2014 5th IEEE RAS & EMBS International Conference on
Biomedical Robotics and Biomechatronics (BioRob)
August 12-15, 2014. São Paulo, Brazil

An obstetric forceps contouring the head surface to improve gripping capability in delivery assistance

Masaki Chino[1], Yoshikazu Nakajima[1], *Member, IEEE*, Akira Bekku[1], Hiroyuki Tsuda[2], Tomomi Kotani[2] and Fumitaka Kikkawa[2]

***Abstract*— The requirement of safe child delivery is increasing in developed countries in these decades. We have developed an obstetric forceps contouring the infant's head surface with stiffness-controlled pads. The stiffness of the pad is controlled by using air pressure regulation based on jamming transition. The proposed forceps has two soft material pads facing to the infant's head. The proposed forceps is first thin to get safely inserted into the delivery cavity. The granular tetrapod particles are then injected into the pads to contour the infant's head surface. By vacuuming the inside air of the pads, the particles interlock each other and the pads move onto the solid-like phase. In the experiments, the proposed method worked effectively to decrease the pressure onto the infant's head during delivery assistance and consequently made the operation safer.**

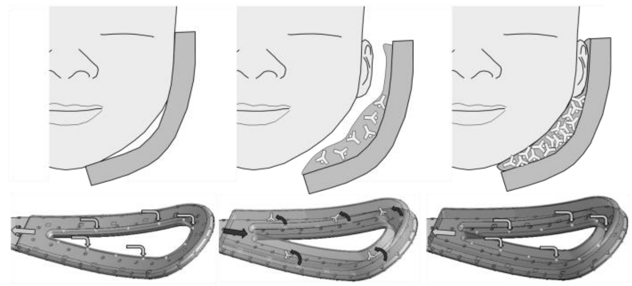


Figure 1. The proposed procedure: (a) Inserting the thin-state forceps; (b) Filling air and grains into the pad; (c) Vacuuming inside air to jam the grains.

I. Introduction

In these decades, the rate of late childbearing is increasing and the birth rate is declining in most European countries, the United States and some Asian countries. These factors require improvement in safer child delivery. Forced delivery is one non-invasive way to assist delivery. This method uses a forceps to grasp and control the infant's head in the parturient canal, however slipping or misplacement can cause excessive pressure to the head, especially to the eyes. Moreau *et al.*[1] proposed the forceps with two force sensors at each grip to monitor surgeon's grasping force. Gehin *et al.*[2] proposed the interface pressure measurement between the forceps' shank and the fetal head. They addressed the importance to control the grasping force in delivery assistance and designed the devices to monitor the amount of force.

To improve gripping safety with forceps, there are some previous researches that can be referred. They improved the capability of gripping soft materials. One possible way is a forceps that bends at many joints to trace the gripped surface. However, this forceps requires many number of joints sequentially and it is hard to compactly assemble this mechanism. It also requires the measurement of passive forces from soft tissues[3, 4, 5, 6]. It is still under development to be introduced to practical applications. Deformable stabilizers, such as cardiac stabilizer Octopus (Octopus Tissue Stabilizer, Medtronic Inc.), are considerable alternatives. An Octopus has a vacuuming pad and a flexible arm. The pad vacuums the heart surface to suppress the heart beat vibration while the arm keeps it spatial position rigidity. The arm can change its flexibility by regulating the tensioned strings which pass through the centers of the arm components. However, the rigidity of the arm is not enough for our purpose of grasping the head. Lang *et al*. proposed a gripper using liquid solidification[7]. However, it worked in negative temperature around -30 degrees and it is too cold to be used for our purpose. There is also another problem that large temperature difference between solid and liquid states may affect both the patient and the infant. Therefore, we propose a novel design of delivery forceps embedded with stiffness-controlled pads. The stiffness of the pads is controlled using air pressure regulation. The pads can contour the head surface in deformable state and then change to solid-like state by jamming transition to hold the head steady. The object gripper based on jamming transition has been originally proposed by Amend *et al.*[8]. They used a granular material to phase transition and assembled a jamming gripper. They tested its capability with respect to gripped object properties such as size, shape and relative geometry.

In this paper, we have employed this method and then optimized and partly modified it to apply to delivery assistance.

