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Design and Development of Mechanical Hardware for Animatronics

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Abstract:

The animatronics industry is highly competitive and hires engineers and artisans that have both experience and expertise in their respective fields. This project is first and foremost an opportunity to gain experience in designing and constructing an animatronic head from the ground up. In addition to gaining experience within the scope of animatronics, effort has been laid down to comprehend and get hands on experience in product design and development. This is a technique that is relatively new in the industry, but it has not been used to its full potential. Indian entertainment industry has immense latent opportunities for implementation of animatronics. Our endeavor to develop animatronic hardware can help us transform our creation into a full fledge business product. Final mechanism designed, though aimed at animatronics hardware has a cross functional utility, and can be used in ventriloquist puppet as well.

Keywords **—animatronics, mechanism, entertainment, industry, mechanism, hardware.**

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I. INTRODUCTION

Animatronics refers to the use of robotic devices to emulate a human or an animal, or bring lifelike characteristics to an otherwise inanimate object. Animatronic creations include animals (including dinosaurs), plants and even mythical creatures. A robot designed to be a convincing imitation of a human is more specifically labelled as an android. Modern animatronics have found widespread applications in movie special effects and theme parks have, since their inception, been primarily used as a spectacle of amusement.

Animatronics is a multi-disciplinary field which integrates anatomy, robots, mechatronics, and puppetry resulting in lifelike animation. Animatronic figures are often powered by pneumatics, hydraulics, or by electrical means, and can be implemented using both computer control and human control, including tele-operation. Motion actuators are often used to imitate muscle movements and create realistic motions in limbs. Figures are covered with body shells and flexible skins made of hard and soft plastic materials, and finished with details like colours, hair and feathers and other components to make the figure more realistic.

Animatronics is combination of “animate” and “electronics”.

The term audio-animatronics was coined by Walt Disney when he started developing animatronics for entertainment and film. Audio-Animatronics does not differentiate between animatronics and androids.

Autonomatronics, was also defined by Walt Disney Imagineers, to describe a more advanced audio-animatronic technology featuring cameras and complex sensors to process information around the character's environment and respond to that stimulus.

II. PROJECT GOALS

The goal of this project is to design and develop an animatronic head and actuate it mechanically. Though initial objective was to automate and program entire movement and perform synchronised motion, however due to limited resources in terms of time, monetary support and programming acumen, we have limited our project to mechanical actuation which can be automated using linear actuators like solenoid or rotary actuators like servomotors etc.

•The head must resemble human/character's head.

•While the head will not have full functionality of human face for simplicity, the features selected to be included must have full range of an average human.

•Final animatronic hardware developed must be able to emulate human-like expressions and seem fascinating and entertaining to viewer.

•Perform eye, eye lid, eye-brow and jaw movement.

The source of inspiration for conducting this specific project is our project guide S R. Patel who introduced us to this alien world of entertainment industry where mechanical engineering is applied extensively.

III. CONCEPT GENERATION

The concept generation is the earliest phase of design and development of the animatronics hardware. In this phase we brainstormed various techniques and mechanism by the virtue of which we can successfully achieve the intended movements. We made a background research on existing designs used in practice, and tried to modify them according to our specifications. The biggest hurdle to overcome is of the eyeball movement in 2 planes i.e. up-down and left right motion. Various ways of actuating the movements has also been thought of and tried. The iterations performed with various techniques are depicted pictorially for ease of comprehension and crisp explanation.

A. Hook-joint Design

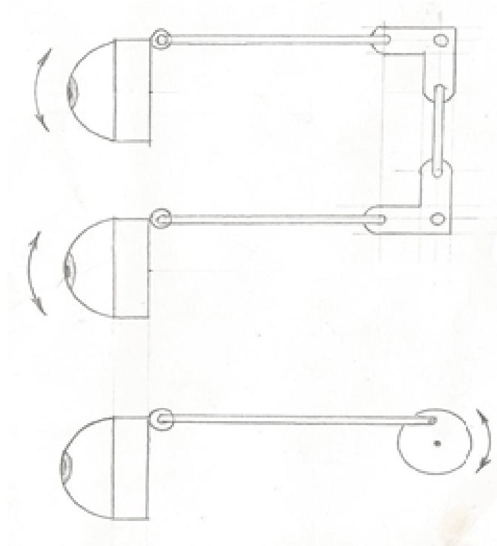


Fig. 1Shows the crank and link for actuation

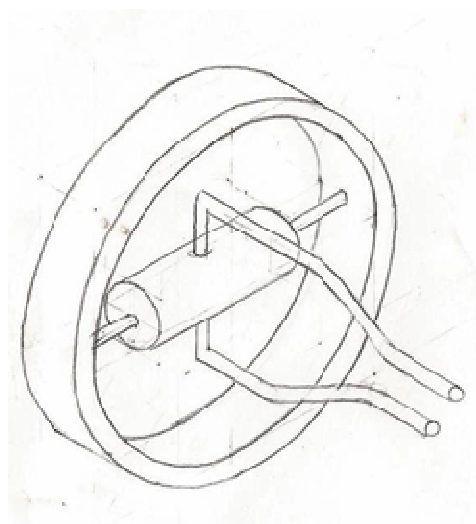


Fig. 2 Shows the crank and link for actuation

Fig. 2 shows hook design used for eye movement. There is requirement of two degrees of freedom around the support, one for each movement of eye. The idea was obtained from gimbal effect seen in a gyroscope. Fig. 1 shows the crank and link for actuation. The mechanism is a 4-Bar chain mechanism, where one of the link is fixed (eye-eye). The arrangement on the top shows the top view of mechanism and moves the eye in horizontal plane.

