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Novel Walking Stick with Gripping and Lifting Mechanism

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ABSTRACT

Walking stick is an external skeleton which supports user's strength during motion. These are used by people having joint pain, backbone injury, etc. The major problem with the people with such mobility disabilities is that, while walking they are unable to stoop down in order to pick the fallen object on the ground. Through this article, we are trying to solve this problem with an addition of gripping and lifting mechanism in walking stick. The complete model of the walking stick is designed and simulated in Solidworks® software platform. The kinematics of the gripping and lifting mechanism are analyzed using the method of forward kinematics. Dynamics of the lifting mechanism is analyzed using method of inverse dynamics. Graphical representation of both the analysis are simulated in MATLAB® programming environment. Material selection is done by observing FEA (Finite Element Analysis) of the components, of the mechanism in Solidworks® simulation. The proposed walking stick is not only capable of picking object but also able to lift it up to the user's comfortable height without losing contact with the ground.

Keywords*: *Forward Kinematics, Gripping Mechanism, Inverse Dynamics, Lifting Mechanism, Stoop Down, Walking Stick.

I. INTRODUCTION

People having troubles in the mobility of the lower extremity are unable to get required torque in their joints. This happens mainly due to the problem of joint pain, bone injuries, bone fracture, etc. Walking motion is among very common activities and are classified as instrumental activities of daily living [1]. In order to provide necessary strength people use walking sticks while walking. Walking stick gives the external support to the body along with the required balance for locomotion. Walking stick is a device used by the people having mobility disabilities for defensive reasons. K. Lawson et al. mentioned the use of walking stick as a method of self-defence [2]. Old age people uses walking stick in order to support their body while walking. J. Balamurugan et al. mentioned that about 22% of the elderly respondents of India uses walking stick during locomotion [3]. Conventional walking sticks used by people are having absence of integration of gripping and lifting mechanism, hence they are unable to pick up the object fallen onto the ground easily. The problem of stooping down can be solved by two ways either we provide an external skeleton which will be attached with the human or modify the conventional walking stick with gripping and lifting functions. This literature attempts to solve this problem by integrating gripping and lifting functions into the walking stick.

The basic function of the conventional walking stick is to give an external physical support to the user. Other than this there are many functions which are being implemented on the walking sticks. Chan King-Fai et al. invented a multi-functional walking stick which has an external torch which can be adjusted by a finger at any time [4]. Niranjan Debnath et al. proposed an electronically guided walking stick for the blind people [5]. R. sheth et al. have provided a simple, affordable yet an efficient solution for the visually impaired by modifying walking stick [6]. Nava L C et al. mentioned in his literature about dynamic walking aids which are adjustable in height with shock absorbing ability [7]. These designs are unable to solve the problem mentioned earlier. Walter P Ringewaldt et al. invented a pick up walking stick mechanism [8]. It has fingers/jaws at the bottom of the stick which retracts to pick up the object fallen onto the ground. One of the major concern with this type of gripping mechanism is that, they are bound to pick certain shape or size of the object. Due to simple rotation of the jaws, it is not sufficient to hold the object having different shapes. Another point of concern in this type of approach is that, while lifting the stick to retrieve the object, it loses contact with the ground. Due to which user will feel imbalanced. User have to lift the stick to his level in order to take the object held by the jaws. In absence of the function of length adjustability in walking sticks, it becomes more difficult for the user to collect the object, hence modification in gripping mechanism is needed along with an efficient lifting mechanism in a walking stick. Along with this to avoid any misbalancing, while lifting, the stick should not loose contact with ground.

Gripping mechanism plays a vital role in holding an object. In order to pick the objects of any shape, the jaws of the gripper should follow a straight line motion. This would enable both the fingers to remain parallel to each other while gripping the object, hence different straight line mechanisms are studied. Gripping mechanisms used a parallelogram structure to close parallel jaws in literatures [9], [10] and [11]. Although these designs are effective in gripping micron sized objects, but the gripping faces inherently move along an arc-shaped trajectory causing area of contact is related to the size of the object. Justin Beroz et al. proposed a straight line gripping mechanism in which jaws follow a straight line while gripping an object [12]. The gripping mechanism used in this literature is modified version of the one proposed in literature [12]. The gripper is actuated by placing two meshing gears instead of threaded screw. Combination of Hoeckens straight line mechanism with parallelogram linkage move the jaws of the gripper in a straight line while the faces remains parallel to each other. The Hoeckens mechanism is a four-bar mechanism that converts rotational motion to approximate straight-line motion. Input rotational motion is driven by servo motor for high precision and required torque.

