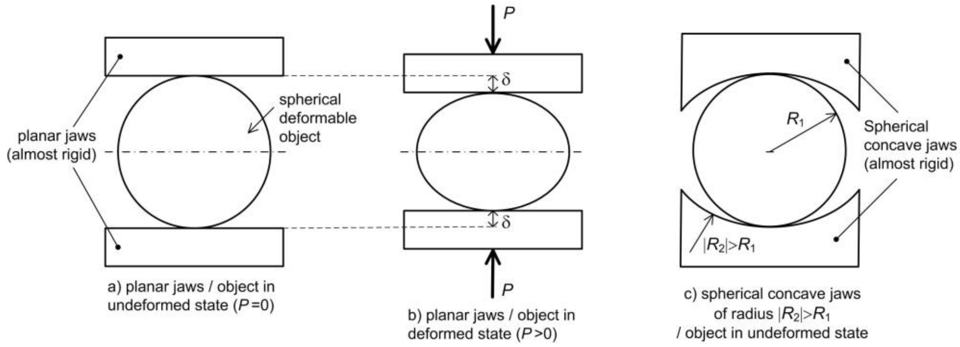


Fig. 1 – Grasping a spherical deformable object, in different poses: a) planar jaws ready to grasp the object ($P = 0$); b) planar jaws grasping the object with force *P*, deforming the homogenous object symmetrically with indentation displacement δ; c) spherical concave jaws with spherical concavity of radius $|R_2| > R_1$, ready to grasp the object ($P = 0$).


Fig. 2 – Experimental stand based on a Festo electric parallel gripper type HGPLE-14-60.

Fig. 3 – The planar jaws (left) and the spherical concave jaws with spherical concavities of radii −75 mm (middle) and −50 mm (right), used for grasping the spherical objects below.

The experimental stand is shown in Fig. 2, being composed of a Festo electric parallel gripper type HGPLE-14-60, with two types of jaws: planar jaws, versus spherical concave jaws with spherical concavities of radii −75 mm and −50 mm. These jaws are attached to the gripper by rigid small L-shaped steel bars of 100 mm length. Figure 3 presents the planar and the spherical concave jaws, manufactured by 3D printing with PLA plastic (PolylacticAcid material), so the jaws can be considered as almost rigid, compared with the deformable grasped spherical object, which are also shown in the figure (tennis ball of radius $R_1 = 62.5$ mm and a small deformable water ball of radius $R_1 = 60$ mm).

The gripping force varies between 0 and 50 N. The maximum force of 50 N corresponds to the Festo product prospectus and has been previously verified experimentally [10] using tensiometric plates applied to the flexible gripping fingers, in the form of a flexible steel bar with a section of 25×1.88 mm.

In fact, a perfect calibration of the gripping force is not necessary, since our goal is to relatively compare indentation results, more precisely to prove that the grasping contact between almost rigid spherical concave jaws of radii −50 mm and a spherical deformable object produce smaller indentation displacements and contact pressures, compared with the case of the grasping contact between almost rigid planar jaws and the same spherical deformable object. A possible small error in the knowledge of the applied force is not relevant here, since our study is mainly a comparative one.

## 3. HERTZIAN CONTACT THEORETICAL RESULTS

Let us consider a Hertzian normal contact between two perfectly elastic solids:

• a spherical perfectly elastic solid, borrowing some characteristics of a tennis ball, *i.e.*, radius $R_1 = 31.25$ mm, Young modulus $E_1 = 4$ MPa and Poisson coefficient $\nu_1 = 0.2$. The Young modulus is estimated from the study of Wojcicki *et al*. [11], where the calculated values are between 3÷5 MPa. The Poisson coefficient is purely estimated, in any case it has little influence in the Hertzian contact formulas. Some possible small errors in Young modulus and Poisson coefficient of the tennis ball are not relevant here, since our study is mainly a comparative one. Obviously, the tennis ball is not a perfectly elastic solid, but a viscoelastic solid. To be more precise, we reiterate the fact that a spherical perfectly elastic solid is considered in this section 3, borrowing some characteristics of a tennis ball, but not its real behavior.

