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A Review on Grasping Principle and Robotic Grippers

[1]Samir Raval, [2] Bhavesh Patel
[1]ME Student,[2]Assistant Professor
Mechanical Engineering Department, L.D.College of Engineering, Ahmedabad

***Abstract* – The design and development of robotic grippers for a specific operation in Industry has been an active research area for a long while. The paper emphasis on study of existing robotic grippers, their basic design and mechanisms used for grasping and securing variety of parts. Gripper must grasp, lift and manipulate the work piece without damaging it also not letting it go. A brief classification of robotic grippers is presented along with important factors to be considered during design of a robotic gripper. This paper summarizes significant research work carried out in recent years and also presents the details of grippers and grasping strategies during this phase.**

***Index Terms* – Robotic grippers, End-effectors, Grasping, Classification of grippers.**

I. INTRODUCTION

A gripper is a device that holds objects for manipulation and has the ability of grasping and releasing objects while some action is being performed. Grippers are an important part of industrial robots interacting with the environment and objects, which are grasped for manipulative task. Usually, a gripper is a custom - engineered part, which grasps one or few objects similar in shape, size, and weight in repetitive or specific operations.

An industrial robot can be defined as a manipulator, one with reprogramming possibility which is able to perform multiple functions as like moving materials, parts, tools, and specialized devices through variable programmed motions for the performance of a variety of tasks [1].

Robot consists of a robotic manipulator and an end – effector. A robotic manipulator is an electronically controlled mechanism, consisting of multiple segments, that performs tasks by interacting with the environment. End – effector of a robot is in direct contact with the object and hence its role is critical. The end – effectors used to handle workpieces are called grippers. They are active link between the handling equipment and the work piece to be grasped.

Their main functions are dependent on specific applications and include:

- Temporary maintenance of a definite position and orientation of the work piece relative to the gripper and the handling equipment.
- Holding back static, dynamic or process specific forces and moments.
- Determining and changing position and orientation of the object relative to the handling equipment by wrist axes.
- Specific technical operations to be performed.

A proper gripper design can simplify the overall robot system assembly. It also increases the overall system reliability and decreases the cost of implementing the system [5]. Thus, the design of the gripping system is very important for the successful operation.

II. THE GRASPING PROCESS

The complexity of grasping process is often underestimated since it looks very familiar for human beings. However the automation of this process creates many problems. Design of a gripper not only depends on the characteristics of the part to be grasped but also is influenced by previous phases such as feeding and following phases such as handling, positioning and releasing. In simple words correctly fed parts require less versatile grippers while handling needs like high acceleration, re-orientation, high precision releasing generates constraints in gripper design or choice [13].

The grasping process (Figure *1*) can be divided into following steps:

i. Approaching the object: This step is the one during which gripper is positioned nearby the object.
ii. Coming into contact: The contact of gripper with work-piece is achieved by this time. In cases of contactless handling, work-piece is in the range of force field of gripper.
iii. Increasing the force: This force increment should be within certain limits such that the prehended parts neither gets damaged nor slips out of the jaws.

iv. Securing the object: When sufficient force is applied total degree of freedom of the object are removed and the object stops moving independently from the gripper.
v. Moving the object: This step involves moving the object to desired location.
vi. Releasing the object: At macro - scale usually releasing of object is accomplished by gravity.