The picked object is needed to be transferred to the user with the help of lifting mechanism. The Lifting of the object can be achieved with the application of straight line mechanism, but achieving it with provision of required range of motion of an end effector (gripper assembly) with less amount of applied force by user is crucial. Threaded mechanisms are capable of providing the required motion, but are time consuming and heavy. Geared mechanisms have accuracy, but it is difficult to handle such a long gear train. Mechanism should consist of linkages connected with each other by simple joints, hence scissor mechanism is considered as the base of the lifting mechanism. Scissor mechanism consists of linkages connected to each other to form a criss-cross 'X' pattern. This mechanism is mostly used in lifting operations and rehabilitation purpose. D. P. Ubale et al. used scissor mechanism as a lifting mechanism to construct a multi-utility home equipment [13]. Scissor mechanism is mostly seen in automobile jacks. The gripper assembly is fixed at one end of the scissor mechanism; hence by actuation of the other end of the scissor mechanism, whole gripper assembly is lifted upwards. Complete mechanism works in two stages – gripping the object with the help of gripping function and lifting the whole gripper assembly along with object to an appropriate user's level.

The walking stick design proposed in this literature solves the problem of lifting the object which is mentioned earlier along with addition of parallel gripping. The gripping mechanism comprises of Hoeckens straight line mechanism along with parallelogram mechanism. The straight line motion of the jaw helps to hold the object more efficiently. The mechanism is optimized to achieve maximum of 10 cm ROM (Range Of Motion) of the end effector (Jaw). ROM of the end effector is calculated using forward kinematics. In order to obtain forward kinematics model, Denavit–Hartenberg (D–H) convention is followed [14]. The picked object is then lifted up with the help of lifting mechanism.

Lifting mechanism consists of simple kinematic linkages and joints. In order to pick up the fallen object, gripping mechanism is built and lifting mechanism is designed to lift the object up to user's comfortable height. The kinematics of the mechanism is analysed in order to obtain required range of motion (ROM) of end effector (gripper assembly). Motion ratio and displacement of the end effector of the lifting mechanism is obtained by using D–H convention. Kinematics and dynamics of the lifting mechanism is studied by computing forces on linkages, gears and joints. Variation of the force which is to be applied on the lever in order to lift payload of 1 kg mass is plotted w.r.t. displacement of the lever. The kinematic parameters of the mechanism are decided on the basis of minimum pulling force needed to be applied on the lever to achieve maximum possible motion ratio of the mechanism. The CAD model is tested on static loading by applying obtained forces on the lever and stick. Factor of safety (FOS) of the corresponding linkages are manipulated by doing FEA analysis of the same. Material of the components is selected on the basis of FOS and weight reduction. The final results of kinematic analysis of both the motions are simulated in MATLAB® programing environment.

This literature is divided into following sections. Section 2 describes the design methodology required to design the walking stick along with working of the design. Section 3 deals with the kinematic analysis of the gripping as well as lifting mechanism. Section 4 deals with the dynamic analysis of the lifting mechanism followed by material selection and FEA of the components. Section 5 discusses the results obtained based on the analysis done in sections 3 and 4. Section 6 concludes the literature with mentioning other applications of the mechanism and future scope.

II. DESIGN METHODOLOGY

The novel design of walking stick is not only capable of picking object but also lifting it to the user's comfortable height. The walking stick comprises of two mechanisms namely – gripping mechanism and lifting mechanism. The gripping mechanism is combination of Hoeckens straight line mechanism and parallelogram mechanism (Fig. 1, 4). The motor is connected to one of the meshing gears. The gear is connected to link L_6 at point A_5. Rotation of the link L_6 activates the Hoeckens mechanism which in turn gives linear motion to the jaws connected to it.

In order to design lifting mechanism, height up to which the object is to be lifted is determined. R. Thoreau et al. mentioned that the handle of the stick should be at the height of user's wrist in order to optimize the ergonomics of the design [15]. The walking stick is designed by considering 95% male configuration.

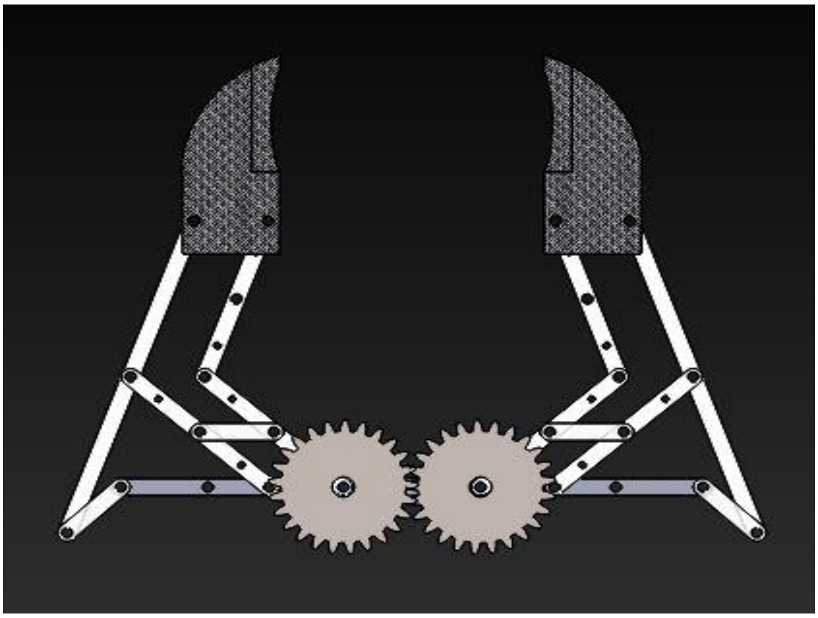


Fig. 1. CAD model of Gripping Mechanism

(a) (b)

