Literature Review on Micro Grippers

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Abstract

The various tasks performed by the robot in industries will depend on what type of grasping technology employed on the robot arm. The requirements such as accuracy in positioning, handling of different size components, complex shapes, repetitive tasks etc. should be considered while deciding on the type of gripper. This paper provides an opportunity to review the various types of grippers specifically miniature size grippers employed in various robotic applications, with respect to implementation of automation in the industries. An extensive literature review is carried micro grippers. This paper gives an overview on how gripper is functioning, mechanism employed and how optimization work is done in the design and development of grippers. Implementation of Automation in industries requires more flexible, versatile and small compact grippers to perform multi-function similar to the human hand. Handling needs such as high acceleration, high precision generate constraints in gripper design which can be minimized with the use of sensors.

Keywords: Automation, Micro Grippers, Design, Mechanism.

1. Introduction to Grippers:

A gripper is a device which enables the holding of an object to be manipulated. Just like a hand, a gripper enables holding, tightening, handling and releasing of an object. A gripper is just one component of an automated system. These devices include not only industrial robots but also testing machines and batch-assembly systems. In robotics, an **end effector** is the device at the end of a robotic arm, designed to interact with the environment. End effectors may consist of a gripper or a tool.

1.1 Introduction to Micro grippers:

As the term "micro" refers to the range for micro would then to be or roughly 31.6 nm to 31.6 micrometers. However, general acceptance considers particles smaller than 100 nm nanoparticles. Anything larger than 0.5 nm and anything smaller than 0.5 mm is considered microparticles. Microparticles are particles between 0.1 and 100 μ m in size. Commercially available microparticles are available in a wide variety of materials, including ceramics, glass, polymers, and metals. Microparticles encountered in daily life include pollen, sand, dust, flour, and powdered sugar. Grippers to hold or grasp these microsized objects are called **Microgrippers.** For holding and grasping microsized objects, microgrippers are needed in robotic arms. For manufacturing very small objects, microgrippers play a major role in automation. Among contact and contactless micro-nano manipulation techniques, such as optical, electrostatic, Bernoulli, ultrasonic and magnetic microgrippers are preferred, because of their ability to grasp different shaped objects with high accuracy and low cost. They have many applications in micro assembly, biology, materials science, information technology, tissue engineering and etc.

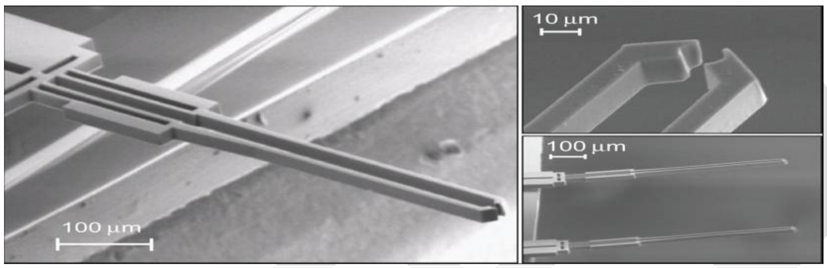


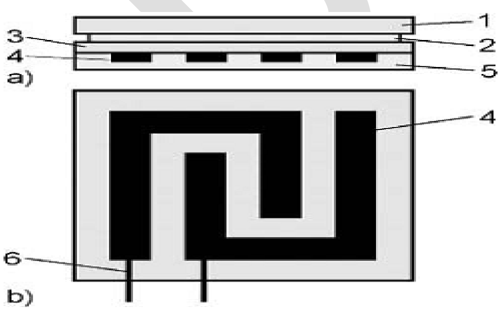
Figure 1 Microgrippers and its size proportion

2. Types of microgrippers:

When referring to robotic prehension there are four general categories of robot microgrippers,

1. Impactive – jaws or claws which physically grasp by direct impact upon the object.(They may be electrostatically driven, electromechanically driven, thermally driven,etc.,)
2. Ingressive – pins, needles or hackles which physically penetrate the surface of the object (used in textile, carbon and glass fibre handling).
3. Astrictive – suction forces applied to the objects surface (whether by vacuum, magneto- or electro adhesion).

Contigutive – requiring direct contact for adhesion (such as glue, surface tension or freezing).



1. Piezoelectric actuator
2. Acoustic coupling
3. Electro adhesive substrate
4. Electrodes
5. Dielectric
6. High voltage connections

Figure 2: Electro adhesive microgripper

a) Side view b) underside view

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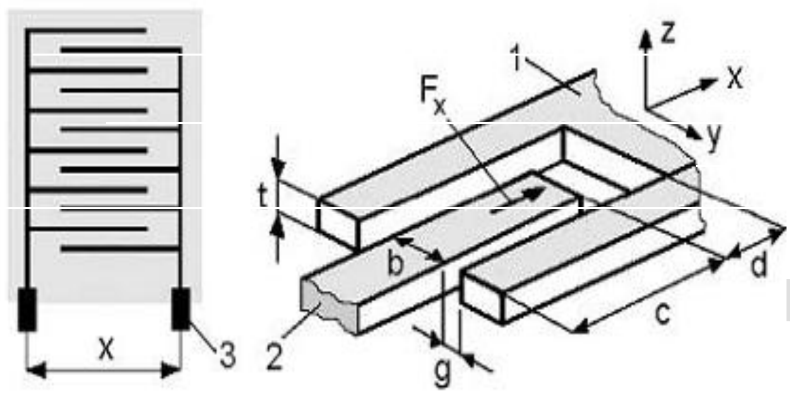


