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ASPECTS REGARDING “SOFT” GRASPING IN SMART AGRICULTURAL HARVESTING TASKS

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Abstract: *Soft robotics is an exciting research field with the potential to revolutionize many engineering domains including precision agriculture. Soft grippers are bio-inspired soft robotics devices with a high degree of compliance which offers unprecedented advantages in grasping and handling fragile objects. In this context, this paper presents aspects concerning the design of grippers with soft grasping capabilities for smart agricultural harvesting tasks. Latest advances of soft gripping technologies are presented in the first part and then a systematic design methodology adapted according to VDI guidelines 2221 is proposed and used to exemplify the phases in designing a soft gripper for harvesting soft and juicy fruits.*

Key words: *soft robotics, soft grippers, precision agriculture, grasping.*

1. INTRODUCTION

Nowadays, an accelerated transition from classical agriculture to precision and vertical agriculture is taking place. This shift is dictated by automatization and is expected to improve the current productivity rate and provide food for a population that is continuously growing worldwide [1]. To expedite this transition, brand-new/adapted hardware and software technologies are needed. Some of them will have to be developed from scratch, while others that already exist will have to be adapted accordingly (e.g. mechatronics technology, digital and robotics technologies, grasping technologies, artificial intelligence, video processing techniques, etc.) [1-3].

According to [4], the main phases of the agricultural cycle are soil preparation, planting, production, and harvesting. In each phase, some tasks must be performed, some of them being exhausting (e.g. cutting certain parts of plants or plant health inspection), repetitive (e.g. harvesting fruits, plants, vegetables) or even dangerous to human health (e.g. spraying with various pesticides). Many of them could be automated but this is not an easy job because agricultural environment is highly unstructured and varied and has a lot of particularities compared to any other environments [3,4].

Automating harvesting tasks is currently one of the main research directions in the field of agriculture because is the job that requires most resources and human labor-intensive activity (e.g. for sweet cheery production is used about 70% of allocated human labor and almost 50% of the total cost is related to harvesting process) [5]. Certain types of crops such as cereals or root vegetables could be fully automated due to the fact that the harvest is done for the whole crop at the same time and there is a high level of homogeneity, but if the harvesting process is extended to a longer period of time and there are significant deviations in size, shape or fragility of the crop product (e.g. crops such as tomatoes, fruits, berries etc.), automation begins to show its limitations. This is because the product must be harvested individually and randomly according to its maturity, shape characteristics, fragility and without influencing anything around it.

Therefore, harvesting these crops cannot be fully automatized in the absence of robotic systems with a high level of dexterity, advanced end-effectors (grippers) with a good grasping strategy and advanced sensorial systems and decision-making subsystems [6].

Grasping plays an important role in automation of harvesting tasks and requires higher specifications compared to standard workpiece manipulation from industrial environment for example. As such, a proper design of the end effector (gripper) it is fundamentally important in this case. In this context, this paper analyzes various aspects regarding grippers with "soft" grasping technologies (soft grippers) and the possibility of use them in agricultural harvesting tasks to overcome the problems presented above.

The rest of this paper is structured as follows. In Chapter 2 we present an analysis of existing soft grasping technologies considering the latest advances, while in Chapter 3 we propose a systematic design methodology of a soft gripper for harvesting tasks that is in accordance with VDI guideline 2221. The methodology is also exemplified for horticulture products like tomatoes.

2. ANALYSIS OF EXISTING SOFT ROBOTICS GRIPPING TECHNOLOGIES

In a simplified approach, we can discuss about two major categories of robots - rigid-bodied and soft-bodied robots - and different constructive variants that make the transition from one side to another depending on the compliance of their material as can be seen in Figure 1 [7]. Soft robotics is currently one of the most attractive direction in the scientific community of robotics, with the potential to revolutionize the role of robotics in society and industry. Currently there are plenty of applications of soft robotics such as robot manipulators, grippers, medical robots, agricultural robots, rehabilitation robots and so on, depending on the application [8-10].