Fig. 2(a) Complete CAD design of the walking stick. 2(b) Lifting mechanism

Lifting functionality is achieved by connecting consecutive pairs of the scissor mechanism (Fig 2(a)). As one end of the scissor is activated, output link also gets opened up. Again both the input ends of the scissor mechanism are attached to the two meshing gears by revolute joints. One of the gear is connected to the actuating lever by a slider crank mechanism (Fig 2(b)). Hence as lever is pulled upward by the user, input gear rotates along with the meshing one. In turn the scissor mechanism gets activated and gripper assembly is pulled upward. With combination of both the mechanisms, object is lifted up to the user.

The working of the proposed walking stick is as follows. If an object falls on the ground, the walking stick is placed over that object in such a way that the object gets trapped between the jaws of the gripper. The gripper collects the object due to movement of the jaws. As soon as the object is held by the jaws and when the user pulls the lever, which in turn pulls the entire gripper assembly along with the object. The lever is pulled till the object reaches to a suitable height and then the object is taken out of the jaws. Motion simulation of the working of the walking stick is shown in Fig. 3.

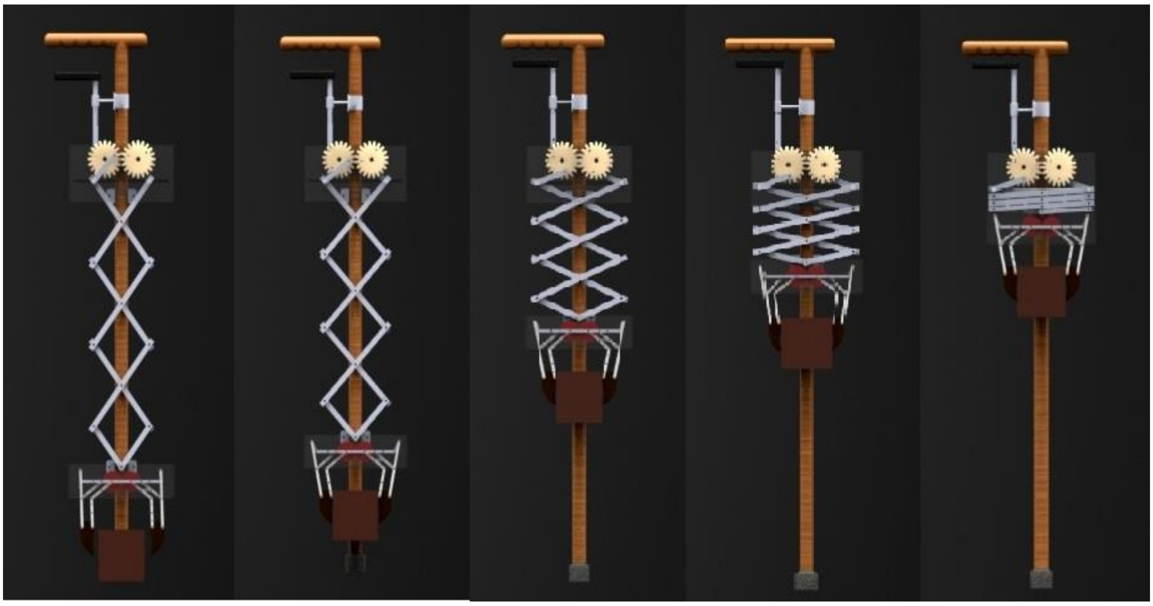


Fig. 3 Simulation of working of Walking Stick in Solidworks

III. KINEMATIC ANALYSIS

3.1 Gripping Mechanism

The gripping mechanism is designed such that the jaws of the gripper follows straight line motion, hence Hoeckens straight line mechanism is coupled with parallelogram mechanism as shown in Fig 4.

As shown in Fig. 4, Link L_6 is rotated using the motor. Joints A_1, A_2, A_3, A_4 and B_1 forms Hoeckens straight line mechanism. Hoeckens mechanism is coupled with parallelogram mechanism. The complete mechanism make points B_1 and B_2 to move in a straight line. The objective of the kinematic analysis is to obtain the ROM of end effector B_2 as motor rotates. In order to obtain ROM, position of the point B_2 is determined with change in θ_1 using forward kinematics. The ratio of the length of the linkages of Hoeckens mechanism so that the end effector would follow a straight line motion is:

$$\begin{bmatrix} L_1 \\ L_2 \\ L_3 \\ L_4 \end{bmatrix} = L \cdot \begin{bmatrix} 1 \\ 1 \\ 0.4 \\ 0.8 \end{bmatrix} \tag{1}$$