1 substrate,

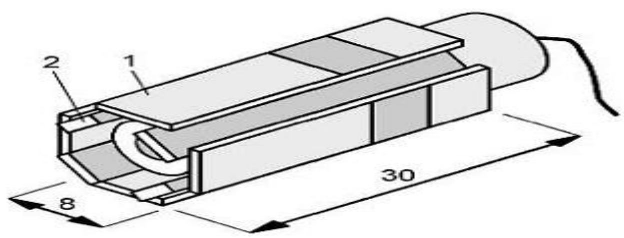
2 finger element

3 gripper jaws

t- Electrode thickness,

x- Gripper stroke

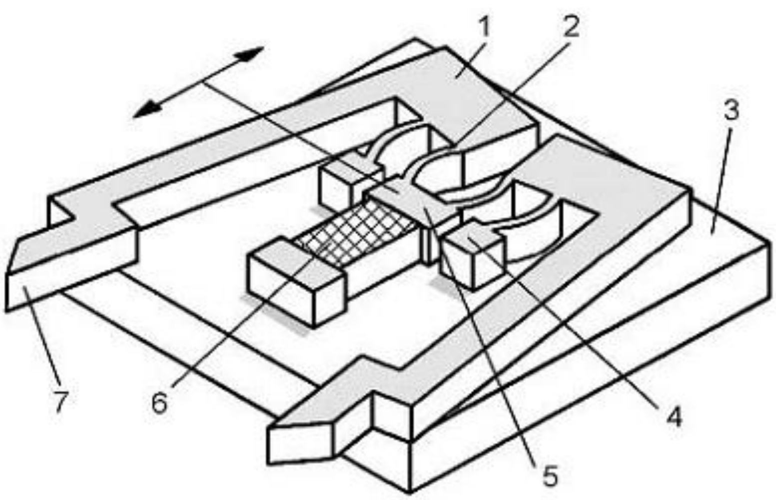
Figure 3Electrostatically driven Impact Microgrippers



1 bimetallic

2 spring steel gripper jaws

Figure: 4 thermally actuated microgripper



1 gripper finger,

2 elastic joint,

3 substrate

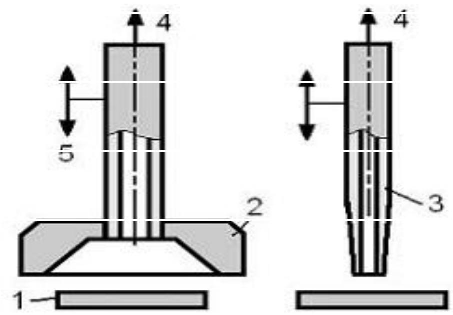
4 secured pivot point,

5 coupling link,

6 piezoelectric translators,

7 gripping surface

Figure5 Silicon gripper with piezoelectric drive



1 SMD component,

2 receiving head

3 vacuum pipette,

4 vacuum,

5 approaching motion

Figure6: Vacuum gripper for SMD components

2.1 Micro clasp Microgripper:

Sandeep &Lakshman [2012] designed and developed a micro clasp gripper for handling complex-shaped micro-scale objects in any orientation using a single rectilinear actuator. The micro-clasp gripper was designed based on systematic topology optimization and energy methods considering environment disturbances and then they fabricated a prototype using conventional micro fabrication techniques to suit micromanipulation and micro assembly tasks. Finally the micro gripper clasping feasibility and functionality is proved by conducting experiments on grasping and repositioning of irregularly shaped micro-particles on a glass substrate.

2.2 IPMC based Microgrippers:

Jain et al [2013] presented the design and control of an ionic polymer metal composite based artificial finger for micro gripper. In their work, IPMC based micro finger is actuated by controlled electromyography (EMG) signal. The EMG signal was taken from human index finger via EMG sensor. This signal is pre-amplified before transferring to IPMC for achieving the large bending behavior of IPMC.

The bio-mimetic actuation behavior of IPMC was studied by movement of index finger muscles through long tendons. The stability analysis of EMG signal from human index finger is carried out by providing the PID control system. Experimentally, it was observed that IPMC finger can hold the load up to 100 mg when IPMC finger is activated through EMG via human muscles.

Jain et al [2013] presented ionic polymer metal composite based artificial finger for micro gripper. A robotic assembly is always difficult because of position errors between two mating parts that is the reason for providing compliance in a selective complaint assembly robot arm (SCARA). Based on Simulation and experimental results carried out in IPMC micro gripper, providing compliance will facilitate peg in hole assembly.

2.3 SPCA driven Microgripper:

A Compliant SPCA-driven micro-gripper required for micro-assembly was proposed by Dapeng et al [2015]. In their study they described the mechanism design, kinematic model, static model, control strategy and conducted series of experiments to verify the feasibility of the micro-gripper. In addition, a glassy micro-tube with 150 lm diameter was clamped non-destructively by the developed micro-gripper.

Jiming and Yangmin [2010] designed a novel two-degree-of freedom (2-DOF) compliant parallel micromanipulator driven by piezoelectric actuator (PZT). They analyzed the static performance of the mechanism and verified the accuracy of the established kinematic model. They conducted finite element analysis using ANSYS software and simulation results shows that the mechanism is providing ideal linearity in terms of the kinematic and static properties.

The need for handling and manipulating micron size objects initiated the use of Micro-Electro-Mechanical System (MEMS) in micro-assembly, biological, tissue engineering like applications. Based on the above need, Nikoobin & Hassani [2012] designed the microgrippers after reviewing and comparing their different types of micro grippers available. They selected the optimized micro gripper based on study conducted by considering the following parameters: material specification, displacement amplification factor, gripping range and stroke, jaw motion characteristic, normally open and normally closed gripper, ideal shape of tips, aspect ratio, number of degree of freedom and micro actuator specifications etc. in various types of micro grippers. Finally considering all these parameters an overall algorithm is developed to design the microgrippers.