II. Method

The proposed procedure is shown in Fig. 1. The pad is first empty and thin to get safely inserted into the delivery cavity. Then granular particles are mixed with air and injected into the pad through the discharge duct (Fig. 2) to contour the head surface. Air is naturally exhausted through the vacuum ducts to keep pressure inside the pad constant. By continuing the granular particle delivery, particles accumulate in the pad thanks to meshes placed at each of the vacuum ports on the pad base. After completing the particle injection, air inside the pad begins to be forcedly vacuumed out and the amount of

[1]Masaki Chino, Yoshikazu Nakajima and Akira Bekku are with the Graduate School of Engineering, the University of Tokyo, 113-8656 Tokyo, Japan (e-mail: {chino, nakajima, bekku}@ image.t.u-tokyo.ac.jp).

[2]Hiroyuki Tsuda, Tomomi Kotani and Fumitaka Kikkawa are with the Department of Obstetrics and Genecology, Nagoya University School of Medicine, 466-8550 Nagoya, Japan (e-mail: {hiro-t, itoto}@med.nagoya-u.ac.jp).

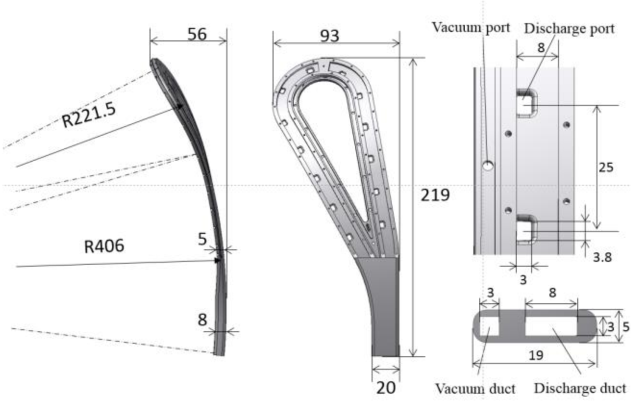
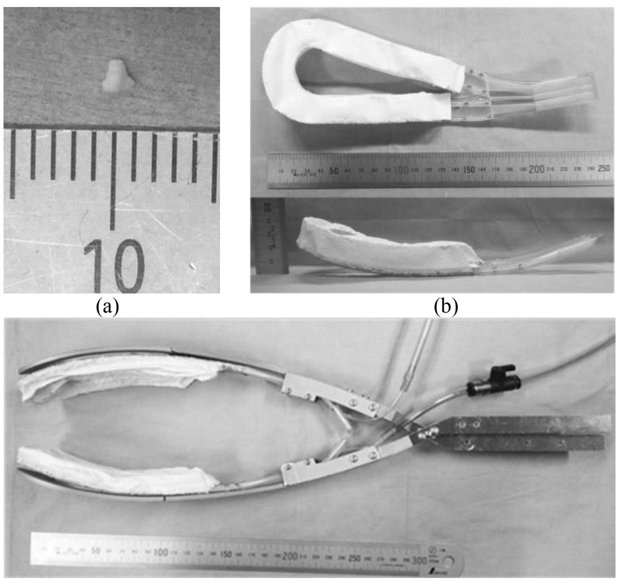


Figure 2. Geometry of the forceps base



(a) (b)

(c)

Figure 3. The proposed forceps: (a) A gain, (b) A pad and a duct, (c) Appearance of the forceps

intake air through the discharge duct is reduced step-by-step to make the pad solid-like state.

A. *Design and prototyping*

The proposed obstetric forceps consists of the two bases and two pads. The bases are shaped as a conventional forceps. They were prototyped with plastic (Objet FullCure 810, Stratasys Ltd., USA) by a 3-D printer (Objet Connex 500, Stratasys Ltd., USA). Each forceps part contains two cavity ducts. One is for discharging air and grains and the other is for vacuuming air as shown in Fig. 2. The size of discharge ducts is 8 mm and 3 mm for width and height, respectively. The size of the vacuum duct is 3 mm and 3 mm. At each of vacuum ports, a mesh is fixed to protect grain incursion into the duct. The pads are made of silicon rubber with fiber strings. Each grain is shaped like a tetrapod and the size is less than 2 mm in diameter as shown in Fig. 3(a). It was made with calcium oxide by a 3-D printer (Z printer 450, 3D systems Inc., USA). The reason for the tetrapod shape is to be able to interlock each other while not choking air due to adequate interspace between grains. The forceps thickness was 5 mm of the base and totally 6 mm including the pad membrane while in thin state. The maximum stroke of the pad is 15 mm as shown in Fig. 3(b). The grip parts are made of stainless steel. The forceps is 300 mm of the inserted parts and 135 mm for the gripped parts for length and around 100 mm for width as shown in Fig 3(c).