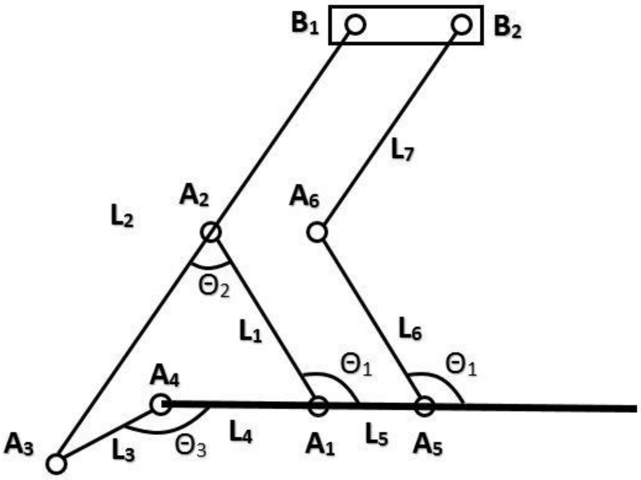


Fig. 4. Schematic diagram of gripping mechanism.

As parallelogram mechanism is attached with the Hoeckens mechanism, L_6 = L and L_7 = L. L_5 is decided on the basis of radius of the gear, hence the kinematics of the mechanism depends on the two variables L and L_5.

In order to optimize given design for picking min 10cm size object, we need to find displacement of jaw i.e. B_1, B_2. D – H convention is followed to study the forward kinematics of the mechanism. The position of the joints are determined using transformation matrices, where ${}^{i}_{j}H$ is the transformation matrix of jth joint w.r.t. frame i.

$${}^{1}_{2}H = \begin{bmatrix} \cos\theta_1 & -\sin\theta_1 & 0 & L_1\cos\theta_1 \\ \sin\theta_1 & \cos\theta_1 & 0 & L_1\sin\theta_1 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{2}$$

$${}^{1}_{4}H = \begin{bmatrix} 1 & 0 & 0 & -L_4 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{3}$$

$${}^{2}_{3}H = \begin{bmatrix} \cos\theta_2 & -\sin\theta_2 & 0 & 0.5L_2\cos\theta_2 \\ \sin\theta_2 & \cos\theta_2 & 0 & 0.5L_2\sin\theta_2 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{4}$$

$${}^{4}_{3}H = \begin{bmatrix} \cos\theta_3 & -\sin\theta_3 & 0 & L_3\cos\theta_3 \\ \sin\theta_3 & \cos\theta_3 & 0 & L_3\sin\theta_3 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{5}$$

$$ {}^{1}_{3}H = {}^{1}_{2}H . {}^{2}_{3}H = {}^{1}_{4}H . {}^{4}_{3}H \tag{6} $$

As we need to determine the end effector position w.r.t. rotation of link 6, we need to find all parameters in terms of θ_1. Using link closure principle (Eq. 6), we could find the position of point A_3 in terms of θ_1. Link closure equation also finds θ_2 and θ_3 angles in terms of θ_1.

$$ {}^{2}_{B_1}H = \begin{bmatrix} \cos(\pi+\theta_2) & -\sin(\pi+\theta_2) & 0 & 0.5L_2\cos(\pi+\theta_2) \\ \sin(\pi+\theta_2) & \cos(\pi+\theta_2) & 0 & 0.5L_2\sin(\pi+\theta_2) \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{7} $$

$$ {}^{B_1}_{B_2}H = \begin{bmatrix} 1 & 0 & 0 & L_5 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{8} $$

$$ {}^{1}_{B_2}H = {}^{1}_{2}H . {}^{2}_{B_1}H . {}^{B_1}_{B_2}H \tag{9} $$

From (9), the position of an end effector is determined w.r.t. input angular displacement of link 1. This kinematic analysis enables us to locate end effector position for each rotation of input link 6. Due to this we can observe the motion of end effector and optimize it further to achieve 10 cm movement. Graphical representation of the variation of the end effector w.r.t. rotation of link 1 is further discussed in section 5.

3.2 Lifting Mechanism

Once the object is picked up, lifting mechanism is actuated by linear motion of the lever. Vertical displacement of the end effector (gripper assembly) is dependent on the amount of lever pulled upward. In order to design lifting mechanism, motion ratio of the mechanism is required to be optimized with minimum lifting force. Motion ratio is the ratio of displacement of output end effector (Gripping assembly) and input lever. In order to reach up to the user's comfortable height, end effector has to get displaced by approx. 40 cm (section 2), when lever is pulled completely from its initial position. This condition of the ROM of the end effector is followed while designing the lifting mechanism. Motion ratio is obtained by analysing the kinematics of the mechanism.