The one in bottom enables to move eye in vertical plane, with the help of a crank.

B. Gimbal Mechanism

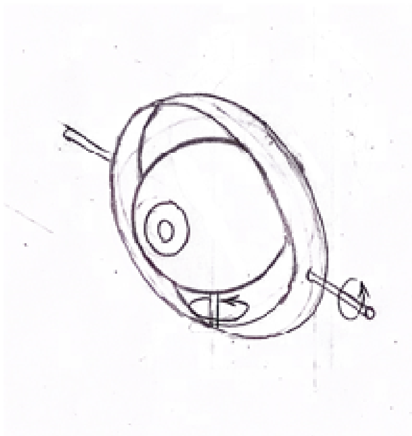


Fig. 3 shows the gimbal mechanism derived from a gyroscope

Derived from the gyroscope this mechanism offers the required two degrees of freedom for the eye ball movement with an only difference being use of single gimbal instead of two gimbals used in gyroscope. Onto the gimbal the eye ball is fixed with the help of bolt. Hence the gimbal offers one degree of freedom by rotating about the bearing axis and the bolt offers second degree of freedom for rotation about the bolt axis.

C. Spring Retracted Actuating Mechanism

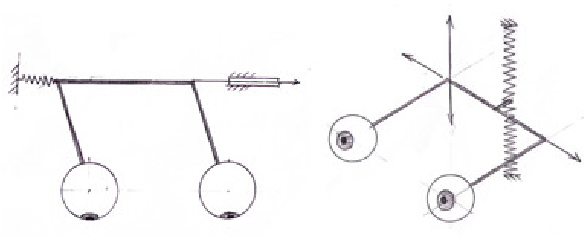


Fig. 4Shows spring retracted actuating mechanism

This arrangement had been used for the actuation of eyeballs. The links are connected to the tension spring. The links are pulled with help of cable wire, and the retraction is achieved by the spring. The stiffness of spring is contemplated iteratively and optimum length of spring is selected. The stiffness of the spring affects the pulling force required to actuate the mechanism. Hence length of spring is selected which is ergonomically suitable.

D. Cable Operated Actuating Mechanism

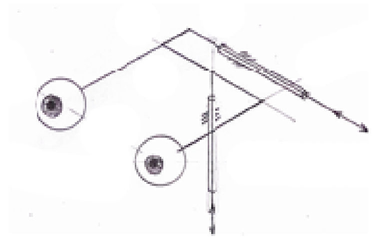


Fig. 5 Shows bicycle brake cable operated mechanism

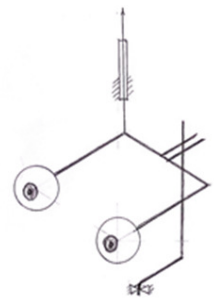


Fig. 6 Shows push-pull cable operated mechanism

Similar to spring retracted mechanism, another idea conceived was of actuating the mechanism with help of cable wire. The rigidity of cable was enough pull-push the mechanism. Since the loads are negligibly small actuating with cable wire is feasible. However, effort had to be made to ensure limited or permissible buckling of the cable without sacrificing loss of motion. Fig. 6 shows one such arrangement. The cable is push-pulled with the help of controller.

The arrangement shown in Fig. 5 was selected for the final design because of compactness and lesser lost motion in mechanism than former arrangement. The cables used are brake wires of cycle. Bike clutch wires could also be used but proved to be over rigid, hence bending was an issue.

E. Eyelid Mechanism

Fig. 7Design of Eyelid mechanism

Eyelid is assembled into the gimbal and is guided by a wire which is bent according to the required contour of eyelid. The crank is extended to the back end of frame where it is connected to a spring. Another end of spring is grounded on to frame. The clearances between the bolt head used for eyeball and top of eyelid and between gimbal and eyelid are very critical. The eyelid is cut out of spherical plastic ball using development of surface.

F. Jaw Mechanism

The jaw is spring retracted. Springs are used to locate and actuated the Jaw. A plaster of Paris moulded teeth is placed in the jaw cavity to give real feel. The jaw is actuated by nylon thread and is controlled by hand of the performer.

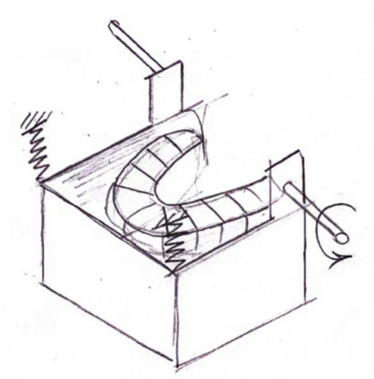


Fig. 8Design of Jaw mechanism

G. Eyebrow Movement

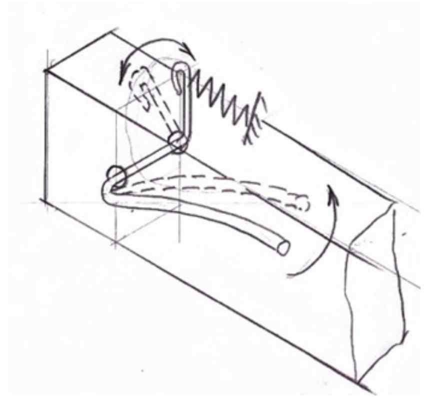


Fig. 9Design of Eyebrow mechanism

Eyebrows should be actuated such a way that they are able to show astonishment of the puppet. The eyebrow is spring retracted and is actuated with the help of nylon thread and controlled by fingers of performer.