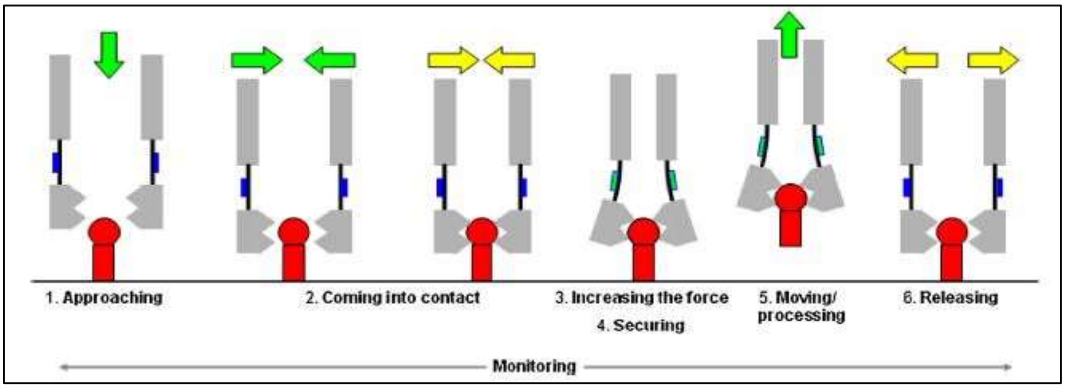

Figure 1: Steps included in a grasping process [11]

During each and every step monitoring of the grasp is required for judging the effectiveness of grasping which can be done by using various sensors like force sensors, torque sensors, slip sensors, contact sensors, etc.

III. THE RELEASING PROCESS

In general releasing of an object is achieved through gravity when the grasping principle is deactivated. However in some cases gravity alone is not sufficient as residual grasping forces remain even after grasping deactivation e.g. in cases of magnetic grippers or adhesive grippers at micro – scale and hence gravity alone is not sufficient. This calls for both active and passive releasing strategies to allow a reliable and controlled releasing [7].

As shown in releasing strategies can be divided into two groups: passive strategies: obtained by reducing surface forces, and active strategies: where an additional force allows the gripper to release the object.

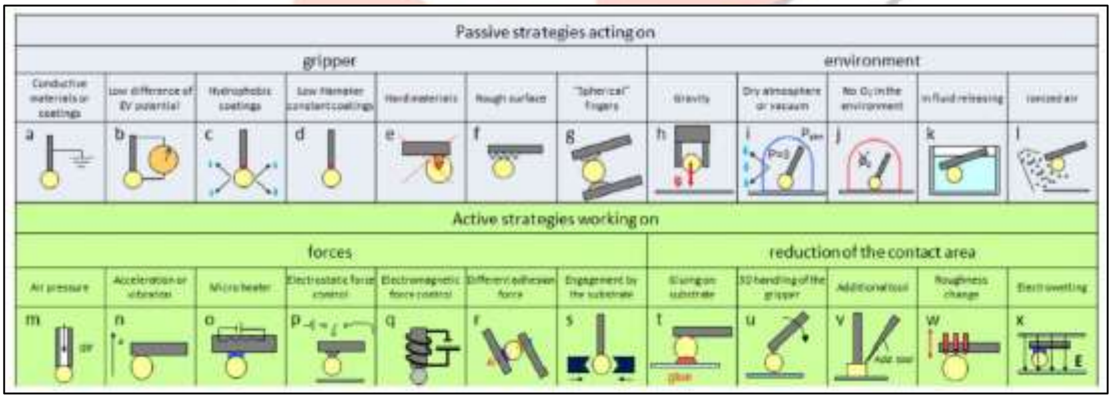

Figure 2: Releasing Strategies [7]

IV. TYPES OF GRIPPERS

The joint in the kinematic chain between robotic arm and the hand or tool is referred to as robot wrist. Depending on the application, wrist may have one or more DOF. The arm and wrist assemblies of a robot are used for positioning the end-effector. It is the end – effector that actually performs the work. It must grasp, lift and manipulate the work piece without causing damage to it and without letting it go. The simplest form of end-effector is the gripper. Being less adaptable than human hand/artificial hands, it needs to be designed specifically for a particular application.