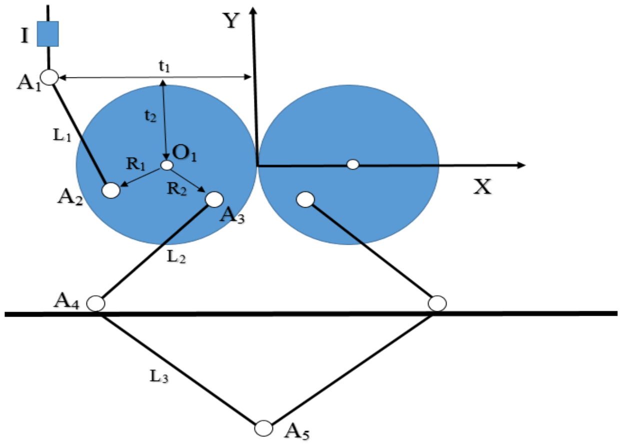


Fig. 5. Schematic diagram of lifting mechanism.

Schematic model of the lifting mechanism is shown in Fig. 5. A_i denotes the position of i^{th} joint. O_1 is the centre of the gear 1. L_1, L_2, L_3 are the link lengths and R is the radius of pitch circle of the gear. When the lever is pulled up, A_1 moves vertically upward. As A_1 moves, A_2 rotates the gear 1 and therefore corresponding meshing gear also rotates. Rotation of both the gears lifts the joint A_5 vertically upward.

Kinematics of the above mechanism is analysed by obtaining position of the end effector in terms of input lever motion using forward kinematics. In forward kinematics the end effector co-ordinate are calculated in term of angular and liner displacements of driving link. Forward kinematics of lifting mechanism is done by following D-H convention.

$$ {}^{0}_{1}H = \begin{bmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & -x \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{10} $$

In (10), x is the displacement of the lever w.r.t. stick. Where ${}^{i}_{j}H$ is the transformation matrix of j^{th} joint w.r.t. frame i. D-H convention is used to obtain individual transformation matrix.

$$ {}^{1}_{2}H = \begin{bmatrix} \cos\alpha_1 & -\sin\alpha_1 & 0 & L_1\cos\alpha_1 \\ \sin\alpha_1 & \cos\alpha_1 & 0 & L_1\sin\alpha_1 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{11} $$

$$ {}^{6}_{2}H = \begin{bmatrix} \cos\alpha_2 & -\sin\alpha_2 & 0 & R_1\cos\alpha_2 \\ \sin\alpha_2 & \cos\alpha_2 & 0 & R_1\sin\alpha_2 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{12} $$

$$ {}^{6}_{3}H = \begin{bmatrix} \cos(\alpha_2+\phi) & -\sin(\alpha_2+\phi) & 0 & R_2\cos(\alpha_2+\phi) \\ \sin(\alpha_2+\phi) & \cos(\alpha_2+\phi) & 0 & R_2\sin(\alpha_2+\phi) \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{13} $$

$$ {}^{3}_{4}H = \begin{bmatrix} \cos\alpha_3 & -\sin\alpha_3 & 0 & R_1\cos\alpha_3 \\ \sin\alpha_3 & \cos\alpha_3 & 0 & -D \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{14} $$

$$ {}^{4}_{5}H = \begin{bmatrix} \cos\alpha_4 & -\sin\alpha_4 & 0 & 0 \\ \sin\alpha_4 & \cos\alpha_4 & 0 & L_3\sin\alpha_4 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{15} $$

In (10 - 15) α_1, α_2, α_3, α_4 are the angular displacements of the joint angles. (10 - 15) give the final transformation matrix.

$$ {}^{0}_{5}H = {}^{0}_{1}H\,{}^{1}_{2}H.{}^{2}_{3}H.{}^{3}_{4}H.{}^{4}_{5}H \tag{16} $$

From (16), the final position vector of the end effector is determined. The position of the end effector changes with change in *x*. The graphical representation of the end effector is explained in section 5.

IV. DYNAMIC ANALYSIS

Dynamic analysis of the lifting mechanism is carried out using inverse dynamics. In inverse dynamics analysis, forces on the body are calculated based on the kinematics of the body. Forces are calculated by considering the lifting motion as a quasi-static motion. Weight of the object gripped by gripping mechanism is considered to be 1 Kg. Based on this weight, forces on each joint are calculated. Here F_1, F_2, F_3 are the tensile forces acting on the link 1, link 2 and link 3 respectively. F_{lever} is the force applied on lever by user. R is the radius of the pitch circle of the gear.