The proposed forceps was mounted to an electromagnetic compressor (CP-100, Nakatomi Corp., Japan) and a vacuum generator (VBH07-66H, Nihon Pisco Co., Ltd., Japan) to inject and suck the inside air. An ejector (VRL50-010808, Nihon Pisco Co., Ltd., Japan) was also used to mix grains with air.

III. EXPERIMENTS AND RESULTS

A. *Test for grain shape and size*

We addressed stiffness tests for grain shapes and sizes. Spheres and polyhedrons were the two kinds of shapes tested. The sizes were 1.01 mm for spheres and 0.29, 0.81, 1.14 and 1.87 mm for polyhedrons. The grains were filled into a cage as shown in Fig. 4. The cage was made of plastic at bottom part and silicon rubber at upper part. The width and height of the silicon part was 50 mm and 30 mm, respectively. After sucking inside air at -30.7 kPa negative pressure, the metal

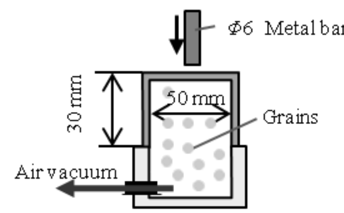
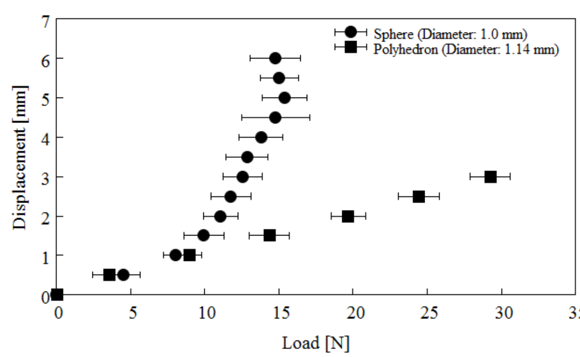
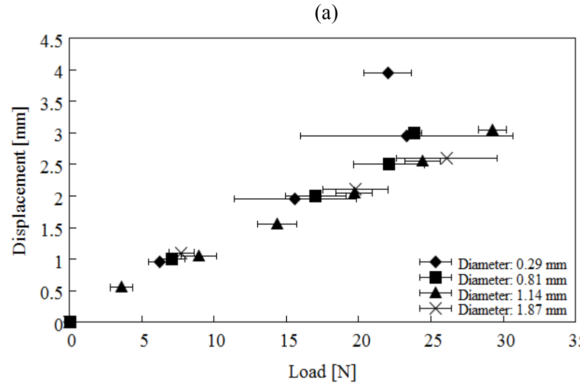


Figure 4. Experimental condition



(a)



(b)

Figure 5. Deformation for external force: (a) Difference for sphere and polyhedron shapes, (b) Difference for diameter variety

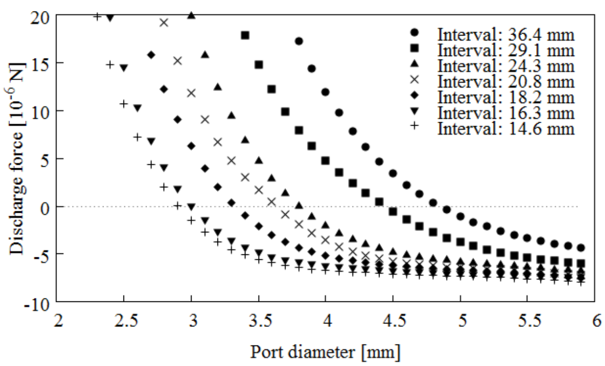


Figure 6. Discharging force of grains

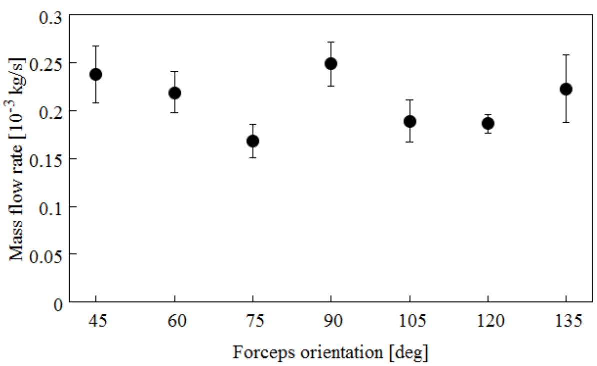


Figure 7. Mass flow rate for forceps orientation

bar of 6 mm diameter was pressed down on the top of the cage and perpendicular external force from the cage was measured. The test was conducted 5 times for each condition.