IV. PROTOTYPE DESIGN AND TESTING

After brainstorming all the possible techniques of achieving desired motion, all the ideas need to be tested by making real prototypes or card board models. For these we prepared prototypes for different types of mechanism explained earlier. The best mechanism is the one which is able to perform the intended design specification or in other words should be able to move the eye, eyelid, jaw and eyebrow by required amount. The design specification for various movements is as shown in the table below;

TABLE I
DESIGN SPECIFICATION FOR VARIOUS MOTIONS

Sr No.	Description	Values
1	Eye ball movement	LR 35º UD 35º
2	Upper Eyelid movement	42º from neutral position
3	Lower Eyelid movement	8º from neutral position
4	Eyebrow movement	26º for up position
5	Jaw movement	50º from closed position

A. Testing of hook-joint design

This is the foremost idea thought of when we started working on hardware development for our project. The U-Clip wire was bent to required profile to make a loop like structure. This was fixed to a horizontal member made out of pen. The pen was mounted on to a horizontal axis with the help of wire which was grounded on the white ring shown in Fig. 9.

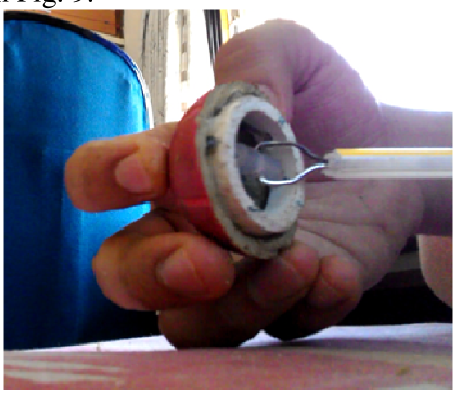


Fig.10Design using U-clip and pen

One degree of freedom is achieved at the loop-pen joint and second degree of reaction is achieved at the pen-wire contact. This idea had to be dropped because after testing we found that the lost motion due to mechanism's inaccuracy was beyond permissible values. Also we faced problem with the assembly of the mechanism and rigidity of the loop was not up to required degree. The loop joint resembles the doctor's stethoscope. Since the eye motion is in two planes thus the point of contact between links and eye has to allow some free movement which was not feasible in this design.

B. Testing of Gimbal Mechanism

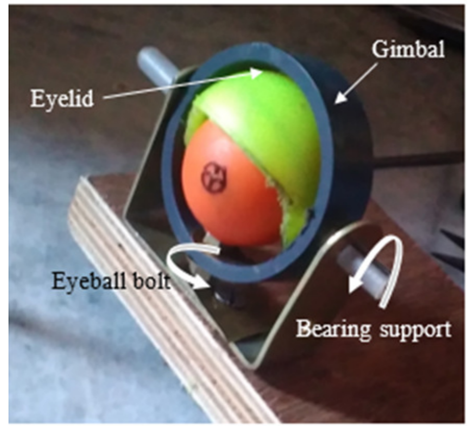


Fig. 11Design made using gimbal mechanism

This gyroscope derived design has a single gimbal. The arrangement is shown in the Fig. 11. The eyeball will move in horizontal plane i.e. left right direction by rotating about the bolt axis, and move in up down position by rotating about the bearing support axis. Thus the simultaneous movement about each axis produces n 2D movement of eye pupil giving viewer a feeling of realism. This arrangement proves to be reliable and aides ease of assembly, hence we selected this design for final hardware development. The lost motion was reduced remarkably compared to previous design. Thus after selecting the eyeball mechanism we focussed on ways of actuating the eyeball movements.

C. Testing of Gimbal Mechanism

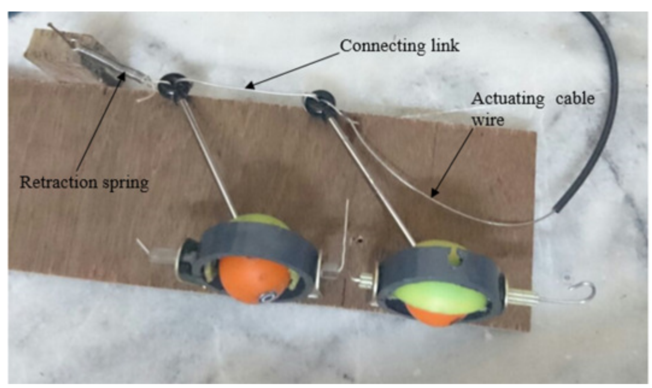


Fig. 12Four bar mechanism, spring is grounded at one of the extreme ends of the frame and one of the links is attached to other end of the spring

The crank-crank 4-bar chain mechanism with changeable plane of rotation link is connected to spring. There are two possibilities of achieving this is shown in Fig. 12 and Fig 13. The other end of spring is grounded to frame body. The cable wires are used to pull the link. The spring stretches and retracts the mechanism when the cable loosens.

As shown in Fig. 12 the spring is grounded at one of the extreme ends of the frame and one of the links is attached to other end of the spring. When one pulls the cable the spring will try to retract the mechanism back to its normal position. Here it should be noted that the normal position of the eyeball is at extreme left, which is one of the major drawbacks of this design because the eyeball's normal position should be centred. Another drawback being the grounding point for spring lies beyond the available design space, thus making it infeasible. Thus this design is rejected because of this fault.

