Design and analysis of mechanisms for improving maneuverability in borewell rescue devices

Abstract: This paper deals with mechanisms for improved maneuvering into borewells for rescue operations. The constraints observed in existing borewell devices, such as the size of the borewell, the orientation of the child and the ease of maneuverability were analyzed. The work consists of various mechanisms subsystems such as; anchoring, module's translation and rotation, gripper actuation and control. This paper aims to improve the existing devices used to rescue children from borewells by developing modules that can maneuver through the confined space, stabilize the sway, and aid the gripper in safely reach and rescue the child.

Additional Keywords and Phrases: Borewell rescue, Sway mitigation, Maneuverability, Parallelogram mechanism, Slider crank mechanism, Module, Module translation, Module rotation, Lead Screw mechanism, Gripper actuation and control

1 INTRODUCTION:

In the initial phase, rope techniques were used by responders. They also tried digging holes parallel to borewells for carrying out the rescue operation. But later, because of the failures in their attempts, researchers came up with different techniques such as balloon inflation, vacuum suction, cage enclosure and mechanical gripping.

Currently used mechanical grippers [1-4] does not take the rope sway, attributing to poor gripping of the child, and maneuvering constraints into account. The ones that did employ [5-6] modules for stabilization have compromised on the size constraints of borewell. The solution to this problem is to use the space available along the borewell surface rather than the radial one.

The motivation behind this paper is to provide maneuverability and sway mitigation to existing borewell rescue devices and minimize the rescue time. Gopinath et al. [7] and many others, have proposed various ideas, but they have not been tested in real-time. Pattery et al. [8] has proposed a design that uses a cage to enclose the child. Sakhale et al. [9] developed a balloon system that aids the gripper setup. The designs does not accommodate the space limitations rendering it ineffective. Jayasudha et al. [10] used a belt system that lifts the child by gripping the hands. Looping the belt around the hands would be very challenging, as the device has limited degrees of freedom. Our solution aims to address these issues by using mechanisms that help to navigate in the confined space.

A proof of concept prototype was fabricated and examined in real-time. A detailed study has been conducted to validate the robustness of the mechanisms. The objective of the project is to create compact mechanisms without compromising its maneuverability.

2 DESIGN CONSIDERATIONS:

The factors taken into consideration while designing the mechanisms are as follows:

1. **Size of the borewell:**
   The size of the borewell diameter varies between 152.4 to 355.6 mm (6 to 14 inches). The mechanisms must be within 152.4 mm (6 inches) to ensure adaptability to different borewells.
2. **Weight of the child:**
   The mechanisms must be able to withstand the combined loads of the child and its other components.
3. **Orientation and position of the child inside the borewell.**
4. **Avoiding backlash in actuation and transmission systems.**

3 ASSEMBLY:

The work has mechanisms such as; anchoring, module's translation and rotation, gripper actuation and control. The basic frame in the anchor module is created with the help of cylindrical tubes and circular plates. They are joined to each other through weldments. Motors are screwed to the plates with the help of brackets. They are attached to the lead screws through couplers, eliminating the diametrical variations. The leadscrew being connected to the ball bearings at the top ensures smooth running. It hosts a nut which navigates on the thread up and down. The movement of nut is responsible for the deployment of the anchor pads radially. A parallelogram mechanism links the anchor pads and the nut. The parallelogram mechanism consists of two sets of rigid links joined by rivets. It ensures the anchor pads are constrained to move vertically when deployed. The anchors are connected to additional grippers that aid the child while being lifted. The curved path decreases the gripping area of the additional grippers attached, hence decreasing the chances of a successful lift. Each one of the anchor pads is operated using the leadscrew; the nut being the slider and the parallelogram mechanism being the coupler. The rotation of the motor controls the retraction of the anchor pads back and forth. A leadscrew operated by a motor runs through this entire setup which facilitates the vertical translation motion. A motor controlling the rotation of the module below the translation motor is housed in a plate below it. A double-threaded leadscrew is used for the gripper control which is actuated by gear transfer from a motor below the rotational motor.

4 MECHANISMS WORKING:

The following mechanisms have been devised to ensure the rescue operation is successful. The transmission and actuation systems for various components are designed to avoid backlash. Backlash would de-stabilize the entire setup and hence, leadscrews and nuts are used to avoid it.

4.1 Anchor deployment for sway mitigation and maneuvering:

A set of three anchors (Fig. 1), spaced equally apart, are deployed at a considerate height from the child. They gently press against the borewell surface, thus aiding in avoiding the sway. They adapt to the different borewell surfaces seamlessly with a torsional spring placed at the revolute joint between the set up and the anchors. The module's center can be freely traversed within the horizontal plane of the borewell as each of the anchors are individually controlled. This helps us to improve the accessibility of the grippers near the child.