As shown in Fig. 5(a), the spheres yielded at less than 15 N of loading force. Whereas, the polyhedrons displaced linearly. This shows that the non-smooth shape of polyhedrons was effective with respect to rigidity. The size difference showed no tendency as shown in Fig. 5(b).

The volume difference between before and after air sucking was evaluated. The pad volume could slightly shrink by sucking air out. This appeared as a thickness change and could cause physical separation and looseness of the interface between the pad and the infant's head. In the experiment, a cage was filled with grains. The cage size was 30 mm ×30 mm ×40 mm and can shrink along the 40 mm axis. The grains were tetrapod shaped and the size was around 2 mm. The air inside the cage was sucked out at a pressure of -30.7 kPa while the cage was dipped into water. Volume change was measured for the water levels.

The result was less than 5% of the cage volume. This result shows that the cage thickness changed less than 2 mm. This also leads that the proposed pad's thickness might have changed less than 0.75 mm due to the difference between the cage height and 15 mm thickness of the proposed pad.

B. Optimization of discharge port geometry

Size and interval of the discharge ports affect grain filling capability. Discharging force was evaluated for port diameter and interval in numerical simulation. Discharge force is given as $F_{\text{discharge}} = C_d S(\rho \upsilon_a^2)/2 + (p_a - p_0)S$. Where, C_d, S, ρ and υ_a are resistance coefficient, sectional area of the cavity, air density and flow velocity, respectively. p_a and p_0 are pressure in the cavity and pressure of the atmosphere, respectively. Downward force to the inside is given as $F_{\text{downward}} = mg\cos\alpha$. Where, m, g and α are grain mass, gravity acceleration and the declination angle of the forceps to the vertical direction, respectively. $F = F_{\text{discharge}} - F_{\text{downward}}$ is total force to discharge grains from the cavity.

Port diameter changed from around 2 mm to 5 mm and port interval changed as 36.4, 29.1, 24.3, 20.8, 18.2, 16.2 and 14.6 mm which was geometrically determined by each port number from 4 to 10, respectively. Considering contact to the infant's head, 25 mm was acceptable for port interval and then 3.8 mm was optimal in this case as shown in Fig. 6.

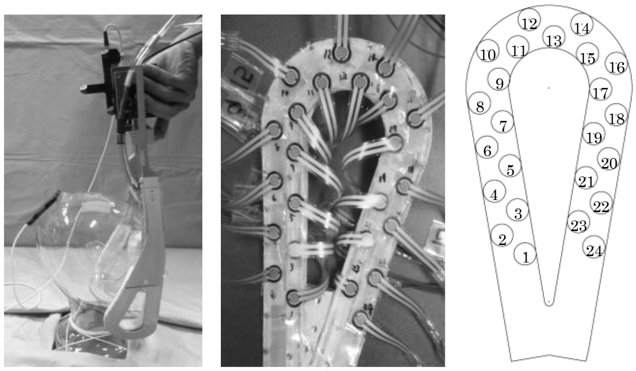
We also evaluated discharge force with respect to the forceps orientation. The orientation was defined as the angle between the forceps plate and the vertical direction. Negative pressure was -20 kPa. Time period until the amount of grain reached 65.4 g was measured 5 times and then mass flow rates were computed. 65.4 g corresponded with 66.7% of the full volume and provided 10 mm of average pad thickness. It would be practical amount which could contour the infant's head.

Mass flow rates for each forceps orientation is shown in Fig. 7. It was found that there was not clear connection between forceps' orientation and mass flow rate.