In some papers, soft robotics is called *Bio-inspired robotics* in order to highlight the similarities with biological systems where it predominates mainly soft materials (tissues), adaptable to any structure and which offer unprecedented advantages in grasping applications, soft touch, human-machine interaction, handling fragile objects, etc. [11].

Soft grasping devices (soft grippers) are products of soft robotics and represents a viable solution for agricultural harvesting tasks and the problems emphasized in Chapter 1.

Traditional robotic grippers are well known handling mechanisms that can be divided into different categories according to different classification criteria like: number of fingers, type of actuation used, mode of gripping, type of mechanism used, method of gripping and so on [12,13]. Soft grippers, on the other hand, are products where compliance of material and gripping method are the most important aspects. Also, actuators and structure of the gripper is closely integrated in this case resulting a dual actuator/structure functionality [7] and unlike classic grippers were an actuator exist for each DoF, soft grippers are considered underactuated grasping devices where not every DoF can be controlled separately.

According to [9], soft gripping can be classified in three technologies: (1) gripping by actuation, (2) gripping by controlled stiffness and (3) gripping by controlled adhesion. However, the evolution and development of these technologies span from 1970 to present and were influenced by many advances over the years that are presented in a condensed manner in Table 1. Also, Figure 2 puts in perspective the fact that gripping by actuation was the most developed and used over the time. From this category, Fin-Ray structures, compliant mechanisms, shape memory alloys and tendon-driven human hand/fingers were used in many applications [9], but Fluidic Elastomer Actuators (FEAs) are by far the oldest and widespread ones (e.g. *mGrip* Ecosystem Kits as commercial products). Electroactive polymers (DEAs and IPMCs) are commonly used in researches applications such as drug delivery and manipulation in surgical applications.

Controlled stiffness and adhesion are two bio-inspired characteristics very used in soft interaction with environment. *VERSABALL* from Empire Robotics is one of the most representative commercial products that use granular jamming technology to achieve flexible and adaptive gripping through rapid hardness modulation.

Gecko-adhesion also showed good versatility to manipulate many kinds of rigid objects with smooth surfaces [9].

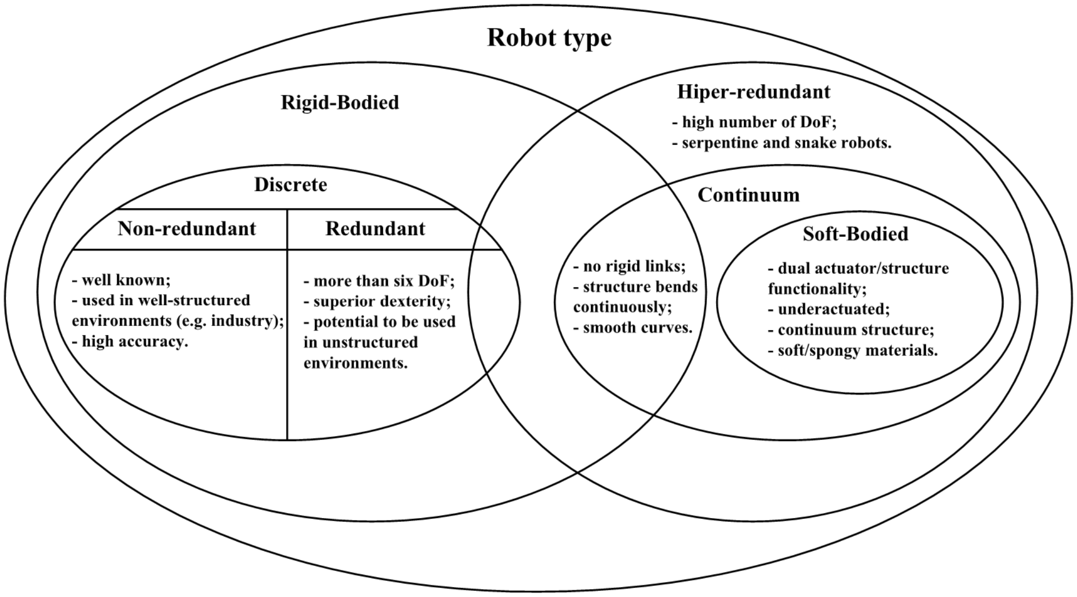


Fig. 1. Evolution from rigid-bodied to soft-bodied robotics. Analysis detailed in [7].

