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Optimum Kinematic Synthesis and Development of an Automatic Onion Transplanter

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ABSTRACT

Mechanization is needed to raise productivity in rain-fed lands and to increase cropping intensity in irrigated farms. Transplanting of seedlings is a labour intensive operation in involving skill and working in a stooping posture in the field. There exists a need to mechanize this operation. A number of transplanter including automatic have been developed giving satisfactory performance but have not been successfully employed in India for a number of reasons including cost of machine, lack of technical know-how, complexity of the process as a whole, etc. A mathematical model of the onion transplanting mechanism is established and implemented in MATLAB to find its optimum linkage parameters following the required trajectory. The optimization of the model linkage parameters is done using Genetic Algorithm (GA) application in MATLAB. The model is then simulated in ADAMS-View which made the analysis of the mechanism intuitive and visible. The locus curve is found to be in agreement with the results in MATLAB. The transplanting cycle is found to be of 1.027 s satisfying the high transplantation speed requirement. The maximum velocity of the mechanism was 0.57 m/s and acceleration maxed at 7.25 m/s^2 found to be within the required limit. The final prototype manufactured is seen to satisfy the results obtained earlier.

Keywords— **Automatic onion transplanter, optimum kinematic synthesis, onion seedlings, transplanting mechanism, MATLAB, GA, ADAMS-View.**

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I. INTRODUCTION

Mechanization in agriculture has released millions of agricultural workers in the industrial sectors, and has helped to contribute remarkably in industrial expansion. Outputs have been increased dramatically, while reducing levels of manpower and the burdens of the worker. Every year, demand is increasing for food and fibers and will continue to increase due to a constantly expanding population.Many operations in agriculture are now being performed by machines. There are some areas, like vegetable transplanting, where mechanization has progressed very slowly, though India is the second largest producers of vegetables in world. Transplanters are particularly advantageous because they can minimize peak labour demand during transplanting operation. These peaks labour demands occur over a relatively short period of time each year. Another important element is that mechanization improves the ability to produce and deliver the product for successful marketing of vegetables. A continuous supply of products into the market has a significant effect on the economy.The transplanters are either semi - automatic or automatic. In semi - automatic machines, the plants are fed by hand into the plant-placing device. Usually automatic implements use preloaded plant cartridges, trays or potted plants, stacked on the planter, which mechanically convey the plant and place it in the ground. In automatic transplanters, the labour is partially reduced compared to semi-automatic machines. Cultural practices for some crops have been changed to modify growth habits, decreasing required labour and growing periods.

Werken J. et al., (1991) developed a finger-tray automatic transplanting mechanism. It is an early attempt of automatic transplantation based on the finger-tray invention. The finger-tray design makes it possible to discharge the plugs from the tray by pulling the plugs, with the plants, through the tray by means of a gripper. The transplanter machine consists of a furrow opener with an inbuilt gripper for pulling out the plugs and two press wheels which follow the gripper. Ryu K. et al., (2001) developed and evaluated a robotic transplanter for bedding plants. The transplanter consisted of a manipulator, end-effectors, plug tray conveyors and a vision system. The vision system was used to identify empty cells and to reduce transplanting time. Kumar G. et al., (2011) developed a 9.75 kW walk-behind type hand tractor powered 2-row fully automatic vegetable transplanter for individual paper pot seedlings. It consisted of two sets of feeding conveyor, metering conveyor, seedling drop tube, furrow opener, soil covering device, an automatic feeding mechanism, a depth adjustment wheel and hitching arrangement. Kumar G. et al., (2012) developed an automatic feeding mechanism consisting of a timing shaft, an actuating device and a clutch for feeding paper pot seedlings from a horizontal slat type chain conveyor to a horizontal pusher type chain conveyor of a vegetable transplanter was developed. Ting L. et al., (2009) discussed the seedling planting transplanting mechanism which is applied in transplantation of tobacco, corn, beet, eggplant, tomato, cotton, etc. A mathematical model of the seedling is established and the model is calculated & simulated with MATLAB.Kunjur A. et al., (1997) presented a genetic algorithm based technique for dimensional synthesis of mechanisms. Liu F. et al., (2011) presented a transplanting mechanism which was composed of planetary gear, planetary carrier, connecting rod, groove cam and planting arm. A 3-D model is built using PRO-E which is further imported to ADAMS wherein kinematics analysis and synthesis of the parameters affecting planter arm locus is done. The analysis results are of theoretical significance to the parameter synthesis and optimization. Hu J. et al., (2014) studied the dimensional synthesis and kinematic simulation of a high-speed plug seedling transplanting robot for improving the automation and efficiency of plug seedlings transplanting in greenhouse. It made use of a 2-DOF parallel mechanism with a pneumatic manipulator.The simulation results were in perfect agreement with the planned trajectory and a single transplanting cycle took 1.08s ensuring the practicality of the model and the path planned.Dülger L. et al., (2014) presented an optimization approach for synthesis of planar mechanisms. Genetic Algorithm (GA) from the optimization toolbox of MATLAB was used for the study with the constraints assigned. The GA is then compared with nonlinear constrained optimization command fmincon.