• a spherical concave jaw, considered as a perfectly elastic solid with the Young modulus and Poisson ration borrowed from PLA: Young modulus $E_2 = 2\,380$ MPa and Poisson coefficient $\nu_2 = 0.33$. The radius $R_2$ of the spherical concave jaw varies from −32 mm to −∞.

For this pair of perfectly elastic solids in Hertzian contact, we compute the equivalent Young modulus $E^*$ and equivalent radius $R$ using the following expressions [1]:

$$\frac{1}{E^*}=\frac{1-\nu_1^2}{E_1}+\frac{1-\nu_2^2}{E_2}, \qquad \frac{1}{R}=\frac{1}{R_1}+\frac{1}{R_2}.$$

The theoretical Hertzian contact of two elastic solids, having the form of a sphere and of a spherical concave jaw respectively, is governed by the following equations [1]:

$$\delta=\left(\frac{3P}{4E^*\sqrt{R}}\right)^{\frac{2}{3}}, \qquad p_0=p_{\max}=\frac{3P}{2\pi a^2}=\frac{1}{\pi}\left[\frac{6P(E^*)^2}{R^2}\right]^{\frac{1}{3}}, \qquad a=\left(\frac{3PR}{4E^*}\right)^{\frac{1}{3}},$$

where $P=50\,\text{N}$ is the applied force of the normal contact, $\delta$ is the indentation displacement or penetration depth, due to the applied force, while $a$ is the radius of the contact patch. The contact patch represents the area of all the points of the two solids which are in contact under the applied force, they have obviously the same contact pressure. $p_0$ or $p_{\max}$ is the contact pressure in the center of the contact patch, being the maximum contact pressure.

The variable of our study is the radius $R_2$ of the spherical concave jaw, which varies from –32 mm to –∞. For –∞ we have the case of planar jaw. Figures 4 and 5 show the evolutions of the indentation displacement $\delta$ and of the contact pressure $p_0$, function of the radius $R_2$ of the spherical concave jaw. On these figures are marked with red dots the values of $\delta$ and $p_0$ for the following values of $R_2$: –32 mm, –50 mm, –75 mm and –∞ (planar jaw).

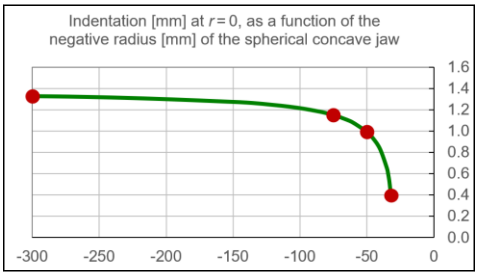


Fig. 4 – Indentation displacement $\delta$, function of the radius $R_2$ of the spherical concave jaw.

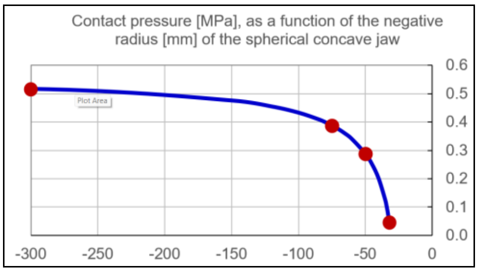


Fig. 5 – Contact pressure $p_0$, function of the radius $R_2$ of the spherical concave jaw.

Even if for $R_2=-32\,\text{mm}$ or $R_2=-31.26\,\text{mm}$ the reductions in $\delta$ and $p_0$ are spectacular, this is not a feasible case in practice, since our interest is to further use these spherical concave jaws for grasping apples or oranges, thus we cannot have the radius $R_2$ of the spherical concave jaws too close the radius of the apple or orange grasped object. In this context, it is more realistic to consider spherical concave jaws with $R_2 = -50$ mm, for which the reductions in δ and $p_0$ are 28% and 48% respectively, with respect to the planar jaws. We will also consider in the experiments presented in next section spherical concave jaws with $R_2 = -75$ mm, for which the reductions in δ and $p_0$ are 18% and 32% respectively, with respect to the planar jaws. All these results have been obtained for the theoretical case of a Hertzian contact between perfectly elastic solids. It is obviously not the real case, but this theoretical study shows the orientation for the real case, since the elastic behavior is the main component of our contact problem.