Grippers can be broadly classified as per various means in following manner:

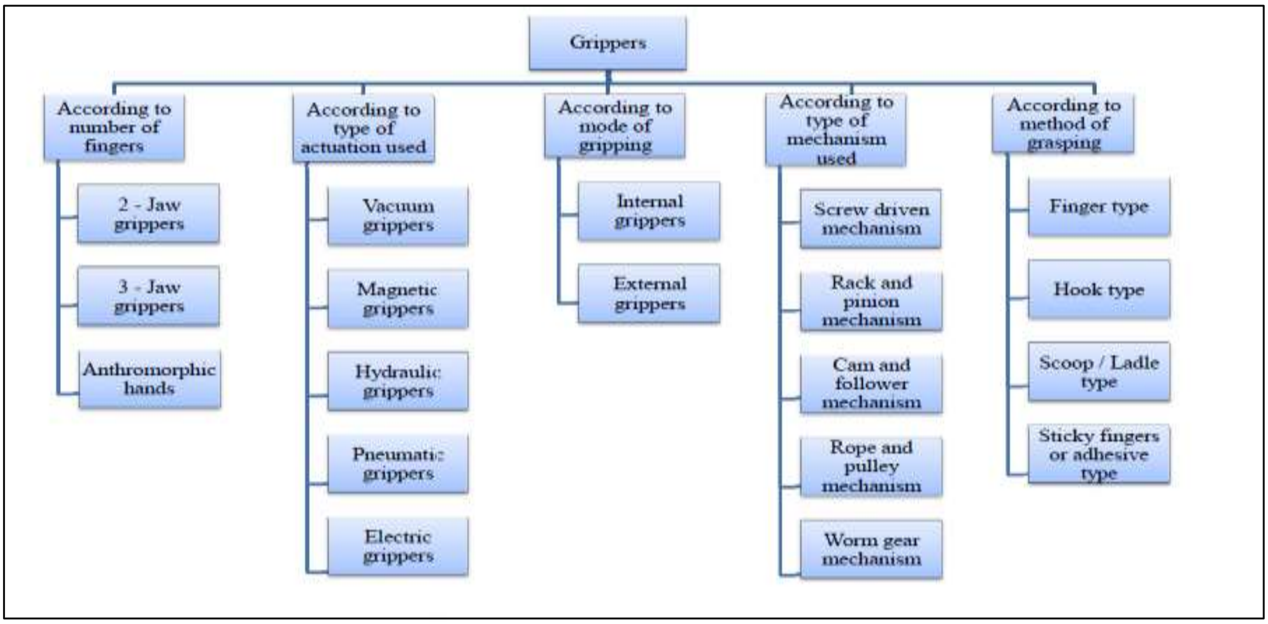

Figure 3: Broad classification of robotic grippers

According to number of fingers: The number of fingers refers to the number of contact surfaces of a gripper which interact with a part being grasped. 2-jaw grippers are the simplest of all kinds. 3-jaw grippers can form an enclosed grip of the part providing more secure grasps. Anthromorphic hands or grippers are the one having more than four fingers with many degrees of freedom suitable for adaptable grasping of irregular parts.

Figure 4: Classification according to number of fingers

According to type of actuation used: This classification of gripper is based upon the actuator source used by the gripper. Pneumatic grippers use pressurized air as a source for movement of its fingers by applying pneumatic actuators like pneumatic motors, cylinders, etc. Pneumatic grippers are most simple of all types. Also they provide highest gripping force per unit weight. Hydraulic grippers on other hand are more powerful grippers making use of hydraulic actuators but increase the system weight due to auxiliary needs like a tank, compressor, oil recirculating channels, etc. Electric actuators can on other hand provide added advantages like highly efficient and clean systems. Being easily controllable, its use is increasing day by day.