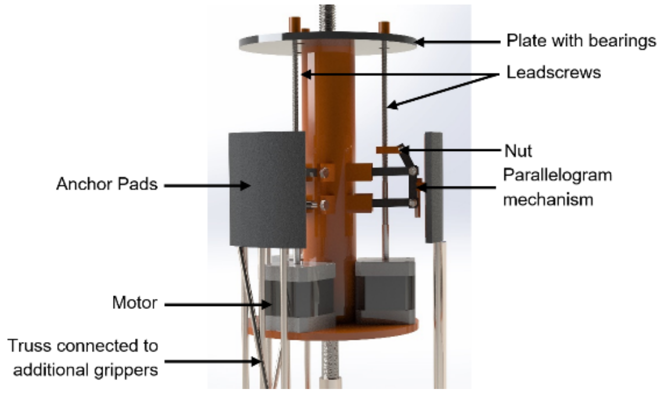


Figure 1: Side View of CAD design of the mechanism (See online version for colors).

4.2 Module translation and rotation:

A module of the setup is deployed down to carry out the rescue operation. A leadscrew mechanism is used to achieve the same (Fig. 2). The anchor module being grounded acts as fixed support, allowing the other module to move up and down with the help of the leadscrew.

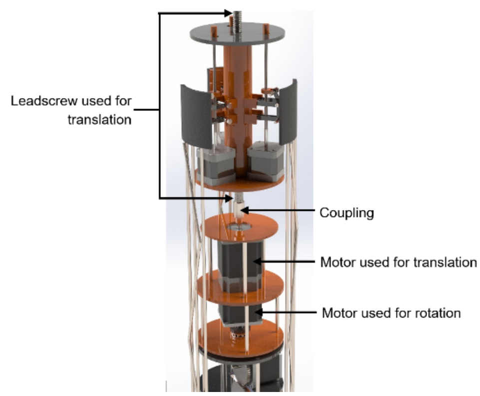


Figure 2: Side view of translation and rotation module along with anchor module.

The motor responsible for rotation is attached below translational one with the help of brackets. The shaft of this motor is connected to the gripper setup. The coupling, welded with the rotational components, rests on a thrust bearing (Fig. 3), which takes the vertical load away from the motor's main shaft.

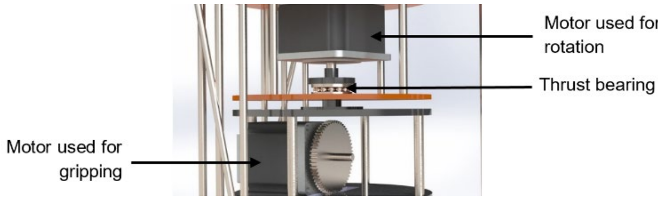


Figure 3: Side view of the rotational module.

4.3 Gripper actuation and control:

The relative distance between the grippers is controlled with the help of a leadscrew having opposite threadings on either side. The leadscrew is actuated by a motor through a set of spur gears (Fig. 4). It is held in place by a set of ball bearings on both ends. The gripper setup, connected to a set of nuts on either side of the leadscrew, move away from each other when the motor is rotated clockwise. They move towards when the motor is rotated counter clockwise. The load from the gripper is transferred to the main frame through the nuts and bearings. Another dedicated set of motors is placed at the gripper end to facilitate the rotation of each gripper.

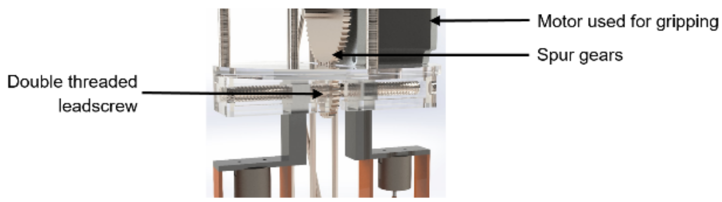


Figure 4: CAD Model of Gripper actuation.

5 CALCULATIONS FOR MANEUVERING:

The plane corresponding to the circular plate has been taken as XY for ease of explanation. The point of concurrency of the anchor's line vectors is taken as origin. R represents the borewell radius. The initial position when one of the anchors touches the borewell surface is taken as (X_1, Y_1). The final position after being maneuvered is taken as (X_2, Y_2). Figure 5 shows this initial and final positions. (A, B) are the coordinates to which the center of the module needs to travel to achieve the final position.

The line joining the center of the module and the anchor can be represented by the following line vector:

$$\mathrm{X_1 i + Y_1 j = R\cos(2n\pi/3)i + R\sin(2n\pi/3)j} \quad (1)$$

Where n = 0,1,2 depending on anchor.