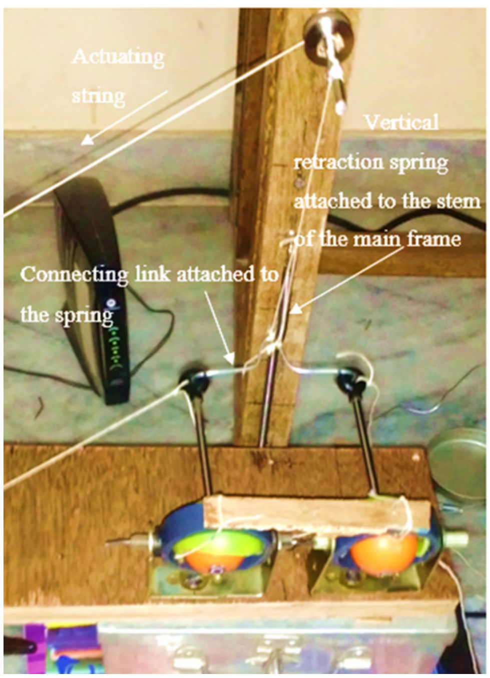


Fig. 13 Four bar mechanism,a spring is grounded vertical on the stem of frame

Fig. 13 shows another arrangement wherein a spring is grounded vertical on the stem of frame. At the centre of the spring the connecting link of the 4 bar chain mechanism is connected. The actuating cables pull the link in horizontal and vertical direction, resulting into 2D movement of the eyeball. Though this mechanism could overcome the drawbacks of previous design, it brought along its own drawbacks. This mechanism needed four cables to move the eyeball in all direction. Use of four strings resulted into clashing with other actuator like that of eyelid or eyebrow. Hence this design was also eliminated.

D. Prototyping of Cable Operated Actuating Mechanism

After trying out previous ideas, finally we came down to actuation using wire cables. Here we used an acrylic plate as connecting link and used cables to actuate both vertical and horizontal movement of the eyeball.

The crank-crank 4-Bar Chain Mechanism with changeable plane of rotation is seen in Fig. 14. The cables have an outer cover which is grounded on to frame and wire can slide easily inside the cover.

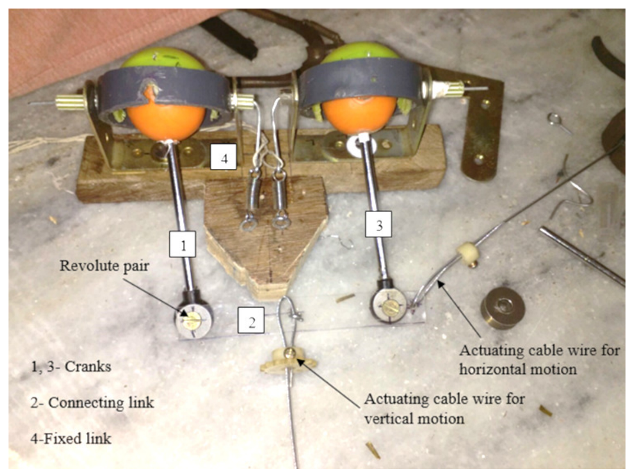


Fig. 14 Prototype of cable operated mechanism

One end of the cable is connected to the connecting link at either extreme points for horizontal actuation and at centre of the link for vertical movement. On testing this mechanism we could nearly achieve the design specifications laid down at the beginning. Hence this arrangement wasfinalised for development of hardware for animatronics. However, the rigidity of cable is of prime importance. Cable wire often tend to buckle under load and leads to lost motion.

E. Testing of Eyelid Mechanism

Fig. 15Various Eyelid Movement

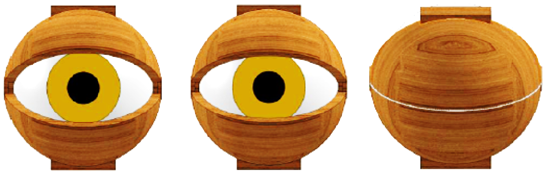


Fig. 16Various Eyelid Movement, using CAD model

Eyelid mechanism is used to move the eyelids. Our design allows winking as well as simultaneous blinking of eyelids. Due to simplicity we have used only the upper eyelid and have not taken into account designing of lower eyelid. The upper eyelid should move 42º from the neutral position. The eyelids are spring retracted and are pulled with the help of nylon threads. The Figure 15 shows eyelid movement of one of our team member, which is simulated by eyelid mechanism developed by us.

The eyelid is cut out of spherical plastic ball. The radius of eyelid ball is slightly less than gimbal radius, which is enough for easy movement of eyelid inside the gimbal.

F. Testing of Jaw Mechanism

The Jaw is made out of wooden ply. Tooth moulded with POP is placed inside the Jaw. The Jaw is retracted with help of three springs. Two springs hung on the sides act like human muscles which are responsible for the movement of lower mandible. Third spring is attached at back side, whose one end is grounded on the stem of frame. The jaw is pivoted on a rod.