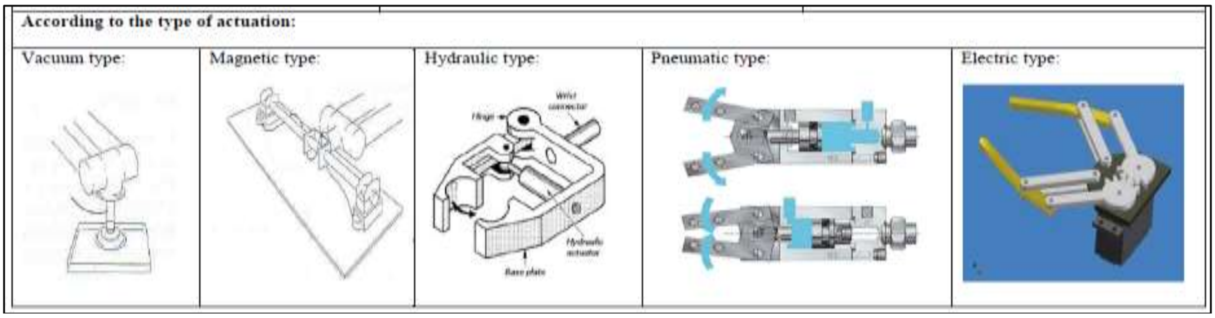

Figure 5: Classification according to types of actuation

According to type of mechanisms used: The linkage category covers a wide range of design possibilities to actuate the opening and closing of the gripper. The design of linkage determines how input force Fa to the gripper is converted in to gripping force Fg applied by the fingers. The linkage configuration also determines other operational features such as how wide gripper fingers will open and how quickly the gripper will actuate. Gear and each actuation covers the method of actuating the gripper fingers using a gear and rack configuration. The rack gear would be attached to a piston or some other mechanism that would provide a linear motion. Movement of rack would drive two partial pinion gears and these would in term open and close the fingers. Cam actuation covers a cam and follower arrangement using a spring located follows, cam provides the opening and closing action of the grippers. Screw – Type actuation method has a screw turned by a motor, usually accompanied by a speed reduction mechanism. When screw is rotated in one direction, this causes a threaded block to be translated in one direction. When the screw is translated in opposite direction the threaded block moves in opposite direction. The threaded block is, in turn, connected to the gripper fingers to cause the corresponding opening and closing action. Rope, and pulley mechanisms can be designed to open and close a mechanical grippers. As the nature of these mechanisms, some form of tension mechanisms, some form of tension device must be used to oppose the motion of rope or cording pulley system.

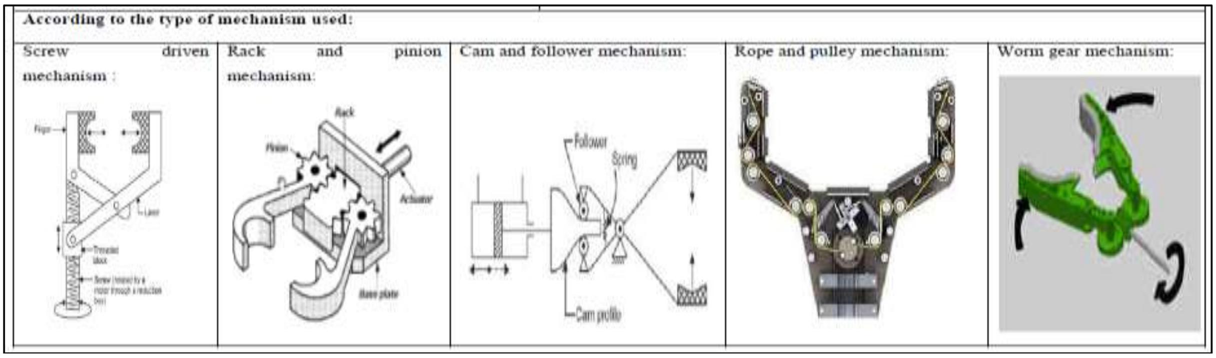

Figure 6: Classification according to type of mechanism used

V. GRIPPER FORCE CALCULATION

The gripping force required at the jaws of a gripper can be calculated as below:

Friction force= $\mu \times$ gripping force $\geqslant \frac{(a+g)*m}{2}$

Gripping force $= \frac{(a+g)*m}{2*\mu}$ = Reaction force at Jaws

Where, m is the mass of object
a is the acceleration imparted by robot
g is the acceleration due to gravity
μ is the coefficient of friction between object and Jaws of the gripper

VI. EXISTING LITERATURE

Chen F. Y. [3] studied the kinetic characteristics of grippers for industrial robots. Primary concern was to establish the input-output force relationship of grippers, and to determine the safe gripping force in coping with the postural change between the gripper and the work-piece during a load transfer process. Paper concludes about how the selection of grippers is influenced by the exterior form of the work-piece. Also, mechanical properties of the work-piece and the surface conditions, fragility are equally important factors. Figure shows some typically important factors for a gripper design.