Similarly for handling miniature parts in a robotic micro assembly, Ravi et al [2015] designed a mobile micro manipulation system with compliant piezoelectric actuator based micro gripper. The compensation for misalignment was required during peg-in-hole assembly since piezoelectric actuator will produce displacement in micron range and generates high force. The speed of mobile micro manipulation system was also estimated during picking and placing of the peg from one hole to next hole position. The piezoelectric actuator based micro gripper was analyzed by controlling the voltage through a proportional-derivative (PD) controller.

Bong et al [2012] developed a new micro-gripper using MEMS technology for a robotic micro-manipulation system. They analyzed the stiffness of the gripper with the Pseudo-Rigid Body Model to estimate the grip force of micro-grippers of various scale s and materials. They conducted simulations and experiments to validate the proposed model and finally they conducted actual gripping test to evaluate the robotic manipulation system.

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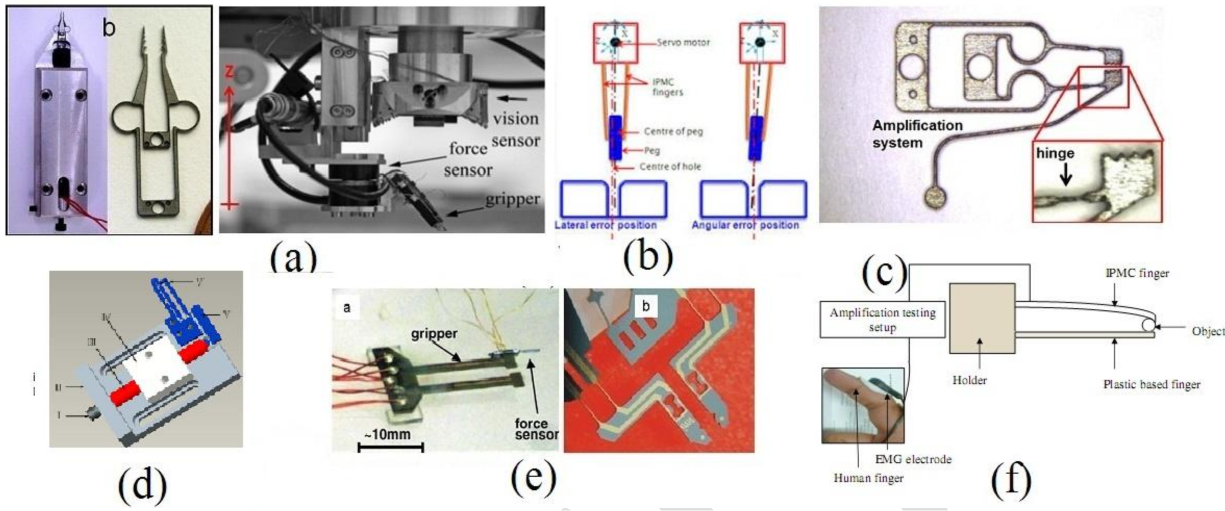

Figure.7. (a).Simple Micro Grippers and Micro Gripper with force and vision sensor
(b).Two finger based IPMC micro gripper
(c). mechanically amplified micro gripper
(d). SPCA driven Micro gripper
(e). Monolithic micro gripper with integrated silicon force sensor and microgripper with integrated force sensor
(f). IPMC based micro gripper driven by EMG signal

For the micro products assembly, a new capillary microgripper for grasping and releasing of mini and micro parts has been designed, fabricated and tested by Gualtiero et al [2013]. The developed micro gripper demonstrated good capability in grasping and releasing parts of different size, shape and material in manufacturing process of elastomeric rubber but the drawback identified was sticking of dust particles to the water droplet and the process also changes the property of rubber which reduces the reliability of the gripper

2.4 Electrostatic and Piezoelectric Microgripper:

Araz and saber [2015] investigated the mechanical behavior of electro statically actuated functionally graded piezoelectric micro gripper having two clamped micro beams symmetrically located against each other in vertical direction .They investigated the dynamical behavior of a MEMS based composite micro-gripper. The mechanical properties such as elasticity modulus, density, and piezo electricity coefficient are varied exponentially along the height of the micro-beam which is subjected to simultaneous electrostatic and piezo electric excitations. They also performed the stability analysis and determined the pull-in volt age of the device.

Holger Gotze and Lienhard pagel (2007) present a concept of piezoelectric microgripper on printed circuit board (PCB). Piezoelectric actuators used for its advantages like forces up to several Newton, stable displacement, high response speed and ease of use. Basic structure of microgripper is a construction of two manipulators with pikes of tungsten. These pikes are connected with a tungsten wire linkage which is connected with three piezoelectric bending actuators. The actuators are fixed on a PCB. Pikes are made by electrochemical etching of Tungsten wire by dipping in KOH (potassium hydroxide solution). Piezoelectric actuators are made up of piezoelectric ceramic plates which are bonded together with carbon fiber reinforced plastic (CFRP).

