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Design and Development of a Borewell Rescue Robot

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Abstract: *We describe the design and working of a robotic device that can be used for the rescue of children trapped in borewells. The design is inspired by taking into account the reasons for failure of previously existing methods. A key feature of the device is its ability to lift a child with the help of a safety cage, instead of a grasping mechanism. The device has the capacity to shrink the size to lower into the borewell, thereby not affecting the wall. The joint angles have a facility of rotating 360 degrees, enabling the device to find a gap in any direction, without hurting the child. The radial movement of the device also enables it to function for a borewell ranging from 25.4 centimeters to 45.72 centimeters in diameter. The suitability of the proposed system is demonstrated by several experiments to test reliability of the developed prototype.*

Keywords: Rescue robot, Borewell, Robot

I. Introduction

A borewell is a narrow shaft dug vertically into the ground. It may be constructed for various purposes, such as the extraction of water for daily human usages, or in other cases, other liquids (such as petroleum) or gases (such as natural gas). It is a well known fact that India has been facing a severe groundwater crisis over the past few years. Low rainfall and excessive water demand for irrigation, industrial and domestic purposes, is causing the overexploitation of groundwater resources. This has led to the lowering of the water table and increasing numbers of defunct wells. Most borewells that are constructed for the purpose of water extraction are found in areas where there is human activity, and some of these constructions are unsuccessful in yielding any groundwater. These borewells are often left open which has been known to be hazardous to human life. The mouths of these constructions are often covered only with polythene sacks or brittle blocks of cements, which are never adequate measures for sealing a potentially hazardous hole in the ground. Children aged six or less tend to fall into these open borewells and get trapped. Rescuing these trapped children is both difficult and risky for everyone involved with the operation. Even a small delay in the rescue can cost the child his or her life. In addition to the challenges mentioned above, lifting the child out of the narrow confines of the borewells is a tedious task. Victims often suffer trauma from the fall, either in the form of psychological trauma from being placed in a highly restricted environment over many hours, or physical trauma where they find themselves running out of oxygen which may lead to death.

A robot for borewell rescue offers a solution to these situations [4] [10] [11]. It is fast, economical and safe. Moreover, it has the capability to monitor the trapped individual, supply oxygen and provide a supporting platform to lift them up to surface level.

When reviewing the design considerations, we examined primary features of the environment and evaluated the best case and worst case scenario. The working environment of the robot is not a well-defined space, which made it one of the most important factors to deal with. In the design we gave due consideration to the fact that rescue time would be as minimum as possible without compromising on the child's safety. Other factors such as the increased complexity of the case when the posture of the child is not in a favorable condition were dealt with. Also, the system was designed to be fail-proof, rugged and reliable. The mechanical design of the borewell robot has been given paramount importance so that it does not get stuck inside the well or cause harm to the child. Any electrical fault or shocks may worsen the rescue operation. It should also be noted that the pressure varies as we go deep down to the core of the earth, and structure of the soil also plays a crucial role in the rescue operation. Situations where robots have to perform rescue operations above 600 feet from sea level may also arise.

After factoring in all these parameters, an optimal design for a borewell rescue robot was prototyped and tested.

II. Present Day Rescue Systems

Year	No of Borewell Accidents (2006-2014 Aug)	Percentage
2006	1	3
2007	7	20
2008	2	6
2009	4	12
2010	1	3
2011	2	6
2012	4	12
2013	5	14
2014	8	24
Total	34	100

TABLE I: Borewell accidents between 2006-August 2014

Table 1 represents the total number of borewell accidents that have occurred in India from the year 2006 [12]. A

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majority of the children were dead before they could be rescued, with only 7 out of the 34 children being recovered safely. There are various factors that limit the rescue operation in such scenarios.

Figure. 1: Traditional rescue method

The common method used to find the depth of child is with the help of a rope. In normal rescue operation [13] [14] carried out by the army, a pit is initially dug parallel to the borewell, and a horizontal path to the location of the child is caved through. This is a highly time consuming process as well as risky to both, the rescuer and rescuee. The soil has to be stiff since loose structure will result in the cave collapsing. Moreover, it involves a lot of energy, manpower and expensive resources which are not easily available everywhere. Throughout the entire process, there is a high risk factor that surrounds injury to rescuer or rescuee. Also, the body may trap further in the debris and jeopardize the rescue operation.