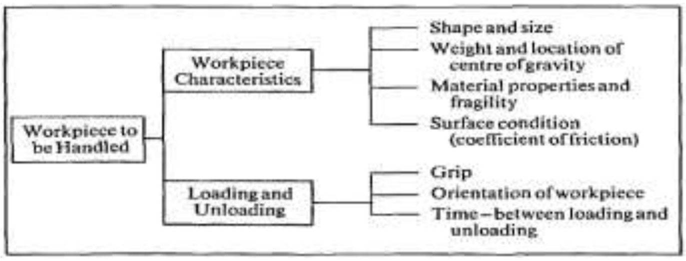

Figure 7: Important factors for gripper design [3]

Chen F. Y. [4] investigated gripping mechanism for industrial robots. A gripping mechanism is a motion converter, which converts a given input actuator's motion into the desired output gripping motion. Many gripping mechanisms have been presented here that are potentially capable of producing the motion requirements for the mechanical jaw type grippers. A elaborated study of various grippers using variety of pair elements is carried out. Such a classification scheme is indeed essential as a basis for organised study of gripping devices for industrial robots.

Dutta A., Muzumdar G., Jayarajan K., et. al [6] presented certain important aspects of design along with experiments carried out using a dextrous gripper developed for nuclear application. The authors have developed a Hybrid position/force controlled gripper with slip sensing ability for their application. Gripper has a payload of 2.5 kg and is actuated by a DC motor via a wire rope. The only draw-back of using the wire rope is that it limits the maximum distance between the motor and the gripper. The results obtained verify that slip prevention is possible by control of the force applied by the gripper. However, the force response is affected by the elasticity and friction of the wire rope.

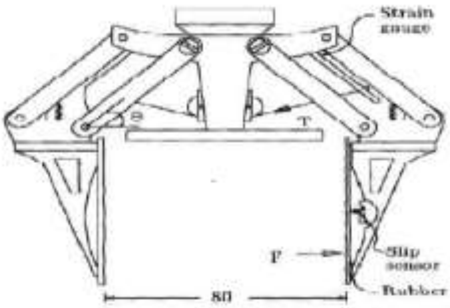

Figure 8: Schematic of gripper developed for muclear environment [6]

Kragten G. [8] achieved stable precision grasp by a simple design modification of fingers i.e., providing a curve on to the distal phalange in under-actuated hands. This modification allows under-actuated hands to grasp and hold small objects without any additional mechanism to be incorporated. Curving of distal phalange alone is not sufficient to achieve stable precision grasp. They do exist when curved distal phalange are combined with a mechanical limit in-between itself and the proximal phalange preventing hyper - extension of the distal phalanx. Thus, curvature provided must be within a certain range based on potential energy approach. Limit mainly depends on the actuation torque, relative torque between both phalanges, maximum extension angle of distal phalanx, its length and object size.

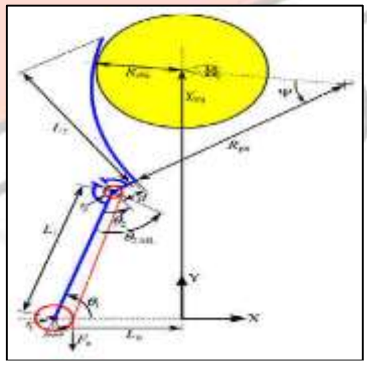

Figure 9: Schematic of the left finger with curved distal phalange [8]

Tincani V., et al. [9] worked upon the design of a novel end – effector that combines the essential mechanics and control simplicity of under-actuated devices, together with the high levels of maniputability usually featured in dextrous robotic hands. The concept of active surfaces i.e., engineered contact surfaces able to simulate different levels of friction and to apply tangential thrust to the contacted object, provides the enhancement in the proposed gripper. A mechanical solution is presented, which implements the proposed idea through the adoption of one DOF active surfaces mounted on the fingers. A mechanical hand actuated by timing belts, idler pulleys and combination of linear spur gears is developed and manipulability analysis of the developed gripper is presented to highlight the introduced dexterity advantage.