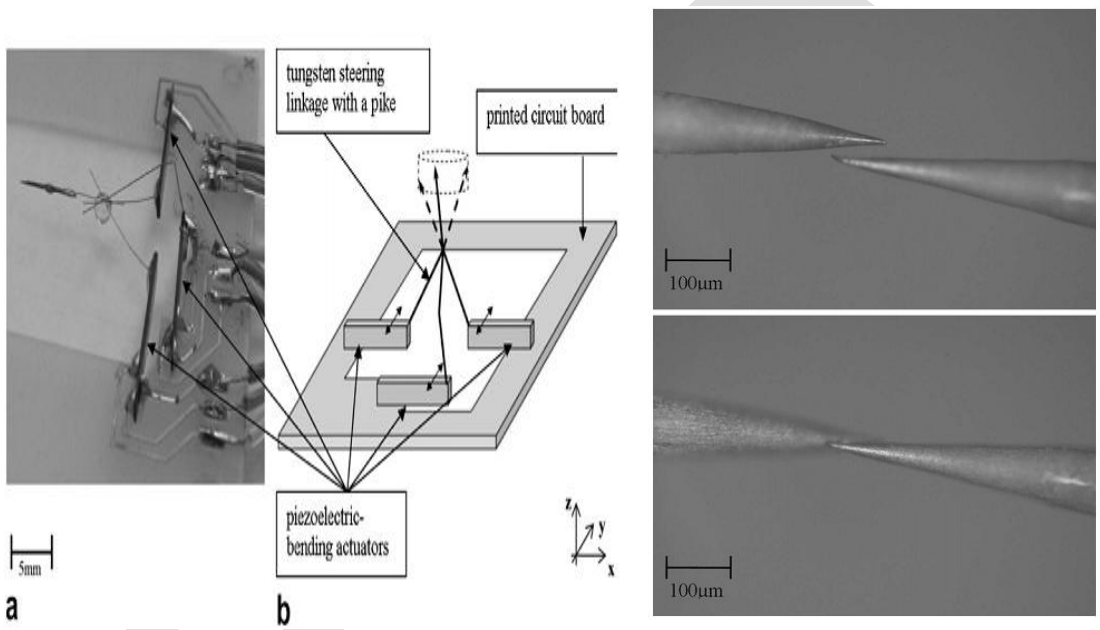

Fig8 a.View of manipulator b.Opening & closing of microgripper

Tao Chen, et al (2010) presented an electrostatically driven microgripper. They propose several approaches to solve the problems such as 1.Reducing the adhesion such as roughing surface to reduce the vanderwaals force, 2.using inertial effects or rolling, 3.using vacuum tool that generates positive pressure to overcome the adhesion between the tool and the micro object.

Since vacuum tools can't provide sufficient constraint forces and in order to handle micro objects effectively, a hybrid type electrostatic comb drive silicon microgripper integrated with a vacuum tool is found. This has the advantage of both electrostatic comb drive microgripper and vacuum tool with positive pressure can assist the gripper to release micro objects adhered to it. This microgrippper consists of the flexible beams, electrostatic comb fingers, gas pipes and glass based. The complete gas pipes are formed by glass layer and silicon layer. Two different microgrippers are designed one is to pick and place objects of a size ranging from 100µm to 150µm and other from 150µm to 200µm. The electrostatic micro actuator generates a small linear horizontal motion which is converted into the big rotational motion of the arms by an S-type flexible beam system.

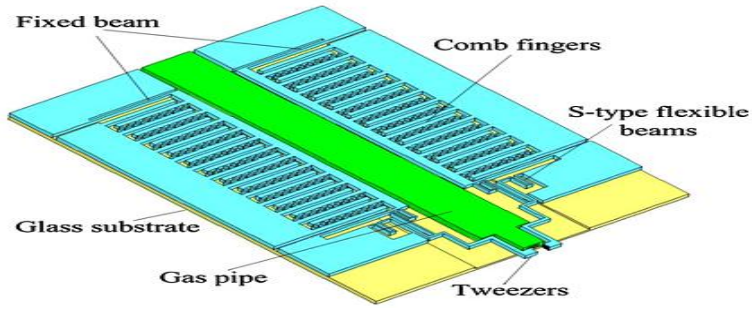

Fig 9 Model of electrostatic comb drive microgripper

Chang Seon Jeon, Et al (2006) designed and fabricated OPPMGs (Out of Plane Piezoelectric Micro Grippers) actuated by micro PZT cantilevers using MEMS processes with the purpose of reducing the power consumption and the attractive forces between objects and the micro jaws. Electromechanical and gripping characteristics of the fabricated micro PZT (Lead Zirconate Titanate) cantilevers and OPPMG (Out of Plane Piezoelectric Micro Gripper) using them were also investigated.

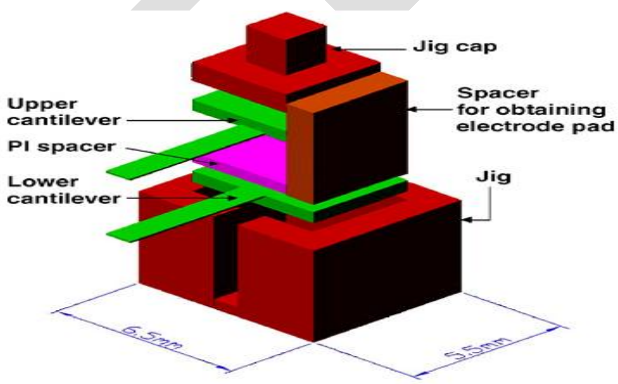

Figure10 Schematic drawing of the jig for packaging process to fabricate OPPMG between two micro PZT cantilevers using PI film spacer.

Ravi , Et al (2014) presented micro gripper which was intended to provide the long term stability to hold the object during robotic micro assembly. Two fingers based micro gripper is designed using two piezoelectric bimorph actuators where piezoelectric actuators are actuated at 0–60 V. This gripper is integrated at the end of lead screw mechanism in a mobile micro manipulation system which provides gripping and holding operations during pick and place of the object. For visualization of robotic assembly, the camera is integrated at the top of work bench. For performing robotic micro assembly operations, a grid pattern of 49 holes (7 × 7) for dexterous handling of micro pins is designed. The distance between one to next hole in a single row and column of grid pattern is kept 5 mm and diameter of each hole is 1.5 mm and depth is 10 mm.