A. *Working Principle of the Transplanter*

The working requirements for the seedling planting mechanism are as follows [8]:

- As the tractor moves forward, the ground drive wheel rotates providing the motion to the planting arm.
- The seedlings are already placed in the trays having specific dimensions of arrays from which they are picked by the planting arm at a determined rate.
- The planting arm then carries the seedling to the metering mechanism tracing the trajectory planned and for which the dimensional analysis and optimization of transplanting mechanism is carried out.
- The seedlings from the metering mechanism are timed by the timing shaft to be placed in the chute one by one which carries the seedling to the furrow opener.
- The furrow opener creates a crater in the soil into which the seedling is placed in upright position. Vertical deviation below 30 degrees is permitted.
- After deploying the seedling into the ground, it should be adequately covered with the soil without causing any harm to it, during the whole process.
- When the machinery advances at a steady speed, the transplanting procedure should be stable and circular.

I. Numerical Analysis

The numerical Analysis of the mechanism is carried out considering the various requirements as have been presented in literature review.

A. *Theoretical Design Considerations*

Based on literature review and laboratory studies the following theoretical design considerations were envisaged for the proposed development of onion transplanter. The developed machine will be automatic in operation [4-7].

- It should be capable of opening the furrows, dropping the seedlings and covering the soil surface in a single pass.
- The total power requirement should not exceed the power available from currently available 25 hp tractors.
- The implement should be capable of operating in medium to heavy soil conditions.
- The implement should be a fully mounted type for good maneuverability.
- The size and weight of the implement should be such that the stability of the tractor is not disturbed.
- The time, energy required and the cost of operation for onion transplanting should be lower than existing conventional systems.
- The depth of placement of seedlings should be at 2-2.5cm.
- The operating width of the implement should cover the wheel track of the tractor.
- The implement should not cause compaction of the soil which could inhibit plant growth.
- The implement should be simple to operate, easy to manufacture and low cost.

B. *Synthesis of Seedling Transplanting Mechanism*

Simplicity is a mark of good design. The fewest parts that can do the job will usually give the least expensive and most reliable solution. At first a four-bar mechanism is tried to address the requirement of seedling transplanting mechanism. The mechanism, though the most simple and fundamental, presented certain complication owing the locus requirement of the transplanting point. The velocity and acceleration profiles obtained from the mechanism are also not satisfactory for the mechanism dynamics and the safekeeping of the seedlings being handled. Pertaining to these requirements rice transplanting mechanisms, semi-automatic vegetable transplanters and other nursery seedling handling mechanisms form the literature cited are studied. A mechanism as studied in [14] was used after modifications and the kinematic model of the mechanism is developed as shown in Fig. 3.1. It uses an RPR chain to provide the basic movement, which is then constrained by the addition ofa RR dyad. The result is a six-bar linkage that provides a more direct movement from picking of the seedling to depositing it in the metering mechanism.