G. Testing of Eyebrow Mechanism

Fig. 17Various eyebrow movement

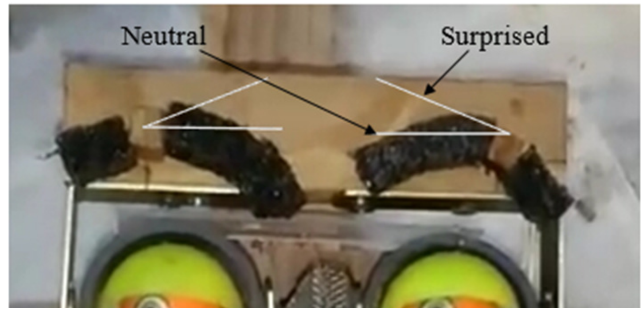


Fig. 18Achieved eyebrow motions in the mechanism

The intended eyebrow motion is of astonishment. The Fig. 17 shows the movement of eyebrows when frowning and surprised. The eyebrows are also spring retracted. In our design frowning is avoided. Each eyebrow is individually actuated, hence offering flexibility in making expressions. The arrangement is as shown in Fig. 18.

V. DETAILED DESIGN AND DEVELOPMENT

After prototyping we concluded the best suitable design for the animatronic head hardware which could perform all the required function and satisfy the design specification mentioned earlier. Henceforth step by step development of the hardware is delineated. The detailed drawings are shown in the figures with required dimensions.

A. Eye and Eyelid Mechanism

The various parts of the eye and eyelid mechanism are shown in the figures. This mechanism includes the assembly of eyeball into the gimbal, eyelid, and link of the crank-crank 4 bar chain mechanism. The pictorial presentation of the assembly is also shown alongside.