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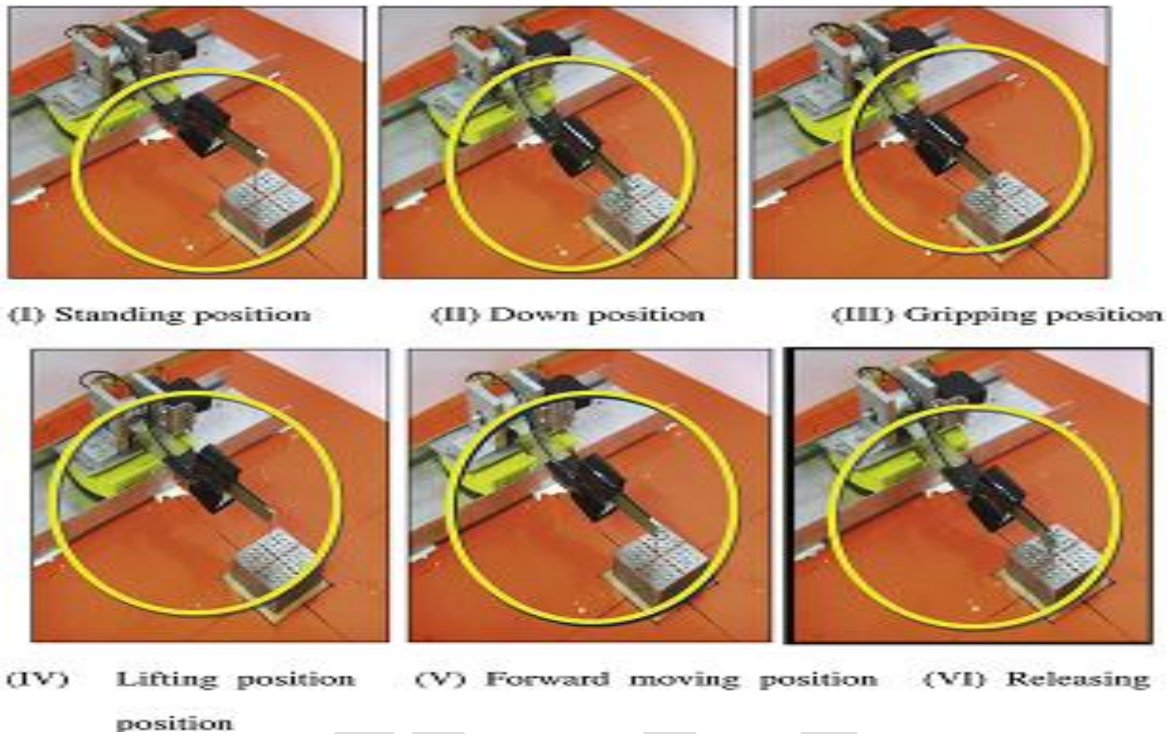


Figure 11 Positions of microgripper

Mokrane Boudaud,, et al (2016) presented the design and the analysis of a gain scheduled controller for an accurate and fast positioning with nanometer resolution of a nonlinear electrostatic microgripper. The controller is designed to achieve a positioning of the gripping arm from few hundred nanometers to several tens of micrometers with some performance criteria. The controller is designed considering noises that are relevant at the nanometer scale and nonlinearities that become significant at the micrometer scale. Therefore, a nonlinear model of the system is proposed and is reformulated into a polynomial LPV (Linear Parameter Varying) model.

Mohsen Hamedi, et al (2012) proposed a microgripper system with electrostatic comb drive mechanism. The system is characterized by fast and reliable function, low power consumption, eliminating coils and magnetic cores, simple fabrication procedure and long lifetime. These actuators, which one is a fixed electrode and the other a movable one, are called stator and rotor, respectively. By applying potential difference, comb drive beams turn to parallel capacitors and produce electrostatic force between rotor and stator which move the rotor parallel to comb drive beams

Guangmin Yuan, et al (2015) proposed a new design for an electrostatically actuated microgripper with a post-assembly self-locking mechanism. The microgripper arms are driven by rotary comb actuators, enabling the microgripper to grip objects of any size from 0 to 100 μm.

The post-assembly mechanism is driven by elastic deformation energy and static electricity to produce self-locking and releasing actions. The mechanism enables the microgripper arms to grip for long periods without continuously applying the external driving signal, which significantly reduces the effects and damage to the gripped objects caused by these external driving signals. The microgripper was fabricated using a Silicon-On-Insulator (SOI) wafer with a 30 μm structural layer. Test results show that this gripper achieves a displacement of 100 μm with a driving voltage of 33 V, and a metal wire with a diameter of about 1.6 mm is successfully gripped to demonstrate the feasibility of this post-assembly self-locking mechanism.

The active force sensor used I microgripper with an accuracy of 0.4N over a large range [-400 to 400] mN and was posted by Abdenbi Mohand , et al[2013].The mechanical structure, through a fiber suspension arrangement, provides exactly one degree of freedom. This design allows for a precised is placement sensing by a laser optical lever. The force sensing principle based on the active control of an electro static bi-polar actuator. A meso-scale prototype has been built as proof-of-concept and an especially designed controller allows for high precision measurements on a large range. The system is validated by measuring both pull-in and pull-off forces during an approach-retract cycle on water droplet. The future work would overcome the limitations of the preset prototype with improved fabrication, while retaining the same design principle.

Nayyerabbas Zaidi and ShafaatA.Bazaz (2014) presents the analytical modeling for the design of a microgripper system that comprises dual jaw actuation mechanism with real-time contact sensing. The inter-digitized lateral comb-drive based electrostatic actuator is used to move the gripper arms. Simultaneous contact sensing is achieved through a transverse comb based capacitive sensor, to detect the contact between the jaws and micro object. The detailed analytical modeling of the microgripper reveals that the stresses induced in the structure is well below the maximum yield stress of 7000MPa for single crystal silicon. The fabricated microgripper produced a displacement of 16 μm at gripper jaws for the applied actuation voltage of 45V, which is approximately the same as predicted by the analytical model.