C. Grasping capability in delivery assistance

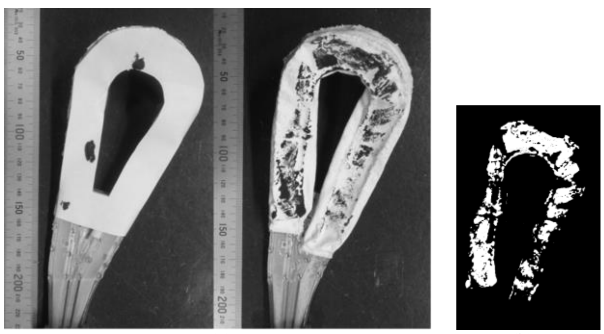
Grasping capability in delivery assistance was evaluated using a plastic human head phantom as shown in Fig. 8(a). The grains were tetrapod of 2 mm diameter. Grasping forces at the grips were 5, 10, 15, 30, 45 and 60 N and traction forces were 5, 10, 15, 20, 30 and 45 N. The test was performed by using a conventional grasping forceps and the proposed forceps. The experiments were performed to address contact area, pressure distribution on the contacting pad and displacement in grasping operation. For the contact area test, red poster color (Pentel Co., Ltd., Japan) was painted on the phantom surface. After grasping, the forceps was captured by a conventional CCD camera and then contact area was extracted by using a house-developed software. Pressure distribution was evaluated by using 24 pressure sensors (FSR 400, Interlink Electronics Inc., USA) fixed on the forceps as shown in Fig. 8(b) and (c), and collected to the computer by using Arduino electronic circuits (Arduino, See http://arduino.cc). Traction force to the forceps was evaluated by using a 6-DOF force sensor (IFS-67M25A50-I40, Nitta Co., Ltd., Japan) attached onto the forceps grips (Fig. 8(a)). Displacement in grasping operation was evaluated by using an optical three-dimensional localizer (OPTOTRAK, Northern Digital Inc., Canada) and trackers (TT001, Traxtal Inc., Canada) that was fixed onto each of the phantom and the forceps as shown in Fig. 8(a). 5 trials were done for each of the contact area test and the displacement test and 10 trials were done for the pressure distribution test.

A case of contact areas is shown in Fig. 9. The contact area rates were 6.5±3.7% and 30.9±17.5% for the conventional and the proposed forceps, respectively, and the proposed forceps improved 4.79 times over the conventional.



(a) (b) (c)

Figure 8. Experimental apparatuses: (a) A transparent plastic phantom of human head, (b) Pressure sensors, (c) Sensor indexes



(a) (b)

Figure 9. A case of contact area measurement: (a) Painted pads (left: the conventional forceps, right: the proposed), (b) A result extracting contact area

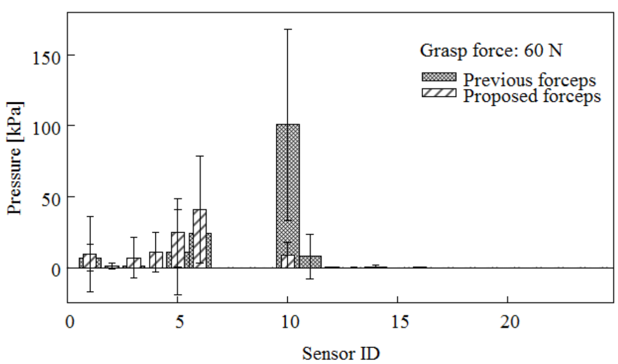


Figure 10. Pressure distribution

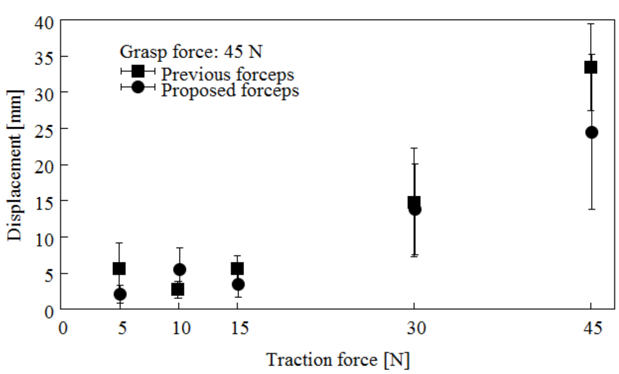


Figure 11. Displacement in grasping operation

Pressure distribution at each sensor is shown in Fig. 10. The horizontal axis corresponds to the sensor indexes shown in Fig. 8(c). In the proposed method, pressure dispersed onto couple of sensors and decreased to about half of maximum pressure compared with the conventional forceps. According to our preliminary experiment performed by five surgeons in obstetrics and genecology, pressure less than 45 kPa is acceptable to prevent damage to the infant's head. The proposed method almost succeeded to reduce the pressure to the acceptable level.

Displacement in grasping operation is shown in Fig. 11. The proposed method decreased to about two-third compared with the previous method.