$$F_3 = \frac{0.5W}{\sin(\alpha_4)} \tag{17}$$

$$F_2 = \frac{F_3 \cos(\alpha_4)}{\sin(\alpha_3)} \tag{18}$$

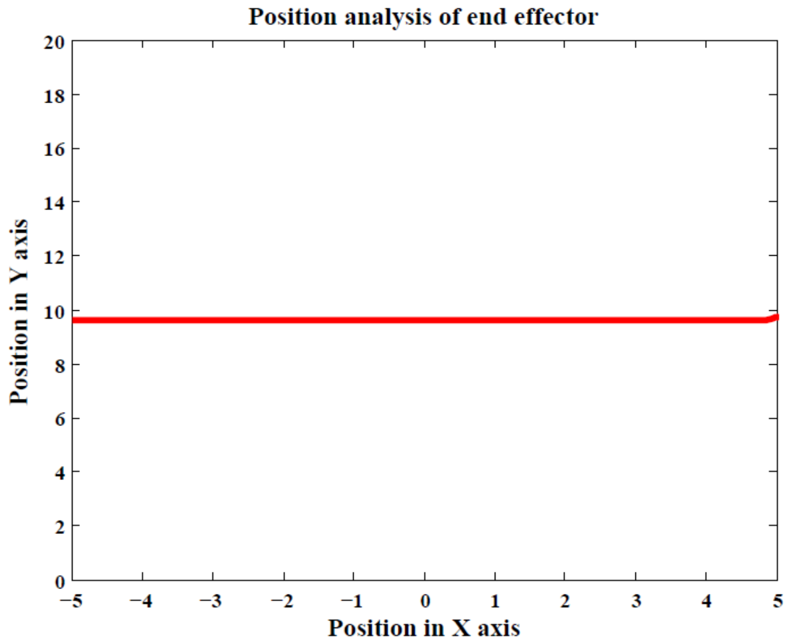
$$R_1 \times F_1 = R_2 \times F_2 + R \times F_t \tag{19}$$

$$F_{lever} = F_1 \cos(\alpha_1) \tag{20}$$

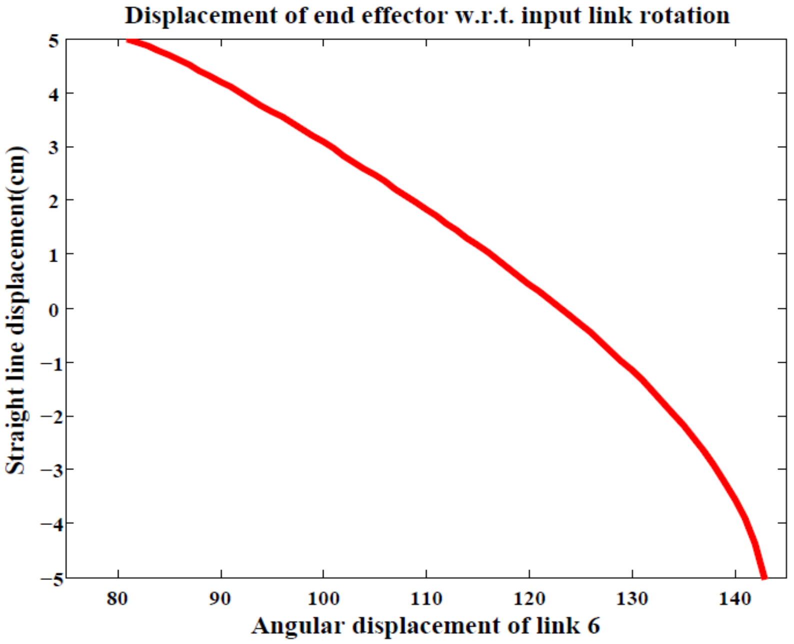
Equation (20) gives the force that is required to lift the 1 kg payload. The maximum forces acting on walking stick and on lever are then applied on the CAD model and corresponding FEA is done in Solidworks® simulating software. The material selection of each component is done on the basis of FOS obtained from FEA and mass of it. The stress generated on the components from the FEA due to the application of peak forces are observed. Graphical representation of the forward kinematics and inverse dynamics along with FEA of the elements are explained in section 5.

V. RESULTS AND DISCUSSION

Design of this novel walking stick is compatible to grip objects inside 20 cm cube. The gripping mechanism is inspected for different values of L (design parameter). It is found that for L =2.4 cm the ROM of end effector comes out to be 10 cm, which satisfies the design criteria. In order to achieve this input link has to rotate 60 deg. his input link will be driven by servo motor for precise motion of end effector. Fig. (6(a)) shows the position of the end effector along Y- axis w.r.t. X- axis. This shows that the jaws of the gripper are having movement in X-direction only. Which shows that the objective of gripping mechanism is satisfied. Fig. 6(b) shows the position of end effector w.r.t. angular rotation of the input link.