Araz Rezaeikivi and Saber Azizi (2015) presented the mechanical behavior of an electro statically actuated functionally graded piezoelectric micro-gripper. They presented micro-gripper includes two clamped micro arms symmetrically located against each other in vertical direction. The micro beams are composed of silicon and Piezoelectric Material based on Lead Zirconate Titanate. The mechanical properties, including elasticity modulus, density and piezoelectricity coefficient are varied exponentially along the height of the micro beam based on power law distribution. The micro beams undergo simultaneous electrostatic and piezoelectric excitations. Two main sources of nonlinearities including geometrical nonlinearity and electrostatic force dominate the dynamics of the gripper. The temporal response is determined by numerically integrating the motion equations and verified by means of method of multiple scales. The contact with the particle is modeled as linear spring which increases the overall stiffness of the grippers. The stability analysis is performed and the pull-in voltage of the device is determined.

2.5 Electro thermal Microgripper:

B.E.Volland, et al (2007) described microgrippers which are needed for manipulation of microscopic samples in biology and other fields of research as micro assembly. Here, electro thermal micro actuators are used for manipulation of silicon made microgrippers for their advantage of low voltage and power requirements. A pair of micro tweezers was actuated by thermally driven micro actuator via a lever system. Duo-action implies to active open and close of micro tweezers. Base material is single crystal silicon. For electrical insulation, the structured silicon is coated with 300nm thermally grown oxide. Electrical contacts are made by 230nm thick metal film. By SEM, length of tweezers is 616µm, width 8 µm and height 20µm.The opening width at 4.5 V is 14µm. The gripping width at rest is 3µm and at 3V is 1µm.The total gripping range is 14µm.

Katerina Ivanova, et al (2006) designed and fabricated a thermally actuated microgripper from single crystal bulk silicon. A gripping width of 5 lm for 5–6 V driving voltage at a current of 50–60 mA was achieved. The gripper was operated in normal laboratory environment and in vacuum. Gripping experiments were done in a scanning electron microscope. A micron-sized object was gripped, picked up and placed.

Belen Solano and David Wood (2007) presents the design, fabrication and testing of a thermally actuated microgripper for the manipulation of single cells and other biological particles. This microgripper has been fabricated with a particular combination of surface micromachining techniques that permit the release of stress-free polymer (SU8)/metal (Au) structures without the use of sacrificial layers. The inclusion of novel thermal actuators, which completely eliminate the parasitic resistance of the cold arm, improves considerably the efficiency of the system and therefore enables large displacements at low input voltages and operating temperatures. Two types of microgripper have been fabricated and tested producing displacements of up to 262 lm at 1.94 V input voltage and 78 mW power. Micromanipulation experiments have successfully demonstrated the gripping, holding and positioning of a micro-sized object.

2.6 Pneumatic Microgripper:

A.Alogla, F.Amalou, et al (2014) developed a new type of pneumatically actuated cantilever based micro-tweezers for operation in air and liquid environment. The pneumatically actuated microgripper consists of flexible gripper arms. The gripper plate was cut from stainless steel using photo etching technology to give outer envelope, which was sandwiched between two PMMA layers. The actuator is a flexible membrane that applies force to gripper pad when the air inlet is pressurized. When the pressure is applied to the pad, arms pivot around a torsional spring consisting of a bar shaped ligament of the gripper plate. The design can be operated with two actuators on the opposite sides of the gripper plates using spring force and compliance of the arms to offer the gripping force, by air pressure. The micro tweezer can be dynamically actuated for a frequency up to 300Hz. The manipulation of micro beads as small as 200µm is demonstrated in liquid environment. The pick and place operation of the microtweezer can be precisely controlled and automated using a CNC machine. The fabrication and assembly technology of the cantilever based microtweezer are scalable, paving way to enable miniaturized devices for single cell manipulation in physiological conditions.

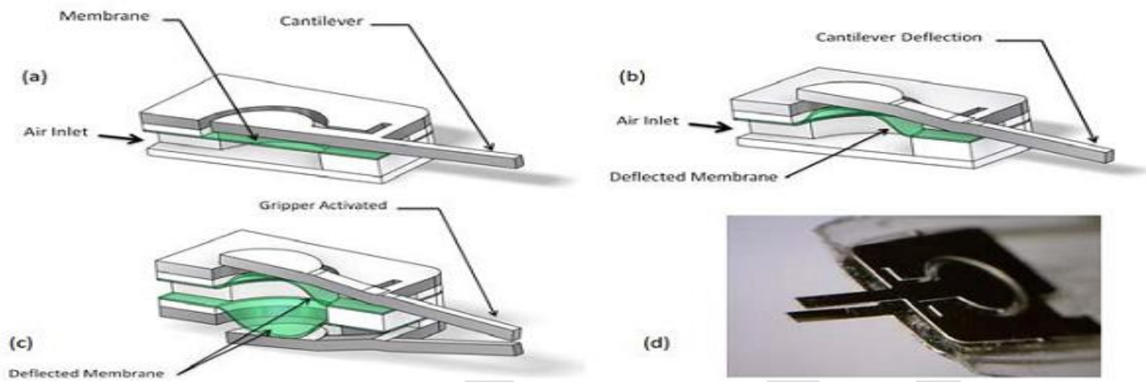


Fig 12 Working of pneumatic microgripper (a-c) , d) assembled microgripper

2.7 Micro-Electro-Mechanical Systems:

Hyum-Wookkang, et al [2013] developed micro-bellows actuator using micro-stereo lithography technology. The micro actuators are developed for an application in biotechnology, biochemistry, micro-sensor, etc. using micro-electro-mechanical system (MEMS) or other technologies. Using the MSTL technologies, they developed a new micro-bellows actuator that has a 3D bellows shape and non-contact motion. When pressure is supplied to the bellows, the angle of the folds in the bellows changes.so the vertical deformation can be obtained. The two micro-grippers were developed using a half-bellows structure with a semicircular crops section. They studied that the development of new micro-bellows actuator with inclination angles of 44° and 0° using MSTL technology.