The final line vector being parallel to the initial line vector is represented by the following vector:

$$(X_2 - \mathrm{A})\mathrm{i} + (\mathrm{Y_2 - B})\mathrm{j} = \mathrm{K\cos(2n\pi/3)i + K\sin(2n\pi/3)j} \quad (2)$$

The line joining the final position of the center of the module and the circle encompassed by the anchors is given by the following equation:

$$\mathrm{(Y - B) = m\,(X - A)} \quad (3)$$

Where m = tan (2nπ/3)

The equation of the circle is represented as follows:

$$X^2 + Y^2 = R^2 \quad (4)$$

Solving Eqn. (3) and Eqn. (4), we get two values of (X_2, Y_2). The value closest to (X_1, Y_1) is taken as (X_2, Y_2).

$$X_2 = \frac{-2m(B - mA) \pm \sqrt{(2m(B - mA))^2 - 4(1 + m^2)((B - mA)^2 - R^2)}}{2(1 + m^2)}$$

$$Y_2 = m(X_2 - A) - B$$

Substituting in Eqn. (2) yields K. The distance each anchor needs to travel is given by D.

$$D = |R - K|$$

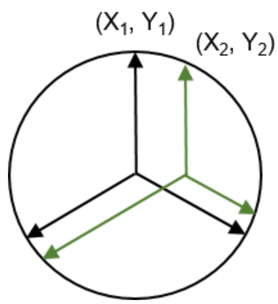
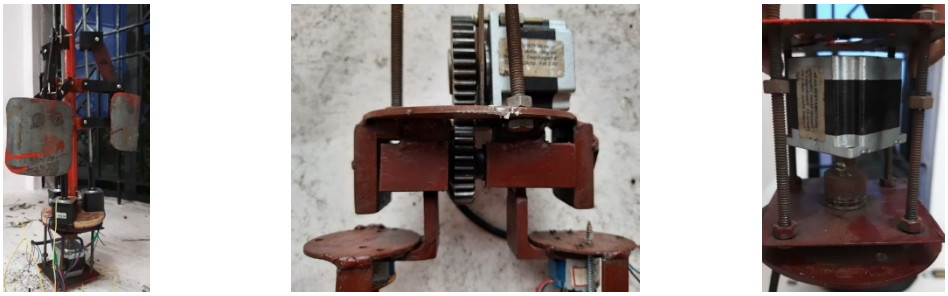


Figure 5: A sketch representing the initial and the final positions of the anchors.

6 CONSTRUCTION AND ANALYSIS:

A proof of concept prototype was fabricated to validate the idea of anchoring (Fig. 6). NEMA 17 stepper motor was used for actuation. Circular plates and cylindrical tubes made of mild steel were chosen because of their ease of availability. Three holes were made to accommodate the bearings of the leadscrew. The plates and tubes were welded together. The leadscrews are attached to the bearing and the motor placed on the plate through machined couplers. Links and anchors, of appropriate dimensions, are joined with the help of rivets. This assembly was then mounted to the base explained previously. The translation, rotation and gripper modules were done similarly.



(a) (b) (c)

Figure 6: Fabricated prototype of the mechanisms: (a) Anchor deployment (b) Gripper actuation and control (c) Rotation (see online version for colors)

7 RESULTS:

The minimum distance an anchor can traverse is calculated through experimentation. Dimensions used for the length of the parallelogram mechanism’s largest link and the leadscrew pitch are 50 mm (1.97 inches) and 2 mm (0.08 inches), respectively. The radial displacement moved by the anchor is given by 50*(1 - cos θ) mm or 1.97*(1 - cos θ) inches where θ is the angle that the largest link makes with the horizontal plane. The value of θ is found to be π/12 for every rotation of the motor. We measured the corresponding radial distance traversed by the anchor as 1.7 mm (0.07 inches). The step angle of the motor employed in the experimentation is π/100, making the least count for the anchor’s travel as 0.0085 mm (0.0003 inches).

The pitch of lead screw used for translation module is 2 mm (0.08 inches). The step angle of the motor used is π/100, making the least count for translation motion as 0.001 mm (3.94 E-5 inches). Similar motor being used in rotation module has an angular least count of π/100. The double threaded lead screw for gripper actuation and control has a pitch of 5 mm (0.20 inches). This makes the least count as 0.0025 mm (9.84 E-5 inches). The least count being very minimal provides greater accuracy while operating and thus, the ease of maneuverability.

8 CONCLUSION:

The borewell devices with these mechanisms aid the responders to rescue the child in minimum time. The mechanisms employed are very compact and robust. By varying the pitch of the leadscrew and the dimensions of the links, we can attain various least counts according to the need. The minimum distance that the anchor can travel is 0.0085 mm (0.0003 inches), and the anchors can adapt to the different borewell surfaces seamlessly. The least count for the translation, rotation and gripper movement achieved are 0.001mm (3.94 E-5 inches), π/100 and 0.0025mm (9.84 E-5 inches) respectively. The least count being very low provides gives unerring operational capabilities. The device is easily operable under the National Disaster Response Force’s Standard Operating Procedure. The aim of the project to provide maneuverability and minimize the rescue time are thus achieved.

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