C. Mathematical Model

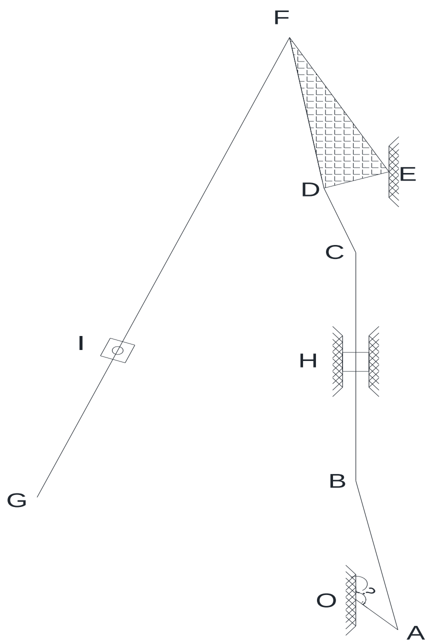

Fig. 1 Kinematic Model of Transplanting Finger Mechanism [14]

Fig. 1 shows the mathematical model of the transplanting mechanism wherein link OA is the crank to which a rotating motion is applied as input to the transplanting mechanism. Link BC is a translating (sliding) link, with respect to fixed link H, connected to link OA through link AB (connecting rod). The planar link DEF, which oscillates about ground point E is moved by link BC via link CD. Link FG is the transplanting arm of the mechanism. It is connected to link DEF at F and slides along link I which is free to rotate around itself allowing the sliding motion of link FG. The locus of the point G is the locus of the transplanter and it is here that a gripper will be attached to pick and place the onion seedlings as the mechanism is developed further.

Point O is considered as the origin (x0, y0), link H is fixed at (x8, y8) while link I rotates at (x9, y9). It is required to find the position of transplanting point G with respect to the position of the crank OA as this will help to plot the locus of the transplanting arm which is to be optimized for design [1-3].

$$x_2 =$$ (1)

$$y_2 = l_1 \sin\theta_1 + \sqrt{l_2^2 - l_1^2\cos^2}$$ (2)

Let θ_{D} be the inscribed angle between DEF, then the position of link EF can be obtained as

$$x_{6I} = l_6\cos(\theta_{5c} + \theta_{DEF} + \pi) +$$ (3)

$$y_{6I} = l_6\sin(\theta_{5c} + \theta_{DEF} + \pi) +$$ (4)

The variable distance between point F and point I is calculated as follows

$$l_{6I} = \sqrt{(x_9 - x_{6I})^2 + (y_9 - y_{6I}}$$ (5)

The instantaneous coordinates of the locus point of the transplanting finger are obtained as follows

$$x_7 = l_7(x_9 - x_{6I})/l_{6I} + x$$ (6)

$$y_7 = l_7(y_9 - y_{6I})/l_{6I} + y$$ (7)

D. Computer Aided Analysis Of Planting Mechanism Based On MATLAB

Matrix Laboratory (MATLAB) is a multi-paradigm, high-level language which is capable of matrix manipulation, plotting and simulations and interactive environment for numerical computation, visualization, and programming. Using MATLAB, you can analyze data, develop algorithms, and create models and applications.

To simulate the moving process of the mechanism, the most important thing to do is to deduce the mechanism's analytic solution of equation of displacement, using kinematic analysis method presented before, the motion equation of mechanism can be easily deduced, then we can carry on the computer aided analysis conveniently with the aid of computer and MATLAB [8, 12].

The locus curve of the mathematical model is the simulated using the MATLAB interface. The MATLAB program to above formula, the simulating curve of planting arm is shown in Fig.2.It is observed that the locus obtained is not satisfying the required pathway and further refinement of the linkage parameters is necessary.