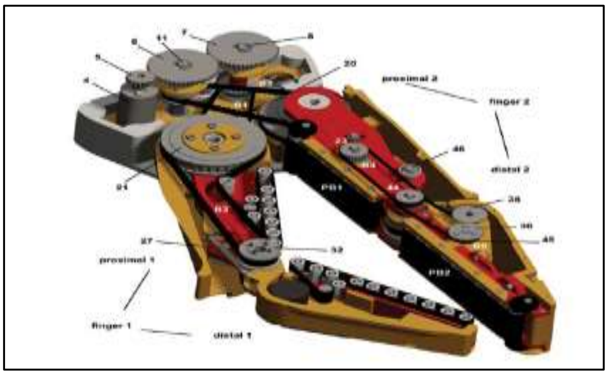

Figure 10: Mechanical hand with active surfaces [9]

Dzitac P. [10] investigated a grip force and slippage control for robotic object manipulation based on mechanical friction. In this paper an approach for holding the required load reliably in a robotic gripper without application of excessive forces is discussed. Using rollers to grip and hold objects is counterintuitive, but it actually works unexpectedly well, mainly because this provides a solution to the challenge of incipient slippage detection. Incipient slippage is the “tell-tale” sign that slippage is about to occur, giving the robot a chance to correct the grip forces in order to prevent uncontrolled object slippage. A 2 jaw parallel gripper with rollers used as fingers is developed and tested to grasp objects. The shafts of the rollers are made of steel and a coating of PTFE has been done on the rollers for proper grip. Most materials work fine, but the low coefficients of friction such as that of PTFE require higher grip forces. The main weakness of this gripper design is that it detects slippage in only one axis. Further work is needed to add slippage detection capability in the other axes.

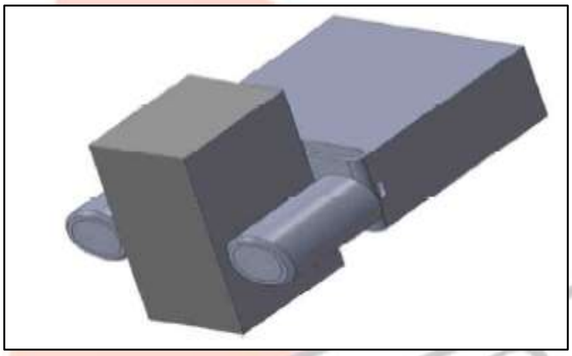

Figure 11: Friction-base parallel jaw gripper with rollers [10]

Chen C. [12] developed a five – bar linkage gripper design with a compliant finger joint. The compliant joint design adopts an innovative clamped and pivoted flexible beam configuration, with one end of the beam fixed to the fingers tip and the other end rotating with a joint. The angular displacement of the beam, which is a linear function of the gripping force, is measured by a magnetic rotary encoder. Therefore, grasping can be controlled by monitoring the angular deflection of the beam. Also additional advantage of the linkage design is that it allows the misalignment of the centreline of the gripper and the work piece. 2 fingered under - actuated gripper’s developed capability can be further enhanced by adding more fingers or increasing number of linkages in each finger to achieve higher dexterity and shape adaptability.

Fantoni G. [14] examined that grasping devices and methods play a crucial role in the handling of a variety of parts, components and products. Sensors used to monitor effectiveness of grasping are classified briefly in the paper. The various automated production processes are presented as case studies and the grasping and releasing problems encountered are discussed. Also the present need for research and development towards more intelligent robotic hands and grippers with an optimal balance between mechanical structure, sensors, degree of freedom and degree of actuation is discussed. Furthermore, the most recent research is reviewed in order to introduce new trends in grasping.