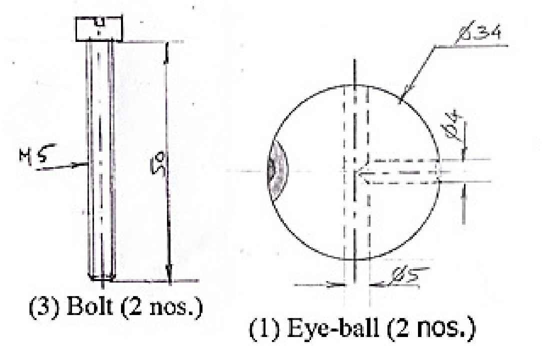


Fig. 19Drawing of Bolt and Eyeball with their part numbers and dimension

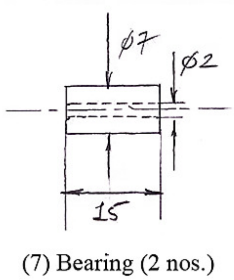


Fig. 20Drawing of Bearing with its part number and dimensions

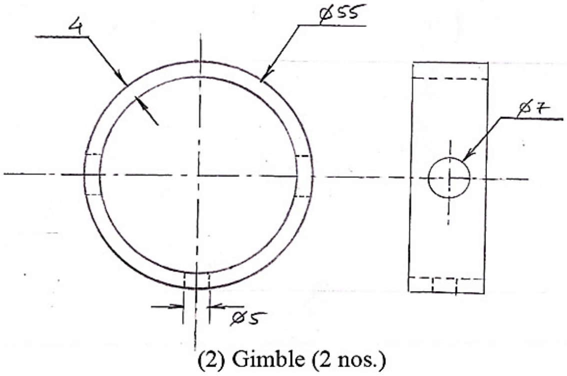


Fig. 21Drawing of Gimbal with its part number and dimension

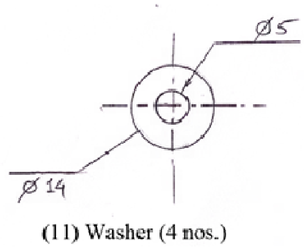


Fig. 22Drawing of Washer with its part number and dimension

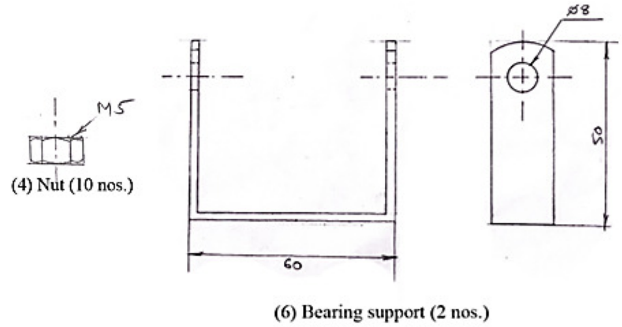


Fig. 23Drawing of Nut and Bearing support with their part numbers and dimension

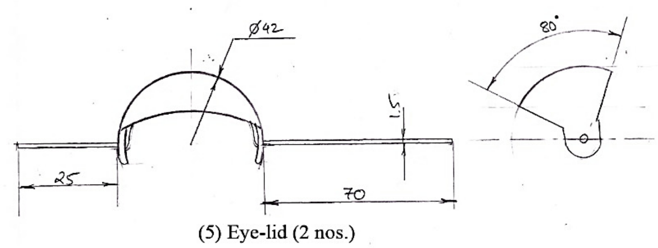


Fig. 24Drawing of Eyelid with its part number and dimension

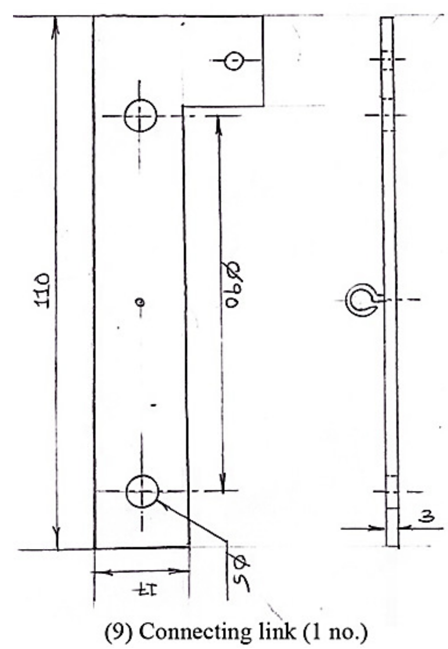


Fig. 25 Drawing of Connecting link with its part number and dimension

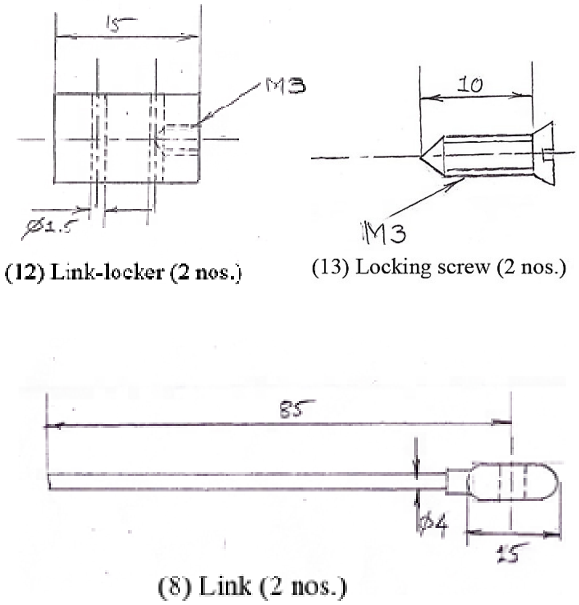


Fig. 26Drawing of Link locker, locking screw and Link with their part numbers and dimensions

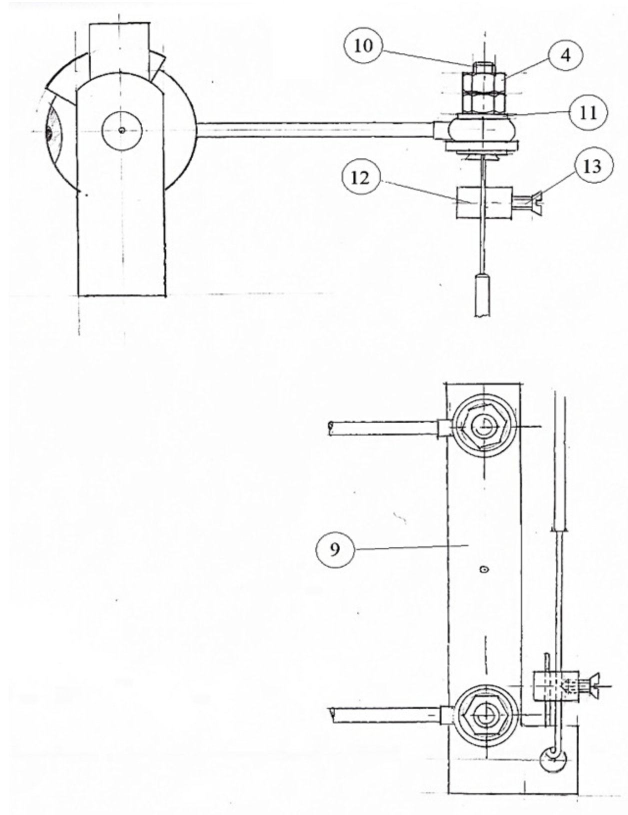
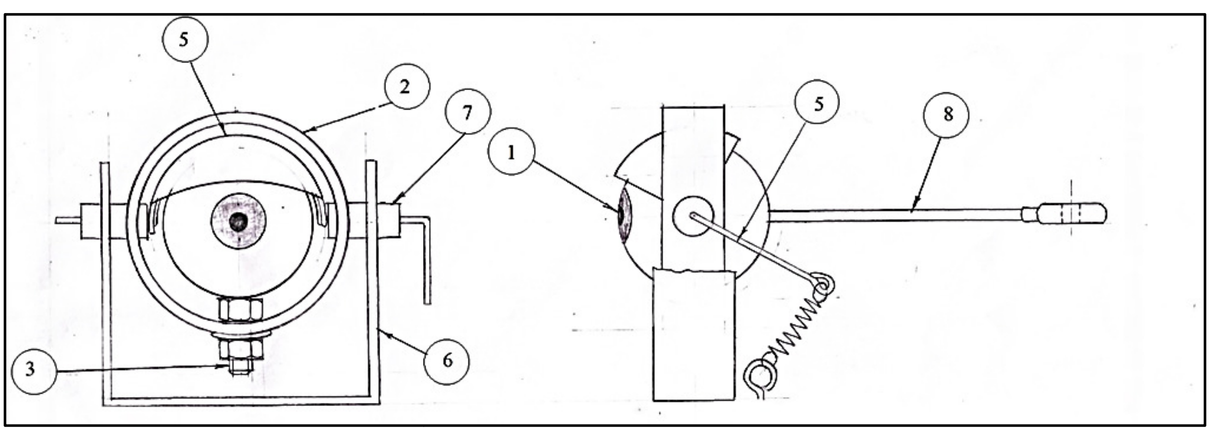