## 4. EXPERIMENTAL RESULTS OF GRASPING SPHERICAL DEFORMABLE OBJECTS WITH SPHERICAL CONCAVE VERSUS PLANAR JAWS

The Festo electric parallel gripper type HGPLE-14-60 shown in Fig. 2 is used here to grasp, using applied forces $P$ varying from 0 to 50 N, two types of deformable balls with nonlinear viscoelastic behavior: tennis ball of radius $R_1 = 62.5$ mm, and a small deformable water ball of radius $R_1 = 60$ mm respectively. The Festo parallel gripper type HGPLE-14-60 is used in force control mode, *i.e.*, we apply gradually forces of 0 N, 10 N, 15 N, 20 N, 25 N, 30 N, 35 N, 40 N, 45 N, 50 N, and for each stabilized force value the device indicates the corresponding displacement. The indentation displacement corresponding for force $P$ is computed as the difference between the displacement indicated by the Festo device for this force $P$ minus the displacement indicated at the beginning of contact, for $P_0 = 0$ N. The small L-shaped steel bars of 100 mm length, fixed on the actuator and supporting the jaws, are almost rigid; nevertheless, the very small flexion of these steel bars (of section 35×6.40 mm) is taken into account, for example for 50 N the maximum deflection is 0.1038 mm.

Figure 6 shows the indentation displacements, as a function of the forces applied by the gripper, when grasping a tennis ball of radius $R_1 = 62.5$ mm. The goal of this paper is thus demonstrated for the tennis ball grasping: the indentation displacements for spherical concave jaws with spherical concavity of radius $R_2 = -50$ mm are smaller than the indentation displacements for spherical concave jaws with $R_2 = -75$ mm, and more smaller than indentation displacements when using the planar jaws. Obviously, if the indentation displacements are the smallest for the spherical concave jaws with $R_2 = -50$ mm, then implicitly the contact pressures corresponding for this case are also the smallest. In terms of relative differences, the indentation displacements are smaller with 45% for the spherical concave jaws with $R_2 = -75$ mm compared to the planar jaws, and smaller with 59% for the spherical concave jaws with $R_2 = -50$ mm compared to the planar jaws.

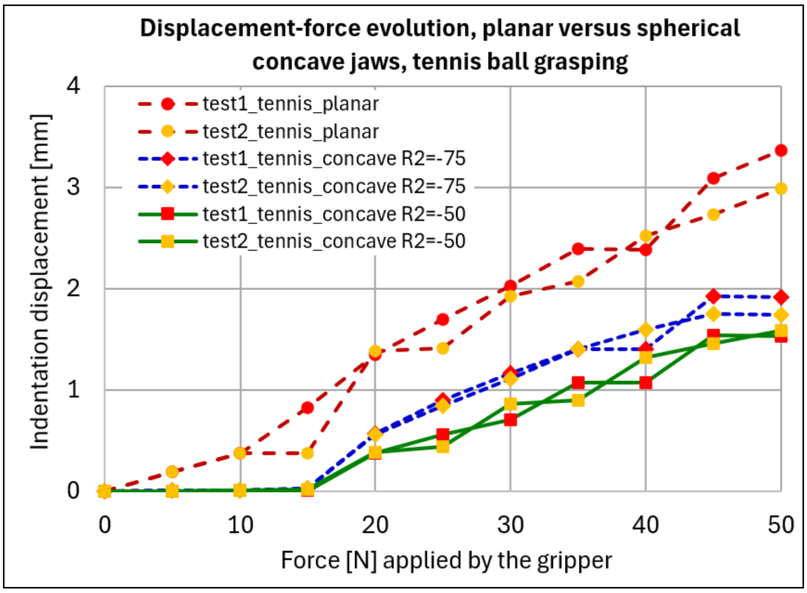


Fig. 6 – Indentation displacement, as a function of the force applied by the gripper, when grasping a tennis ball of radius $R_1 = 62.5$ mm, using: planar jaws (red curves, dashed line), spherical concave jaws with spherical concavity of radius $R_2 = -75$ mm (blue curves, "square dot" line) and spherical concave jaws with spherical concavity of radius $R_2 = -50$ mm (green curves, solid line).