Juan Zhang, et al [2013] presented the concept of position/force Hybrid control system. Micro-assembly technology which is used widely in micro-electro-mechanical system (MEMS) and micro-opto-electro-mechanical system (MOEMS) industry. Micro-assembly system and distance computation is to compute the distance between the small gripper and the ring object; system configuration, distance computation and feature extraction are under the micro-assembly system and distance computation. The impedance control system is used to control and maintain the correct and accurate distance ring object and the small gripper and also to **avoid** the damage.

Brandon K Chen, et al [2011] presented a new micro fabrication recipe for processing SOI wafers. The microfabrication process permits selected feature of a micro devices to be constructed from the thin buried oxide layer, while using the thick devices silicon layer to create high-aspect-ration structure for sensing and actuation. The process was applied to the construction of gripping tools, forming finger-nail-liked thin gripping tips that provide a clear view during the interactions with sub-micrometer-sized objects inside SEM. The SiO_2 gripping tips were able to with stand more than 700µN gripping forces and 38µm out-of-plane bending deflections, proving the gripping tips to be mechanically strong for micro-nano manipulation.

2.8 Shape Memory Alloys Microgripper:

J.H.Kyung, et al [2007] designed a micro-gripper for micromanipulation of micro components using SMA wires and flexible hinges. A micro-gripper with flexible hinge structure was designed to enable the fine handling of micro parts. The structure design of the micro-gripper was refined by repeated FE analyses. The characteristics of its major components, including SMA wires and a stains gauge, were investigated by experiment, and on the basis of the controlled was determined by considering the characteristics of the SMA wires, which has hysteresis response characteristics to heating and cooling. Gripping force control testing was conducted using the fabricated and micro-gripper and a PI controller, in order to verify the performance of the designed micro-gripper.

2.9 Magnetic Microgripper:

A. Ichikawa, et al [2009] presented the concept of on-chip enucleation of oocyte using untethered micro-robot with gripping mechanism. A highly functional untethered micro-robot that can withstand high gripping force in a micro-fluidic chip. The robot has gripping mechanism which is actuated by magnetic power. A permanent magnet is attached at the center of the gripping mechanism, and an electrical magnet control the position of the magnet from the bottom of the micro-fluidic chip. The open-close accuracy of the gripper is about 3.0 m. The micro-robot was made by silicon because of its machining performance, mechanical characteristic and biomedical compatibility, High power handling and cutting and gripping control of this robot.

3. Analysis:

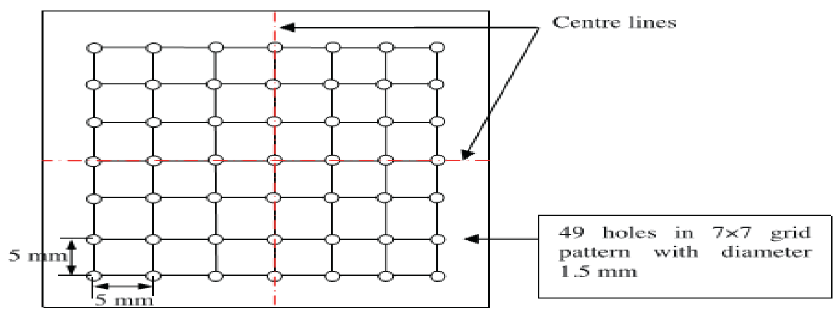
Holger Gotze and Lienhard pagel (2007) while simulating, the microgripper found out maximum deflection of the pike in x, y, z are 82.46µm, 50µm, 80.85 respectively. While performance testing, smallest measured movement of the pike is 60µm, 50µm, 65µm.

Tao Chen, et al (2010) identified that Comb drives produce constant electric force output. Based on FEA results, when driving voltage between electrostatic comb fingers is 80V, then the moving distance of fingers is 8µm. the motion of end effector is amplified to 28µm.

J.Hesselbach, et al (2007) found that in 30 experiments the probe on the load cell was approached from the same arbitrarily chosen position. The dispersion of measured values did not exceed 0.2 μm. The experimental standard deviation was calculated to 0.07 μm. The maximum measured forces with a 600 V positive operating voltage exceeded 1 mN, with 600 V negative operating voltage the reachable force was about 0.7 mN.

Ravi k.Jain, et al (2014) conducted Kinematic analysis:

The kinematics analysis of the mobile micro-manipulation system. is required where the kinematics analysis provides the position of end effector (micro gripper) by applying the Denavit–Hartenberg (D-H) method. Along with different conditions of motion for each wheel during sliding and rolling condition such as spinning, contacting and stepping of all mechanism in the system can also be identified.



Grid pattern for robotic micro assembly.

SIMULATION RESULTS:

•Free length of piezo actuator (Lm) = 40.0 mm

•Width of piezo actuator (bm) = 11.0 mm

•Thickness of piezo actuator (wm) = 0.60 mm

•Voltage range (Vm) = 0–60 V

•Young's modulus (Em) = 4.5 × 10^10 Pa

•Mass of piezo actuator (mi) = 0.0021 kg

•Lateral stiffness coefficient of piezo actuator (Kxi) = 2120 N/m

•Damping coefficient of piezo actuator (bi) = 150 N s/m

•Proportional control gain (kp) = 100,000

•Derivative control gain (kd) = 0.001

4. Conclusion

In this literature review, the various types of microgrippers, its working and the applications were studied in detail. The micro grippers are studied considering its special features in pick and place tasks, holding or grasping the micro sized objects. Based on type of actuation and its operating mechanism, the design features of the micro gripper types such as electrostatic, piezoelectric, electro thermal, micro clasp, pneumatic, IPMC, SPCA, MEMS, Shape Memory Alloys, Magnetic microgrippers were studied in detail. This work focuses on analyzing the micro grippers used in manipulation of smaller objects like single cells, blood vessels, enucleation of oocytes, micro assembly of various objects, etc. Further this study may be extended in the field for testing the prototypes of various types of microgrippers.