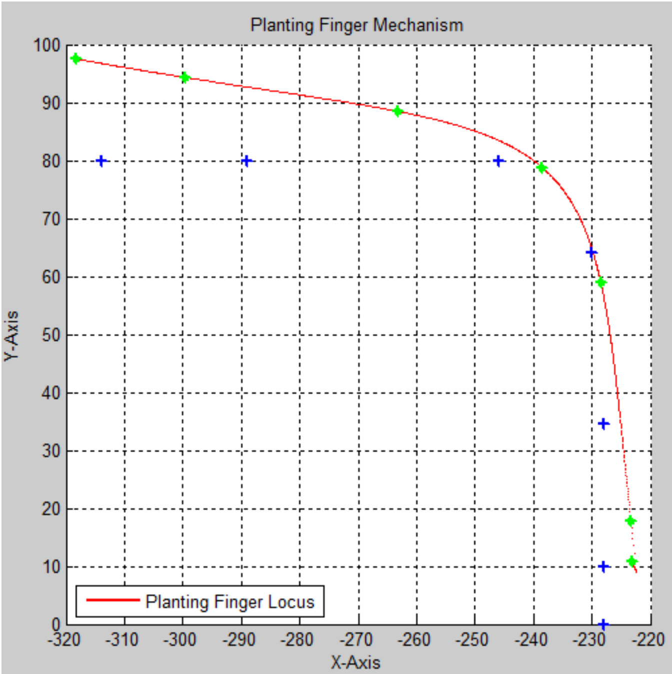

Fig.2Locus of the Transplanting Arm

E. *Optimal Synthesis Using Genetic Algorithm (GA)*

The objective function for the problem at hand is defined by the minimizing the error between the ideal path followed by the planting arm to the actual trajectory followed. This is formulated by taking ideal points at regular interval in the path or specific points of relative importance and comparing their values with the actual points at the same specific position of the input crank as

$$Z = \sum_{i=1}^{n}\left(\left(x_i - x_{i_{req}}\right)^2 + \left(y_i - y_{i_{req}}\right)\right) \quad (8)$$

The constraints to which the objective function is subjected to depend on the geometrical requirements of the mechanism so as to obtain complete and smooth motion of the mechanism without causing any undue effects on the seedlings it carries along the way. These constraints are given by

$$l_4 < \frac{(l_5+}{1.1} \quad (9)$$

To obtain this ideal curve satisfying the points at any instance is impossible. But a close conforming curve can work satisfactorily for practical purposes and is easy to synthesize the link lengths for this curve. Various methodologies are available according to the literature cited, using these parameters so as to obtain the linkage parameters like lengths, angles, etc., which provide minimal error between the expected locus and the actual locus followed by the planting arm. This is basically the optimized link lengths. In our case, genetic algorithm (GA) is implemented to obtain the optimized linkage parameters.

Genetic Algorithm can find global optimal solutions to non-linear multimodal functions [11-13]. In an analogy with the principles of gene mechanics, individuals in a population, called phenotypes, are likened to chromosomes. The optimized linkage parameters obtained using GAs are presented in Table I. After optimization of the linkage parameters, the locus curve obtained is as shown in Fig. 3 showing better agreement to the required locus. The whole mechanism with the locus of the transplanting finger is shown in Fig. 4.

II. TABLE I

III. OPTIMIZED DIMENSIONS OF THE TRANSPLANTING MECHANISM

Sr. No.	Title	Symbol	Dimension
1	Length of crank OA*mm*	l_1	53
2	Length of connecting rod 1, AB*mm*	l_2	137
3	Length of sliding link BC *mm*	l_3	185
4	Length of connecting rod 2, CD *mm*	l_4	83
5	Length of rocker 1, DE *mm*	l_5	59
6	Length of rocker 2, EF*mm*	l_6	173
7	Length of transplanting arm FG*mm*	l_7	543
8	X-coordinate of fixed point E *mm*	x_5	379
9	Y-coordinate of fixed point E *mm*	y_5	24
10	X-coordinate of rotating guide at pt. I *mm*	x_8	164
11	Y-coordinate of rotating guide at pt. I *mm*	y_8	-177
12	Angle between links DE and EF *radians*	th_2	1.39