Earlier proposals for borewell rescue robots comprise of oxygen supply system and temperature detectors. A tube to supply oxygen, approximately of length 200 metres, is placed on the surface and is sent along with the robot to supply emergency oxygen to the victim. Temperature measuring device, placed in the robot, measures the temperature level of the victim. It gives the medical team an estimate of level of medical aid required, once the victim is rescued.

Previous models consist of pulley setup. Depending on the robot motion, the rope is sent into the bore-well hole by a 3 pulley control system. The large pulley is connected to the motor shaft, which helps in push-pull of the rope. Using motion detectors and camera, the victim's position is determined. At the appropriate position the fork will punch into the borewell wall using the motor connected to the level gear setup on the upper plate. Clearly, it has certain limitations and is more reliable only if the victim is a baby (less than 3 years). Also, techniques using a gripper have been implemented in most of the models. Cases such as the child slipping from the gripper and the child's position after fall have not been taken into consideration. Another problem faced is the higher numbers of motors (approximately five) makes the rescue operation difficult. In case of long distance, oxygen hose is prone to break. The power transmission through wires along the rope makes the rope bulkier, which causes further delay.

We have analysed these limitations and have addressed them in our design, making it more reliable and robust.

III. Design Mechanism

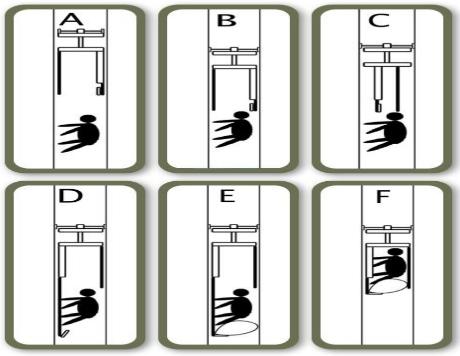

Figure. 2: (A) Robot enters borewell (B) Clamping (C) Positioning (D) Lifting rod in position (E) Bladder inflation (F) Child rescued

A. Clamping Mechanism

The robot, embedded with an infrared camera, is carefully moved through the same borewell as the one the child is trapped in. The instant it reaches a stipulated amount of distance above the child's head, the clamping mechanism, which consists of 3 clamping jaws separated by 120 degrees and driven by a dc geared motor, will help the robot stabilize its position by clamping itself to the walls of the well fixing its prime center and thereby preventing further disturbances.. The system consists of 4 bevel gears one driver and 3 driven wheels which are also separated by 120 degrees. The gear ratio is 1:1.5. Rotary motion of the three bevel gears are converted into linear motion using a screw mechanism, upon which clamps are attached. In this mechanism the prime focus is to prevent the oscillation and rotation of robot as it is being suspended on rope/chain. Hence the force requirement of the clamping mechanism is minimal. The mechanism is designed in such a way that the joints between the clamp and screw shaft will break if we pull the rope with a force greater than 50N. This ensures that even if the clamps gets stuck while unclamping, we can continue to rescue the child by pulling the rope/chain as this will break the collapsible joints.

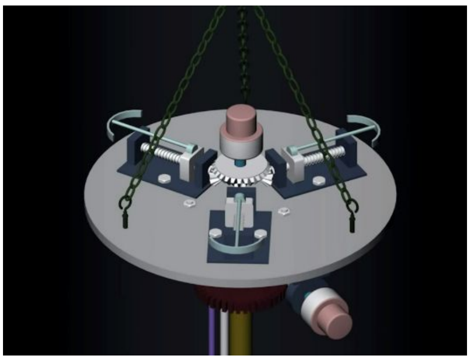

Figure 3: Clamping Mechanism

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B. Positioning mechanism

The positioning mechanism is designed such that it helps the lower part of the robot to rotate with respect to its clamps with the help of a dc gear motor. The fine positioning system allows the lifting rod to slide in radial direction as well.