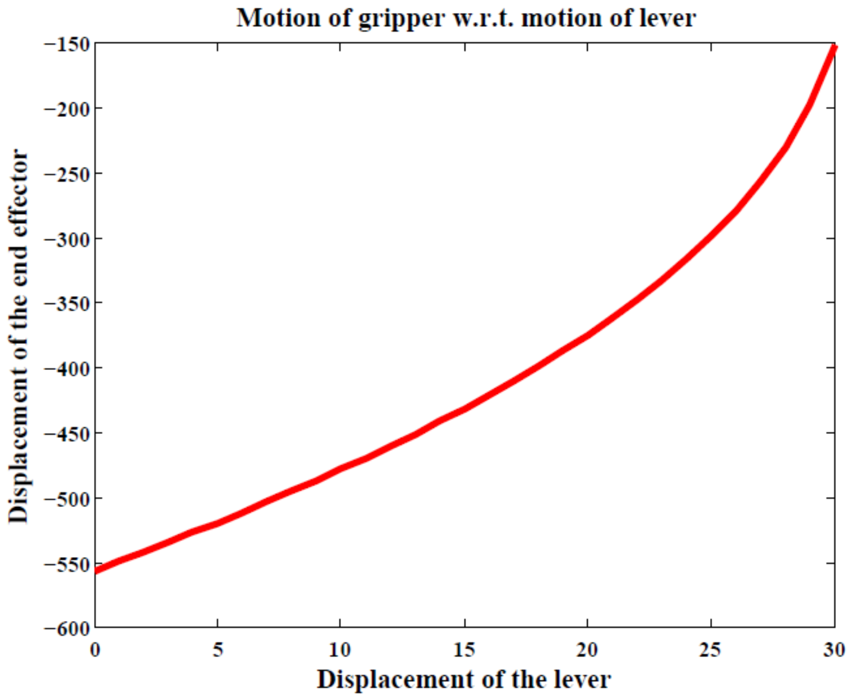


(a)

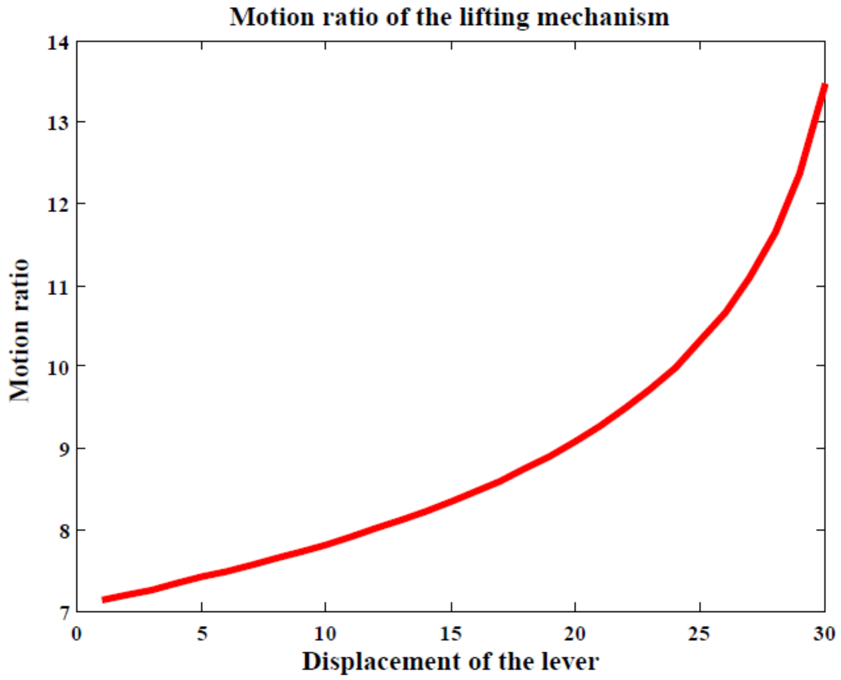


(b)

Fig. 6. (a) Position of the end effector (Gripping mechanism) (b) Straight line displacement of end effector.



(a)



(b)

Fig. 7. (a) Position of the end effector (ROM), (b) Motion ratio of the lifting mechanism.

Fig. (7(a)) shows the range of motion of end effector when the lever is pulled up by just 3 cm. Fig. (7(b)) shows that the motion ratio of the lifting mechanism is an increasing function and design is capable of lifting of gripper assembly up to 40 cm. This shows that the kinematics of mechanism satisfies the criteria of ROM required for an end effector.

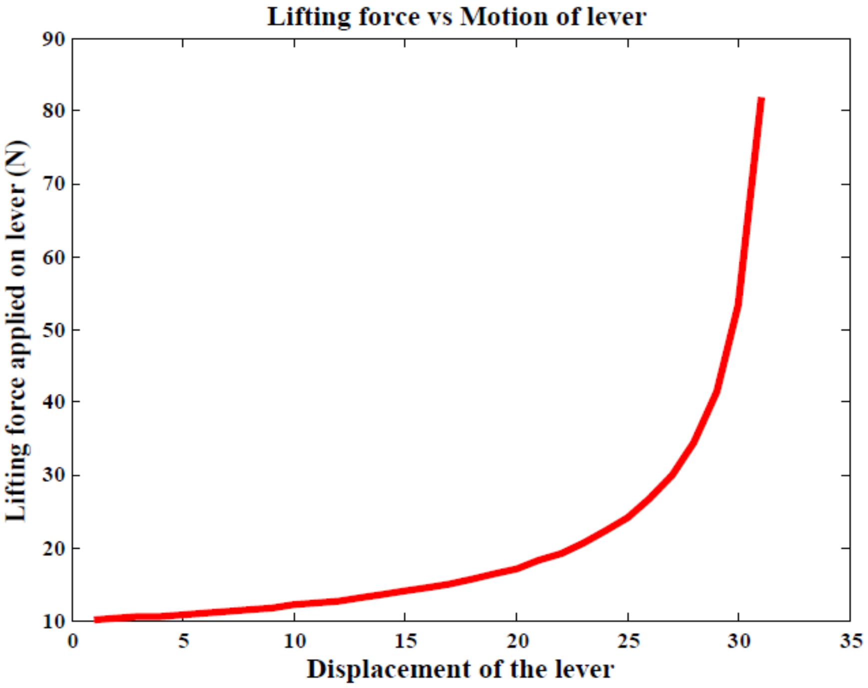


Fig. 8. Lifting force acting on the lever.