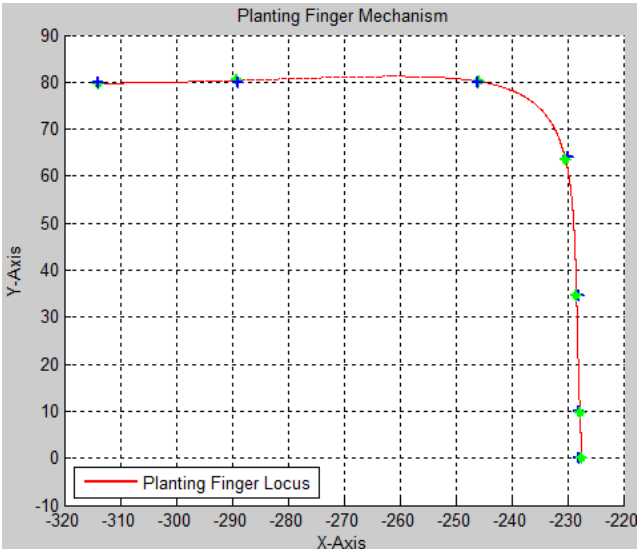

Fig.3 Locus of the Transplanting Arm in MATLAB

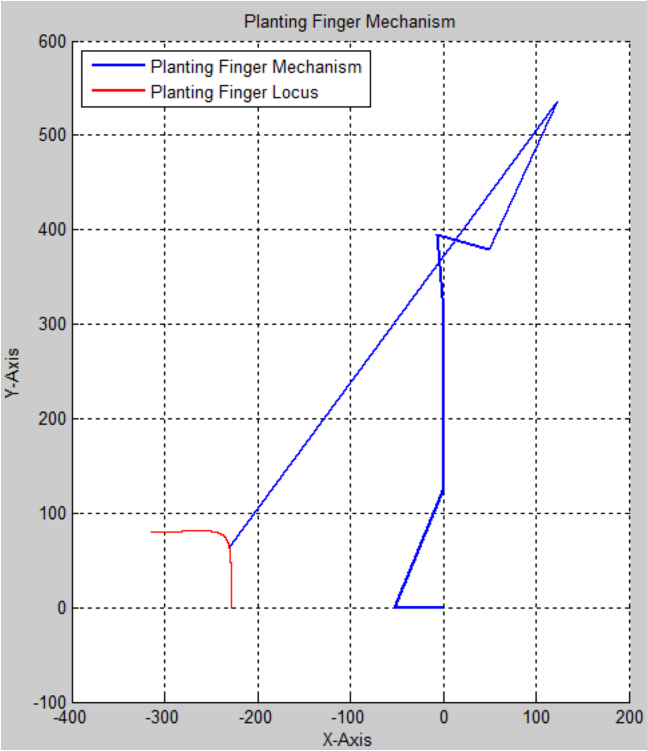

Fig.4 The Mechanism with the Locus of Transplanting Arm in MATLAB

II. Simulation Results

The mechanism developed is simulated in ADMAS to study its motion dynamics.

A. *Automated Dynamic Analysis of Mechanical Systems (ADAMS)*

ADAMS software is used for obtaining the virtual model of the transplanting mechanism. The software also provides with the useful data of transplanter's velocity and acceleration plots which are to be analyzed for the stability and long life of the whole system [10]. The model of the transplanter is as shown in Fig. 5

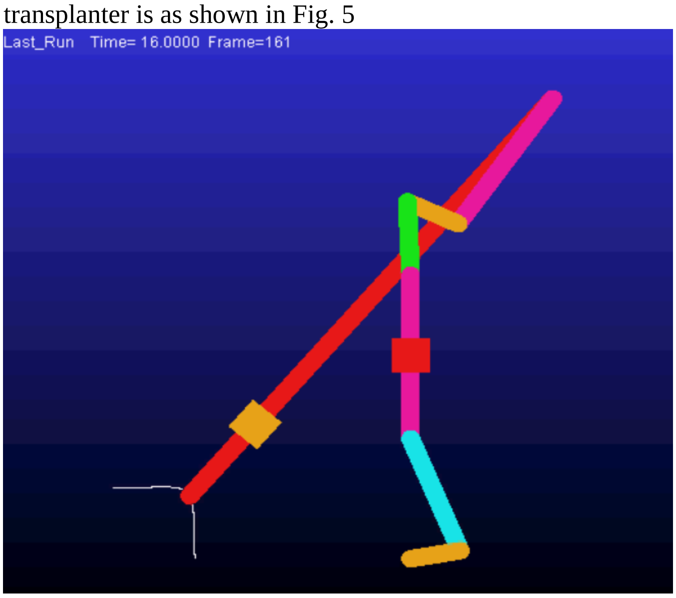

Fig.5 The Transplanter Model with the Locus of Arm in ADMAS

The transplanting locus of the mechanism is plotted in ADAMS View is shown in Fig. 6. which shows perfect agreement with the results in MATLAB.