Fig. 27 Assembly Drawing of Eyelid mechanism with part numbers

Fig. 28 Assembly Drawing of Eyelid mechanism with part numbers



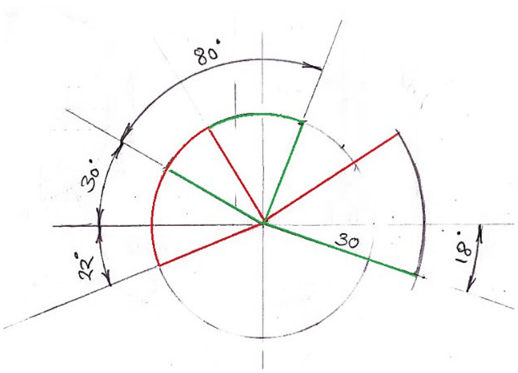


Fig. 29Depiction of Eyelid Movement

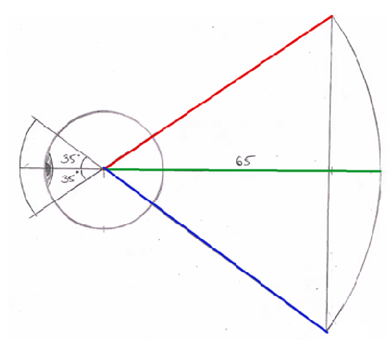


Fig. 30 Depiction of movement of the link of eye when actuated. Graphical Synthesis of Mechanism, individual. (Up-down movement)

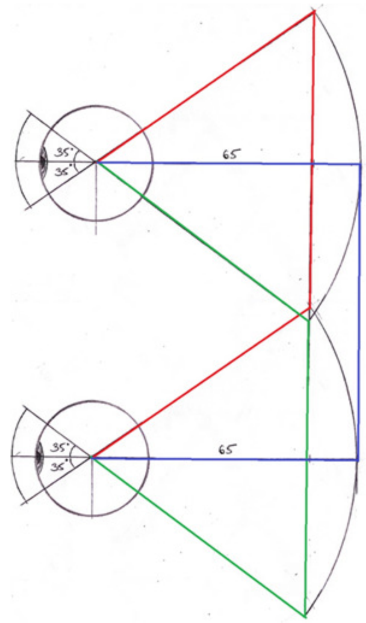
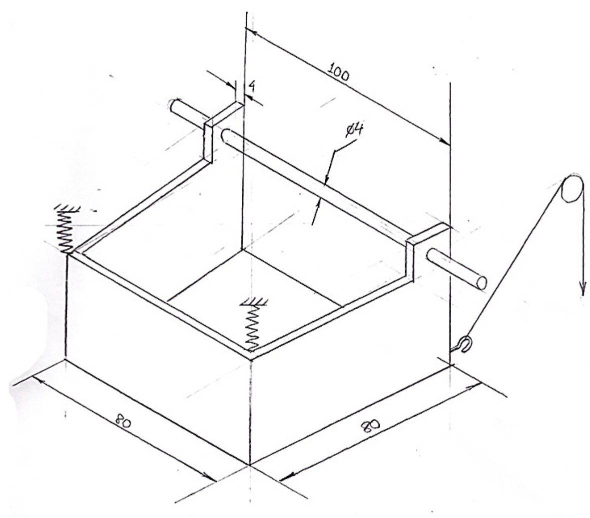


Fig. 31 Graphical Synthesis of eye and eye link movement from top view (left-right movement)

B. Jaw Mechanism

The Jaw mechanism is as shown in the figure. The horizontal rod of Ø 4mm acts as a pivot for the jaw, which is supported at its extreme ends bye the frame. The springs are connected in the fashion portrayed in the sketch. There are three springs used. The jaw is made out of wooden ply. The actuation is achieved by nylon thread tied at back end of jaw.



(16) Jaw mechanism (1 no.)

Fig. 32 Drawing of Jaw mechanism with its part number and dimension

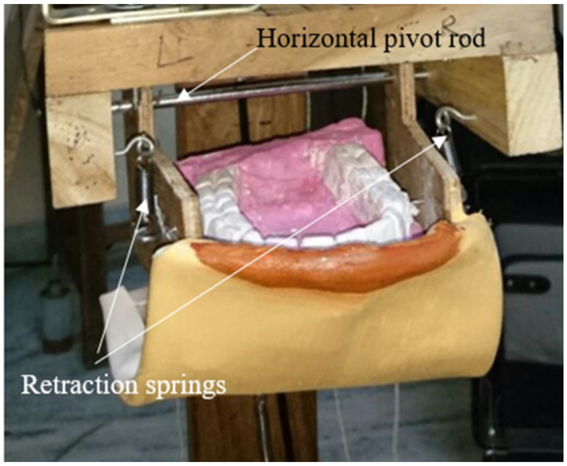


Fig. 33 Jaw of animatronic hardware showing the spring arrangement and pivot rod

C. *Eyebrow Mechanism*

The eyebrow mechanism is spring retracted. The crank is bent on the back of the frame and other end is bend on face of head. Onto this wire acrylic sheet cut in shape of eyebrow is stick to the wire with help of binding wire. Hair from wig was attached onto the foam which was fixed to acrylic sheet. Thus an eyebrow is so formed.