Fig. 2. Statistics of soft gripping technologies from 1970 to present.

Table 1. ***Overview of soft grasping technologies***

Soft gripping type	Technology	Examples
by Actuation	*Passive structure externally actuated* • Contact-driven deformation • Tendon-driven	Fin-Ray structures Compliant mechanisms Human hand/fingers inspired
	Soft Pneumatic Actuation (FEAs)	Elastomeric chambers with/without reinforcing fibres, McKibben actuators, pneumatic bellows, tube-like structures, PneuNets, hydraulically actuated hydrogels, etc.
	Electroactive Polymers (EAPs)	Dielectric Elastomer Actuators (DEAs) Ionic Polymer-Metal Composites (IPMCs)
	Shape Memory Alloys	SMPs, SMAs
	Other Actuation Methods	Stimuli-responsive polymers and gels
by Controlled Stiffness	*Granular Jamming*	Variable stiffness obtained through reversibly granular transition between fluid and solid states

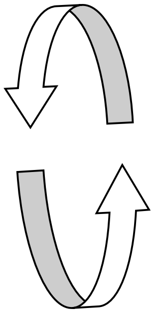
	Low-Melting Point Alloys (LMPAs)	Variable stiffness obtained with Fusible alloys, that change their phase from solid to liquid in response to heat
	Electrorheological Fluid and Magnetorheological Fluids	Variable stiffness obtained by changing viscosity of a fluid under an electric filed (ER fluids) or a magnetic field (MR fluids)
	Shape Memory Materials	Materials such as SMPs and SMAs can change their stiffness through phase transition
by Controlled Adhesion	*Electro-adhesion*	Adhesion is controlled by varying the amount of electric charges between two objects
	Gecko-adhesion (Dry Adhesion)	Adhesion is exploited from bio-inspired geckos that can climb different surfaces by using microfibers on their foot which attract climbing surface by van der Waals force
	Other Adhesion Technologies	Vacuum suction cups, capillary adhesion, octopus inspired nano-sucker arrays film

3. SYSTEMATIC DESIGN OF GRIPPERS WITH SOFT GRASPING CAPABILITIES FOR HARVESTING TASKS

As presented in Chapter 2, soft grasping technologies are varied and practical applications are discussed in many scientific papers, but it worth mention that there are not many studies about how to design soft grippers for agricultural harvesting tasks in a systematic way although grasping technology contribute decisively to the performance of a robotized solution [6]. As a proper design of gripper is of major importance, in this chapter authors will present a systemic approach for the design of grippers with soft grasping capabilities that can be used for harvesting spherical, soft, and juicy fruits. The proposed methodology is based on VDI guidelines 2221 [14] and divides the design in seven iterative steps and four phases with associated results as presented in Table 2. Readers should note that the chosen approach is not unique and other design methodologies can be particularized for designing such kind of grippers.

Next, we will present in more detail every phase from Table 2 putting the accent on the requirements and iterative evolution of soft gripper design for harvesting horticulture products like tomatoes.