Fig. 8 shows the variation of the lifting force which is needed to be applied on the lever by user while lifting 1 Kg weight. The average amount of the lifting force that is needed to be applied is just 19.39 N. The peak force of 80N is needed when the lever is fully pulled up.

Figures (9 to 14) show the stress analysis of the components of lifting mechanism while applying peak forces on the respective joints. The material of the components is selected on the basis of FOS and mass of it. The material used while performing FEA of the components is ABS. Stick used in the design has to sustain compressive load. Wood is used as a material for the stick due to its higher compressive and tensile strength and low cost

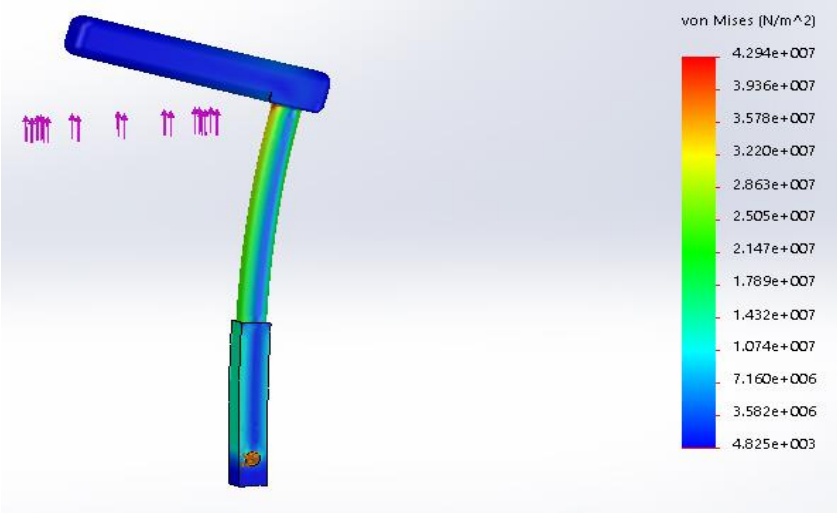


Fig. 9. FEA - lever.

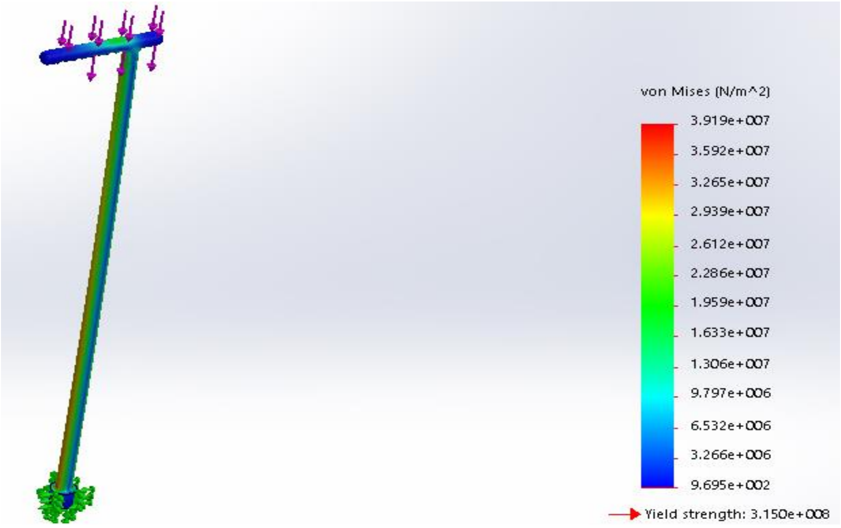


Fig. 10. FEA - Stick

The proposed mechanism is fully capable of gripping the object from the ground and to lift it up to user's comfort. By using this novel walking stick, user don't have to stoop down in order to pick their belonging, hence the major concern of stooping down will be significantly reduced. The lifting mechanism is actuated by average force of just 19.89 N. FEA of the components shows that the mechanism is completely safe to use and can withstand the total weight of 1 Kg.

VI. CONCLUSION

In this article, we proposed a novel walking stick which not only holds the object, but is also capable of lifting it. The mechanism provides optimum motion ratio and ROM of both gripping and lifting mechanism. With the help of this walking stick, the user will not have to scoop down to pick up an object, hence it would be helpful for people using conventional walking sticks. In future, we are planning to manufacture it and implement it on a subject. Other than walking sticks, this combination of mechanisms (gripping and lifting) can be implemented on the rehabilitation devices such as upper/lower extremity exoskeletons. The combine mechanism can also be helpful in agricultural field to take out the fruits/vegetables form the trees. Similar combination can also be used as a pinch type garbage collector in houses, hence looking towards various applications, the mechanism will be extremely helpful to the society.

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