Part No.	Part Name	Material	Qty.
1	Eyeball	Caster wheel	2
2	Gimbal	PVC Pipe Ø 55mm	2
3	Eyeball Bolt	Standard part	2
4	Nut	Standard part	10
5	Eyelid	Plastic ball Ø 42mm	2
6	Bearing Support	Clamp	2
7	Bearing	Disposable pen	4
8	Link	Drafter link	2
9	Connecting Link	Acrylic sheet	1
10	Link Bolt	Standard part	2
11	Washer	Standard part	4
12	Link-Locker	Disposable pen	2
13	Locking Screw	Standard part	2
14	L-Clamp	Standard part	2
15	Frame	Wood work	1
16	Jaw	Wood work	1
17	Eyebrow subassembly	Wood work	1

The Fig. 34 shows the crank arrangement for actuating the eyebrows. The spring is attached between the crank eye and other end grounded to frame.

Fig. 34 Crank and spring arrangement for actuating eyebrows

D. *Bill of Material*

TABLE III

BILL OF MATERIAL FOR THE ASSEMBLY

E. *Assembly drawing*

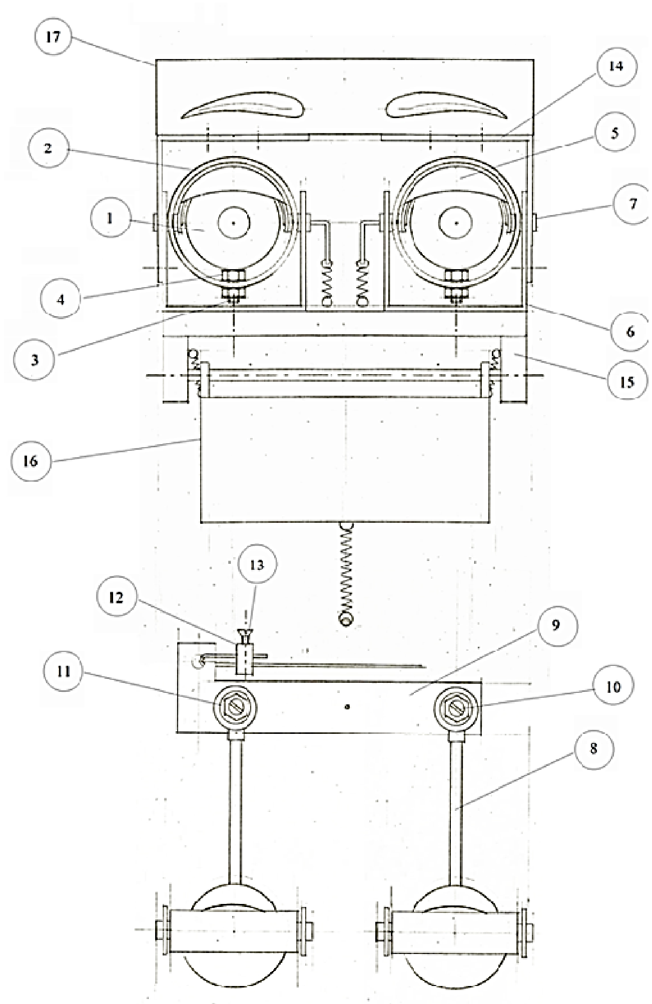


Fig. 35 Assembly drawing with part numbers

F. Making of the Mask

The mask is the outer cover of the head. Mask in other words is the skin of human or animation to be presented. A skilled artisan is required to make mask by moulding however due to limited proficiency in art work we made mask from wire mesh. The Fig.36 shows the model without mask. We built the mask layer by layer with help of Stainless Steel wire as a reinforcing element. Onto this wire we laced wire mesh. The selection of wire mesh is important. Aluminium wire mesh would be best choice since it has less spring back and better formability. However we failed to find one in market so we used MS wire mesh.

Fig. 36 (Left)Head without mask (Right) shows wire-mesh used to form nose area and upper lip, the curvature of jaw is also formed by wire mesh

Fig. 37 (Left) shows complete wire mesh mask, the eyebrows are assembled after laying the mask over the frame of head (Right) Foam applied onto the wire mesh and then painted with skin colour to give a human skin look

VI. DEMONSTRATION OF THE EXPRESSIONS

A. Eye motion (Left and Right)

Fig. 38 Model with neutral, right and left eye position respectively

B. Eye motion (Up and Down)

Fig. 39 Model with neutral, up and down eye position respectively

C. Eyelid motion (Independent and simultaneous)

Fig. 40 Model with right, left and both eyelids closed respectively

D. Jaw motion (Closed-partially open-fully open)

Fig. 41 Model with right, left and both eyelids closed respectively

E. Eyebrow motion (Independent and simultaneous)

Fig. 42 Model with left, right and both eyebrows raised respectively

VII. CONCLUSION

It was a wonderful learning experience for us while working on this creative project with an out of box idea. This project took us through the various phases of product development and gave us a real insight into the world of entertainment industry. The joy of working and the thrill involved while tackling the various problems and challenges gave us a feel of designers and developers. While working on this project we realized that for being a good engineer not only a good theoretical background but hand skills in designing and making are also equally important. Though our attempt was to emulate real human like expressions, due to lack of artisan skills in mask making and resources we could not emulate the expressions effectively. The project can be further developed with more no. of expressions like nose, chick, tongue and forehead motions with electronic controllers.

ACKNOWLEDGMENT

Developing a novel and creative project like this has filled us with immense happiness and confidence of working on real life Mechanical Design. The seeds for this creative project were sown by our guide S R. Patel, to whom we express our gratitude for guiding us and making us aware of ingenious application of Mechanical Engineering in Entertainment Industry. His contribution has been immense in terms of number of contact hours, discussions and brainstorming sessions. We are pleased to have worked under the tutelage of S R.

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