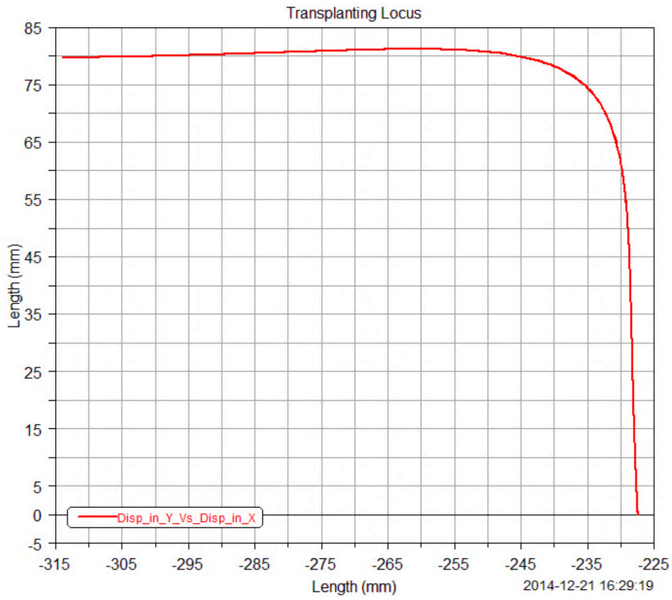

Fig.6Locus of Transplanting Arm in ADAMS

This model is further simulated under various conditions of angular velocity given at the crank input to obtain an ideal velocity and acceleration for optimized motion characteristics of the transplanter.

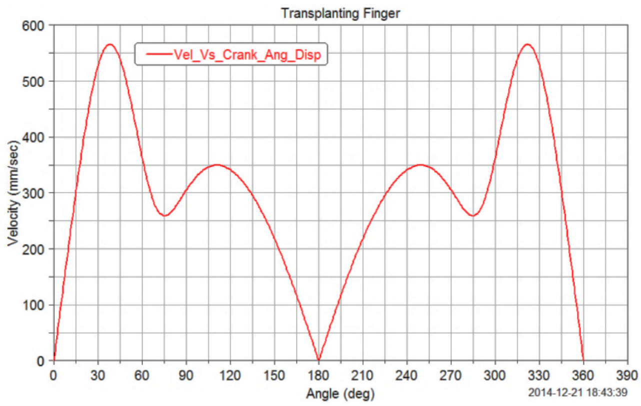

Fig.7Velocity Profile of Transplanting Finger

The maximum velocity observed is 0.57 m/s and the single transplanting cycle is 1.027 s, which meets the high-speed transplanting demand [10]. The angular velocity is zero at the start and end of each transplantation trajectory ensuring the transplanter motion in continuity and smoothness.

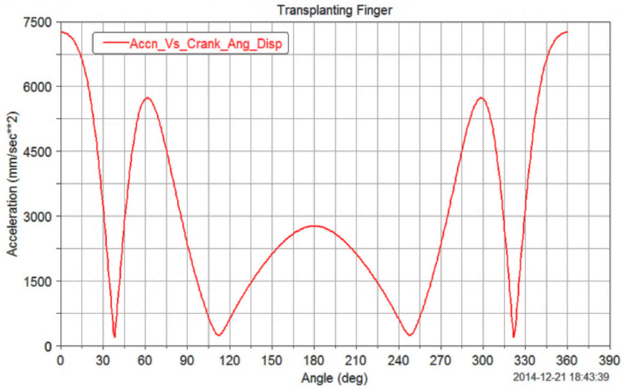

Fig.8Acceleration Profile of Transplanting Finger

The acceleration profile obtained shows a maximum value of about 7.25 m/s^2 which is less than the maximum acceleration of 45 m/s^2 the seedlings can withstand [10].

III. Prototype

Based on the simulation results a prototype of the transplanting finger is manufactured to check the actual working of the mechanism. Fig. 9 shows the final prototype model of the transplanting finger. The working of the prototype is found to be in line with the results obtained from MATLAB as well as the ADMAS simulation results.

IV. Conclusions

An automatic transplanter arm is designed based on six-bar linkage mechanism. The model is then simulated in MATALB to check the locus of the arm. The optimization technique in the form of GA is used to optimize the linkage parameters such as link length, angles and coordinate points of links of the mechanism so as to satisfy the locus requirements.Further dynamic analysis of the mechanism is performed in ADAMS-View which confirms the stability of the system. The transplanting cycle satisfies the criterion for high-speed transplantation with a cycle time of 1.027 s. Also the velocity profile at the picking and deposit points is small further validating the mechanism. Acceleration of the mechanism is also found to be with the specified limits of 45 m/s^2.The prototype is manufactured from the dimensional parameters. The testing of the mechanism validates the results obtained in simulation.

Fig. 9 Final Prototype Model

Acknowledgment

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