Y. C. Lin, L. Y. Huang, and P. C. Lin. [15] developed an under-actuated sensor – rich gripper capable of grasping objects of unknown shape randomly placed within the workspace. The gripper can change its configuration from 2 – finger to 3 – finger mode entailing the benefits of both mechanisms. Gripper also carries pressure sensors, accelerometer and potentiometers to provide valuable information of gripper status for feedback control. Experimental validation is carried out by mounting the gripper on a 4 – DOF SCARA manipulator using cylindrical part as an object for grasping. Compliant finger mechanism allows the gripper to adequately adopt the unknown shape of the object. Authors are in a process of implementing the object identification function, optimizing the grasping configuration to the objects.

Figure 12: Two modes of gripper (a) 3-finger and (b) 2-finger [15]

Tlegenov Y. [16] presented an open source low cost basic robotic end effector platform for facilitating research on robotic grasping. The 3D design model of a three fingered under-actuated robotic gripper is presented and manufactured with minimal number of 3D printed components and an off-the shelf servomotor actuator. The fingers are driven by a worm gear mechanism whose torque ratio can be varied by placing gears of different module. Grasping of various objects is demonstrated. A simple 4 bar mechanical linkage design is used to develop fingers which are actuated by a single actuator. Also the gripper holds relatively high payload comparable with similar size tendon driven robotic end effectors. Future scope includes integration of various sensors for force feedback capability and in depth camera for object recognition to facilitate research on autonomous grasping of different shape objects.

Hassan A. [17] designed and developed a novel robot gripper useful in various automation processes including pick and place operations. The project was developed for educational and research purpose only. The system developed was a single DOF system with four fingers. The electric motor drives a single finger via a four bar mechanism. The driven finger transfers the motion to all the three fingers by a slider crank mechanism. Some geometrical parameters are determined to avoid the singularities. A geometrical study was first performed to find the relation between the different geometric parameters of the gripper. Thereafter, kinematic model was made and singular configurations were identified. Dynamic simulation was carried out. Atemga 8 microcontroller was used to control the gripper. The solution led to a geometrical solution space, which was later verified by CAD model of the gripper. Prototype was finally built and tested for validation.

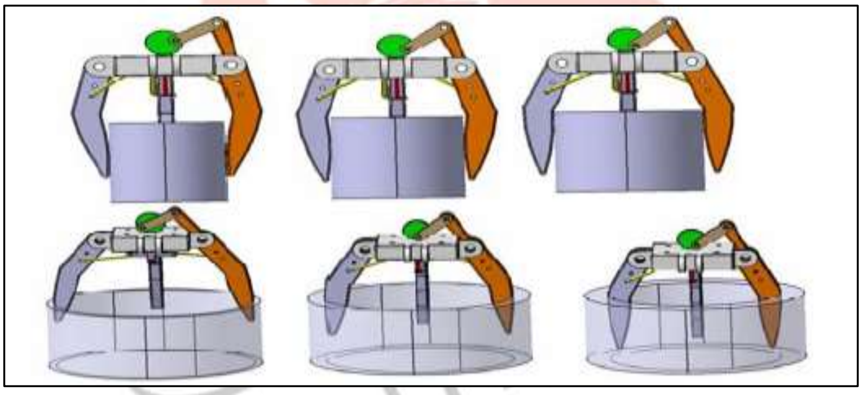

Figure 13: Novel robotic gripper actuated with a slider crank mechanism [17]

VII. SUMMARY

This paper presents a systematic framework for grasping and releasing tasks in automated processes. Moreover a brief classification of robotic grippers is presented. Furthermore summary of significant research work done in recent years is presented along with the details of grippers and grasping strategies used during this phase.

Furthermore the analysis of the recent developments in industries and academia is introduced – both the still open issues and the present and future trends in grasping technology.

After comprehensive study of existing literature on robotic grippers following observations have been made:

- Development of a robotic gripper with an optimal balance between mechanical structure, degree of actuation and degree of freedom is a key activity presently.
- Multi-objective optimization of the gripper mechanism considering both the objective functions i.e., gripping force maximization along with maximization of the object size being grasped is a future requirement.
- The effectiveness of robotic grippers mainly depends upon its ability to secure the parts during manipulation preventing deformation of the object taking care of its slippage at the same time.

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