5. References:

1. Sandeep Krishnan, Lakshman Saggere, 'Design and development of novel micro clasp gripper for micro manipulation of complex- shaped objects', Sensors and actuators A176(2012) 110-123
2. R.K. Jain, S. Datta, S.Majumder, 'Design and control of an IPMC artificial muscle finger for micro gripper using EMG signal', Mechatronics 23 (2013) 381–394.
3. Araz RazaeiKivi, Saber Azizi, 'On the dynamic of a micro gripper subjected to electrostatic and piezoelectric excitations', International Journal of Non Linear mechanics (2015).
4. R.K. Jain, S. Majumder, A. Dutta, 'SCARA based peg-in-hole assembly using compliant IPMC micro gripper', Robotics and Autonomous Systems 61 (2013) 297–311.
5. Dapeng Zhang, Zhaengtao Zhang, QunGao, De Xu, Song Li, 'Development of a monolithic complaint SPCA- driven micro gripper', Mechatronics 25(2015) 37-43
6. Jiming Huang and Yangmin Li, 'Analysis of a Novel 2-DOF Flexure Hinge-based Parallel Micromanipulator in a Polar Coordinate System', Proceedings of the 2010 IEEE International Conference on Automation and Logistics, August 16-20 2010, Hong Kong and Macau.
7. A.Nikoobin, M.Hassani Niaki, 'Deriving and analyzing the effective parameters in microgrippers performance', ScientiaIranica B (2012) 19(6),1554–1563
8. Ravi K. Jain, Somajoyti Majumder, Bhaskar Ghosh, SurajitSaha, 'Design and manufacturing of mobile micro manipulation system with a compliant piezoelectric actuator based micro gripper', Journal of Manufacturing Systems 35 (2015) 76–91
9. Bong-Seok Kim, Joon-Shik Park, Byoung Hun Kang, Chanwoo Moon, 'Fabrication and property analysis of a MEMS micro- gripper for robotic micro-manipulation', Robotics and Computer-Integrated Manufacturing 28 (2012) 50 –56.
10. Araz Rezaeikivi and Saber Azizi "On the dynamics of a micro – gripper subjected to electrostatic and piezoelectric excitations" [2015]
11. HolgerGotze and Lienhardpagel, "Development of a micro manipulator based on Piezoelectric technology",[2007]

12. Tao Chen, Lining Sun, Liguo Chen, WeibinRong, Xinxin Li, "A Hybrid type Electrostatically driven microgripper with an integrated vacuum tool, [2010]
13. Chang SeonJeon, JoonShik Park, Sang Yeol Lee, Chan Woo Moon, "Fabrication and characteristics of out of plane microgrippers using MEMS processes",[2006]
14. Ravi k.Jain, SomajoytiMajumder, BhaskarGhosh, SurajitSaha, "Design and manufacturing of mobile micro manipulation system with a compliant Piezoelectric actuator based microgripper", [2014]
15. Mokrane Boudaud, Marcelo Gaudenzi de Faria, Yann Gorrec, Tassine Haddab, Philippe Lutz, " An output feedback LPV control strategy of a nonlinear electrostatic microgripper through a singular implicit modeling",[2016]
16. Mohsen Hamedi, ParisaSalimi, MiladVismeh, "Simulation and experimental investigation of a novel electrostatic microgripper system", [2012]
17. GuangminYuan,WeizhengYuan,YongcunHoa ,Xiaoyi Li and honglongchang "A Microgripper with a post –Assembly Self –Locking Mechanism"[2015]
18. Abdenbi Mohand Ousaid, Sinan Haliyo, Stephane Regnier and Vincent Hayward, "Micro-Force Sensor by Active Control of a Comb-Drive"[2013]
19. Nayyerabbas Zaidi and ShafaatA.Bazaz "Analytical modeling of dual actuated compliant beam microgripper system" [2014]
20. Araz Rezaeikivi and Saber Azizi "On the dynamics of a micro – gripper subjected to electrostatic and piezoelectric excitations" [2015]
21. B.E.Volland, K.Ivanova, Tzv.Ivanov, Y.Sarov, E.Guliyev, A.Persaud, J.P.Zollner, S.klett, I.Kostic, I.W.Rangelow, "Duo-action Electro Thermal microgripper",[2007]
22. Katerina Ivanova ,Tzvetan Ivanov and Ali Badar "Thermally driven microgripper as a tool for micro assembly"[2006]
23. Belen Solano, David Wood "Design and testing of a polymeric microgripper for a cell manipulation "[2007]
24. A.Alogla, F.Amalou, P.Scalan, W.Shu and R.L.Reuben ,"Development of a Pneumatically Actuated Cantilever based Micro-Tweezer",[2014]
25. Hyum-Wook Kang, In Hwan Lee and Dong-Woo Cho, "Development of a micro-bellows actuator using micro-stereo lithography technology", [2013]
26. Juan Zhang, De Xu Zhen-Tao Zhang and Wen-shen Zhang, "Position/force Hybrid control system for High precision Aligning of small gripper to ring object", [2013]
27. Brandon K Chen, Yong Zhang ,Doug D Perovic and Yu Sun, "MEMS micro-gripper with thin gripping tips"[2013]
28. J.H. Kyung, B.G.Ko, Y.H.Ha and G.J.Chung, "Design of a micro-gripper for micromanipulation of micro components using SMA wires and flexible hinges"[2007]
29. A.Ichikawa, S.Sakuma, T.Shoda, F.Arai and Satoshi Akagi[2009] "On-Chip Enucleation Of oocyte using untethered micro-robot with gripping mechanism"[2013]