Table 2. ***Design methodology adapted according to VDI guidelines 2221 [13]***

Iterations	Phases	Steps	Results
	**I – Task description**	**1.** Clarification and definition of task	Task specifications
	II - Conceptual design	**2.** Determine functions and their structure **3.** Search for technical solutions and economic efficiency **4.** Divide intro realizable modules and develop a preliminary design	Function structures Module structures First concept
	III - Embodiment design	**5.** Optimization of preliminary design **6.** Complete overall layout	Overall product design
	IV - Detail design	**7.** Prepare definitive design and CAD model	Product documentation

3.1 Task description

This is the first design phase and the most important one because the output from this analysis are task specifications that will be used for gripper design. For exemplification, in this paper the design methodology is used to design a gripper with soft grasping capabilities for harvesting medium-size, spherical soft tomatoes. To elaborate the task specifications, an analysis must be conducted. For example, designer should check firstly the OECD international standards for fruit and vegetables which offers information about physical properties such as dimensions, weight, shape, etc. For evaluating grasping force to manipulate tomatoes without damage them, mechanical characteristics such as friction coefficients and compressibility of tomatoes should be considered. After this phase, the designer will know the specifications list which, however, can be updated as the design process goes on.

3.2 Conceptual design

The second phase focus on critically analyzing the existing solutions, identification of essential problems and defining function modules to obtain a first concept of the gripper. Important choices must be made regarding: (1) number of fingers, (2) DoF (3) actuation method, (4) gripping type, (5) grasping method and (6) synthesis of mechanism used. For example, in the case of spherical objects performance and flexibility of the gripper are influenced by the number of fingers and a solution with 2-3 fingers can be sufficient [6]. DoFs influence the complexity of control algorithm so it is recommended to have 1 to 3 DoF if possible. Gripping by actuation is the most used grasping technology and possible solutions could include grasping methods based on tendon driven structures, Fin-Ray structures or compliant mechanisms externally actuated by electric motors. Pneumatically actuated grasping solutions could include FEAs or hybrid soft material/rigid structures to exploit the benefits from both type of materials.

Force/pressure sensors integration into the structure of soft material must be taken into consideration to acquire supplementary information about manipulated tomato.

3.3 Embodiment design

At this phase, a concept of the designed gripper exists, and different types of optimization procedure (analytical or numerical) can be conducted to improve the size, functionality, and control technique. For example, ‘Capability Index’ (C.I.) and ‘Grasping Index’ (G.I.) as defined in [15] can be used to optimize the size of the gripper. Grasping functionality can be improved by controlling grasping force. This can be done by modelling visco-elastic characteristics of tomato with Maxwell and Burger model [6] and then use that model to optimize the magnitude of grasping. Moreover, the mathematical model can be further integrated into grasping hardware controller to estimate the elasticity of tomato and as such to minimize the damage of the fruit. The output of this phase will be the complete design of the gripper with all interconnected function modules.

3.4 Detail design

This is the final phase where the CAD model of the gripper should be available based on the specifications, design criteria and optimization. A prototype of the gripper can be build using 3D printing technologies and molding techniques and if the experimental tests conclude with the specifications then this is the final (definitive) design and manufacturing documentation is the main output of this phase.

4. CONCLUSION

Soft grasping technologies are vectors to support the future of automation in the precision agriculture domain. This paper presented aspects regarding systematic design of grippers with soft grasping capabilities for harvesting tasks. The proposed methodology according to VDI guidelines 2221 was exemplified for harvesting spherical, soft, and juicy fruits like tomatoes.

5. ACKNOWLEDGEMENT

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Aspecte privind prinderea cu strângere ușoară în sarcini de recoltare din domeniul agriculturii de precizie

Rezumat: Robotica soft este un domeniu actual de cercetare cu potențialul de a revoluționa multe domenii inginerești, inclusiv agricultura de precizie. Sistemele de prindere cu strângere ușoară sunt dispozitive de inspirație biologică, cu un grad ridicat de complianță, care oferă avantaje fără precedent în prinderea și manipularea obiectelor fragile. În acest context, această lucrare prezintă aspecte privind proiectarea dispozitivelor de prindere cu strângere ușoară (gripere soft) pentru sarcini de recoltare agricolă. În prima parte a lucrării sunt prezentate ultimele tendințe ale tehnologiilor de strângere ușoară iar apoi se propune și se exemplifică o metodologie de proiectare sistematizată adaptată conform standardului VDI 2221 pentru proiectarea unui griper cu strângere ușoară pentru recoltarea fructelor moi și zemoase.

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