It consists of 2 parts. The former consists of a worm wheel mechanism with a gear ratio of 1:60, driven by 12 Volts DC geared motor. Here, worm gear is used to get more gear ratio with minimum space and least components. Also, it is unidirectional. Thus, we don't need to power the motor in order to maintain the position. The second part consists of a linear motion mechanism made of screw rack. It will give linear motion for a stroke length of 10 centimeters. This mechanism is used to move the lifting rod towards the side of borewell and to keep it as close as possible. It will also help us to use the same robot in borewell of different diameters (25.4 - 45.72 centimeters).

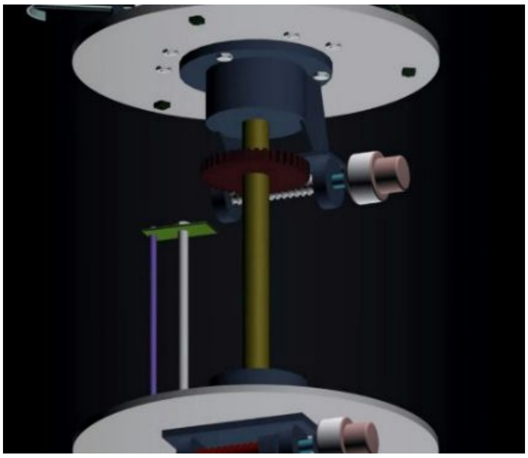


Figure 4: Positioning Mechanism - Part 1

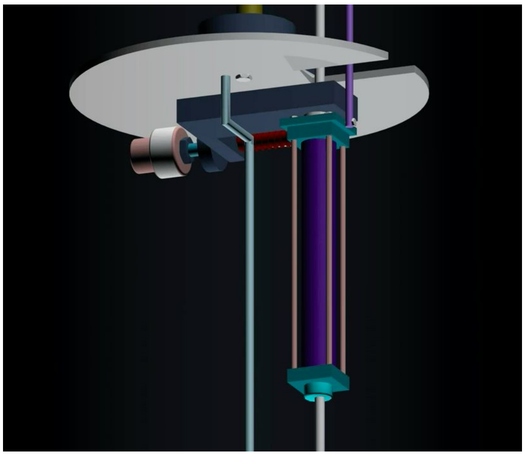


Figure 5: Positioning Mechanism - Part 2

C. Lifting Mechanism

After accurately estimating the gap between the child and the wall, a pipe (diameter of 1cm) is slid through the opening, below the child after which a nylon bladder pops out along with the metallic platform from the tip of the pipe, which is capable of withstanding load up to 30 kilograms. The child is secured and lifted as the robot is hoisted. The system consists of a pneumatic piston with a stroke length of 140 centimeters. High pressure air is supplied using a compressor along with safety valve.

Figure 6: Lifting Mechanism

D. Controls

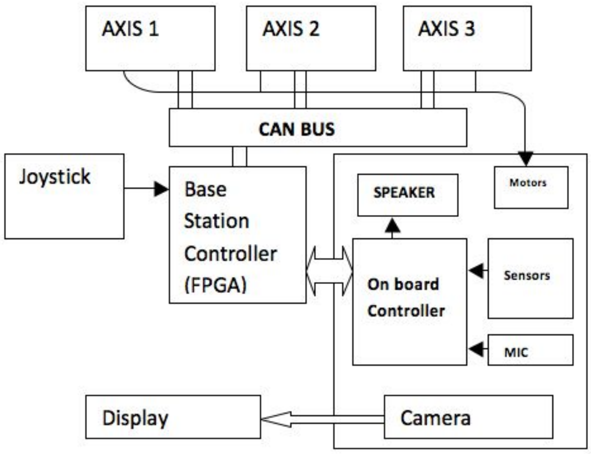


Figure 7: Block Diagram of Control System

The control system consists of two parts: an on-board controller on the robot and a controller at the control station. The on-board controller relays the sensor data to the control station and also logs it on its onboard storage for future reference. Field Programmable Gate Arrays (FPGA) are used as controllers and Controller Area Network (CAN) modules are used for communication protocol.