Figure 7 shows the indentation displacements, as a function of the forces applied by the gripper, when grasping a small deformable water ball of radius $R_1 = 60$ mm. The goal of this paper is partially demonstrated for the small deformable water ball grasping: the indentation displacements for spherical concave jaws with spherical concavity of radius $R_2 = -75$ mm are smaller than indentation displacements when using the planar jaws. As for the indentation displacements for spherical concave jaws with spherical concavity of radius $R_2 = -50$ mm are only slightly smaller than for the spherical concave jaws with spherical concavity of radius $R_2 = -75$ mm. The explanation is that our jaws are quite small (in transversal section, the jaw has only 50 mm in diameter) and the red water ball is very deformable (indentation displacement are much bigger than for the tennis ball), as a consequence both for the spherical concavities of radius $R_2 = -75$ mm and $R_2 = -50$ mm, the deformed water ball ends up "filling" the spherical concavity of the jaws.

In terms of relative differences, the indentation displacements are smaller with 53% for the spherical concave jaws with $R_2 = -75$ mm compared to the planar jaws, and smaller with 56% for the spherical concave jaws with $R_2 = -50$ mm compared to the planar jaws.

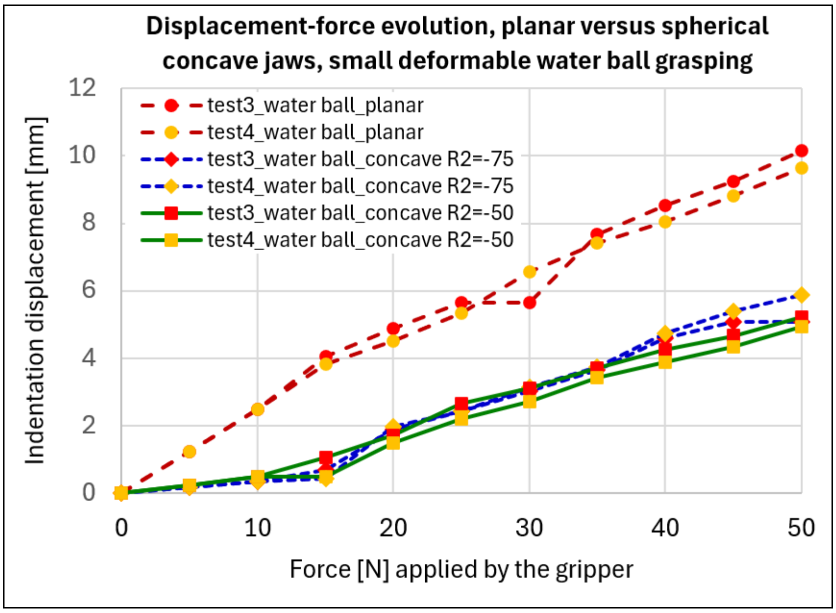


Fig. 7 – Indentation displacement, as a function of the force applied by the gripper, when grasping a small deformable water ball of radius $R_1 = 60$ mm, using: planar jaws (red curves, dashed line), spherical concave jaws with spherical concavity of radius $R_2 = -75$ mm (blue curves, "square dot" line) and spherical concave jaws with spherical concavity of radius $R_2 = -50$ mm (green curves, solid line).

## 5. CONCLUSIONS AND FURTHER WORK

The following intuitive idea was studied and demonstrated in this paper for the grasping of a spherical deformable object: using spherical concave jaws instead of planar jaws leads to smaller indentation displacements and smaller contact pressures. This idea was proved analytically for the theoretical case of a Hertzian contact. It was also demonstrated experimentally using a parallel gripper to grasp a tennis ball and a small deformable water ball, both showing nonlinear viscoelastic behavior. Further work will prove this idea for grasping apples and oranges, knowing that apples show a less elastic behavior. Improving contact shapes to obtain smaller contact pressures and indentation penetrations during grasping and handling of these fruits will ensure their better integrity and preservation. To support this idea, FEM studies have been also conducted and will be further published.

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