IV. Discussion

In the experiment described in the sections III-A and III-C, the non-smooth shape of tetrapod worked effectively to make the pads be a solid-like rigid object. The result showed the possibility that the granular particles interlocked each other, however it is required to address some additional inspections such as numerical simulation analysis and temporal imaging to clearly understand the phenomenon during the change from the deformable state to the solid-like state.

Jamming transition caused the volume change of the pads in the experiment described in section III-A. The amount of the change was less than 5% of the volume, but it might have caused mm-order deformation of the pad shape. This deformation was caused at the coarse parts of the grain density. Air vibration during the discharging has the possibility to make the grain dense higher and overcome some amount of this problem.

In the experiment described in section III-C, the grasping pressure onto the head surface dispersed on the pad surface but still concentrated onto some areas. This concentration might be caused by the change of surface declination. The high-curvature area collects pressure, whereas the low-curvature area disperses pressure onto the area. The capability of pressure dispersion is limited but this curvature-change leads comfortable effectiveness to grasp the object steadily.

Mechanical flexibility with number of joints can trace the head surface. However, it is difficult for the mechanical forceps to be inserted into the tight space between the delivery cavity and the infant's head. Additionally, it can cause critical pressure concentration on the eyes while it passes near the eyes. The proposed method can prevent such problem by limiting the expansion stroke of the pad because the eyes are located at the concave areas on the head.

Also, the rigidity difference between the phantom and an infant's head is another concern in the experiment explained in section III-C. Infant's head is soft and deformable however the phantom used was rigid. This can cause some difference on the pressure distribution; however, we believe that the practical pressure distribution might not cause negative effect to the infant. The pressure would concentrate to hard parts such as cheeks and chin of the bone structure. Regarding on the soft tissues such as around the eyes, which should be prevented from high pressure, the expected pressure would not exceed the experimental results.

V. Conclusion

We have developed an obstetric forceps contouring the head surface with stiffness-changeable pads that is controlled by air pressure regulation. We showed the effectiveness of tetrapod for the particle shape in jamming transition. We also designed an optimal configuration of the air ducts which are contained in the forceps body. In the experiments, the proposed method effectively worked well to decrease the pressure onto the infant's head during delivery assistance and consequently made delivery operation safer.

References

[1] R. Moreau, M.T. Pham, R. Silveira, T. Redarce, X. Brun and O. Dupuis, "Design of a New Instrumented Forceps: Application to Safe Obstetrical Forceps Blade Placement," IEEE Trans. on Biomedical Engineering, 54(7), 2007, pp. 1280-1290.

[2] C. Gehin, P.M. Schmitt, C. Ramon, G. Delhomme and A. Dittmar, "FOR SAFE: instrumented and secured obstetrical forceps," Proceedings of 27^{th} Annual Int'l Conf. of the IEEE EMBS, 2005, pp. 6745-6747.

[3] Gregory Tholey, Anand Pillarisetti, William Green and Jaydev P. Desai, "Design, Development, and Testing of an Automated Laparoscopic Grasper with 3-D Force Measurement Capability," Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Nots in Bioinformatics), vol. 3078, 2004, pp. 38-48.

[4] K. Kuwana, A. Nakai, K. Masamune and T. Dohi, "A grasping forceps with a triaxal MEMS tactile sensor for quantification of stresses on organs," Proceedings of 35^{th} Annual Int'l Conf. of the IEEE EMBS, 2013, pp. 4490-4493.

[5] Xuelin Wang, Yongguo Zhao, Xinjian Fan and Hao Wu, "Active gripping impedance control with dual fingers hand," IEEE Int'l Conf. on Electronic and Mechanical Engineering and Information Technology (EMEIT), vol. 9, 2011, pp. 4531-4534.

[6] Torsten Felsch and Cristian Herker, "Automatic Reconfiguration of Flexible Robot Gripping System," IEEE Conf. on Emerging Technologies and Factory Automation (ETFA), 2010, pp. 1-4.

[7] Defeng Lang Marcel Tichem and Frank Warner, "An Industrial Prototype of a Liquid Solidification Based Micro-Gripping System," Proceedings of the 2007 IEEE Int'l Symposium on Assembly and Manufacturing (ISAM), 2007, pp. 227-232.

[8] John R. Amend, Eric M. Brown, Nicholas Rodenberg, Heinrich M. Jaeger and Hod Lipson, "A Positive Pressure Universal Gripper Based on the Jamming of Granular Material," IEEE Trans. on Robotics, 28(2), 2012, pp. 341-350.