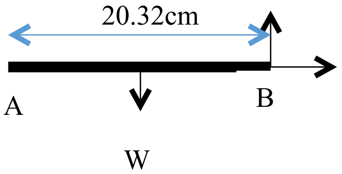
The control station consists of a control system and a motor driver (EPOS) for driving a Maxon motor. The motor is coupled with the rotating mechanism using a worm gear assembly [1]. The system can be operated using the joystick attached to the controller. This type of design makes the system immune to the disturbances caused during the operation.

A bypass circuit is designed as a part of the system to serve as a backup, in case of system failure. When the circuit is activated, the motor will be controlled directly from the base station using a separate independent channel which provide a visual feedback, without relying

on the onboard control data.
In the alpha model, a 3 axis motion control using relays was implemented. In the beta version, the same control was realized by a standalone base controller. For the gamma stage of the system, refining and redesigning the existing algorithm to improve fidelity, performance, durability and solving latency problems is being focused.

E. Force Calculations

Supporting platform (Lifting Mechanism)



1 N = 9.81 Kg

F = + ve

F $\leq$ = - ve

$\Sigma = 0$
$= 30$ Kg $= 294$N
$\Sigma = 0$, $Bz = 0$
$\Sigma = 294 \times 10.16 = 2987.04$ Ncm (Clockwise moment)

Force calculations for the remaining components were calculated in the similar way.

IV. Evolution of Models

A. Alpha Version

Alpha version was the first prototype of the borewell rescue robot, which was made out of mild steel. It was built to prove the concept. It comprised of a single camera system to monitor the child. DC motors were used for actuation and linear actuators helped with the lifting mechanism in the robot. Nylon rope was used to lift the robot from the well. Batteries and controllers were kept outside the well to ensure that their failure doesn't harm the child further. For communication as well as power supply shielded cables were used. The use of wireless communication was avoided as it may fail easily compared with wired one. The alpha prototype was tested to prove that the concept was functional.

B. Beta Version

On considering the advantages of the alpha version and also addressing the limitations of it, a more realistic and revised design was made focusing mainly on the kinematics. Some of the significant modifications were made emphasizing on the safety of the child throughout the entire process. The fine positioning system was replaced with a radial movement mechanism so that it can be used in borewells, ranging from 25.4 centimeters to 45.72 centimeters in diameter along with fine adjustments. The lifting mechanism was changed to pneumatic system [2] to get more power with less weight and to avoid a long linear actuator. In this model, a safety cage was provided for the child and using the lifting mechanism he or she was brought into the safety cage. All the mechanisms and motors were separated from the cage by providing a disc for the lower part. The metallic platform was replaced with a Japanese fan-like metal frame, which could take 30 kilograms of weight. In general, weight of children who got stuck was found to be a lot lesser than this and hence provided optimum support for the purpose. A nylon bladder was connected with the metal frame and the fan-like structure was allowed to spread when the nylon bladder inflated.

Figure 8: Beta Prototype

B1. Test

The beta version of the prototype was tested by allowing the robot to handle a doll filled with sand weighing 15 kilograms. It was placed in a simulated borewell made of polycarbonate that was 20 feet tall to simulate the environment of a child trapped in the borewell. Also, a static test was performed on the metallic base by using a 50 kilogram weight. This assured that the metallic base could hold a heavy child as well. With the two prototypes tested and having proven that the conceptual idea of the rescue robot, optimization of the design was carried out. During the testing of both the prototypes, a number of factors had to be addressed. The motor and the connections had to be ensured to work in such a way that after taking child into safety cage they will not fail. The system, including the clamping mechanism that could get stuck, had to be made robust and not fail while lifting child. The nylon air bag should be strong enough such that it should not tear during the rescue operation. The various positions in which a child could be stuck in, and the adequate space required to find the gap, such that the base of the robot goes beneath him or her, is of prime importance. The most important safety concern that has to be addressed is to ensure that the robot does not startle the child, which could lead to more complex situations, such as the child falling deeper down the pit. To build a model that combatted with the above mentioned issues, the robot was redesigned to incorporate all the extra safety measures.

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B2. Experiments and analysis:

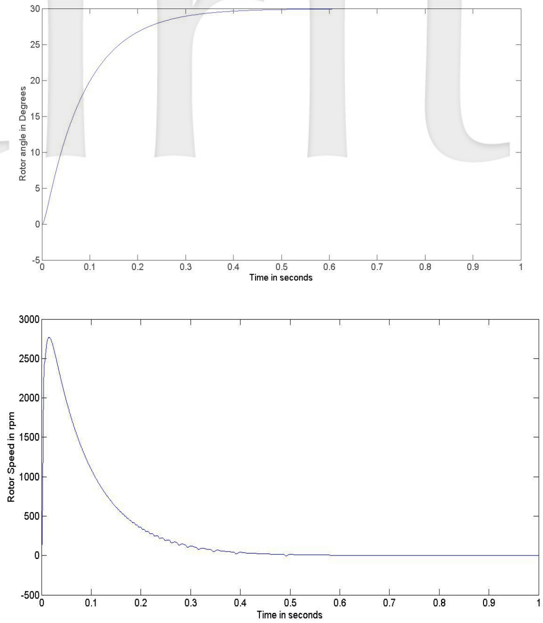

Figure 9: Graph of Position and Velocity v/s time for a single axis position control

Profile position control mode was used for the position control of the motors. The velocity and acceleration profiles affect the settling time of the motors. As the acceleration was increased greater speed was achieved by the motors for position tracking.

The acceleration and speed could be varied directly based upon the dynamic motion parameters, which are weight of the payload and input position command. The input position determines the operation of the axis and higher torque is required to meet up higher position demand values or speed. The weight of the payload can change if extra materials are added onto the robot.

C. Gamma Version

The mechanism was redefined such that the safety cage is allowed to directly hang from the rope. An L-link is provided to ensure that the system has a rough boundary wall. This helps to move to the extreme sides of the boundary. This is done to make sure that the robot doesn't touch the child's body. The clamping mechanism was then designed to have hinges on each of the straight rods used for clamping. These hinges will operate only in downward direction (-90). The need for clamping is to primarily prevent rotation and also to keep the robot to the center. The advantage is that the hinges will not bend even if there is a downward force. Hinges ensure that even if the clamping mechanism fails and the rope is pulled, the joints will get bent and the robot will be free to move up. They will collapse and the joint forms a cone shape. Hence, the robot will get released from the side of the borewell. Even if the lifting fails, the child will be safe in between the lower supporting platform with nylon air bag cushioning and the safety cage.

Figure 10: Gamma Prototype

If the nylon bladder wears off or tears, the safety of the child remains unaffected. The purpose of the nylon bladder is only to provide padding to the child and help the metallic platform to expand to its optimal size. So even if the air bag fails, the child will get adequate support from the metal platform. Motors and actuators with least noise were chosen and the LED light placed in the robot is a backup option. The camera with IR imaging and thermal imaging can be added to aid in rescue operations. These could help in making sure that the child stays calm throughout the rescue process. In gamma model, we added one more pipe with small air bags on through its length. So in case if we are unable to find gap we can just activate the other arm to align the child by activating air bag on the side and simultaneously inserting the other rod. The posture of the child will not matter as we are giving adequate cushioning with the help of air bag. Thus, the child can be rescued with optimum safety and in less time.

V. Conclusions

A borewell rescue robot was designed, prototyped and tested using a novel method involving pneumatics and safety cage. The robot will reduce the time taken to rescue the child from the borewell and also reduces human effort. Unlike any other rescue device available, the proposed system has a mechanism that provides the child support from the bottom and lifts, instead of using a grasping mechanism. We believe that this design will open a rich space for future rescue robot technologies for human rehabilitation and assistance. This rescue robot can also be used in rescuing people stuck in mine holes and man-holes. If sensors [3] [5] [7] [8] are attached to the system, it could use the values to learn and compute for better performance during the succeeding rescue operations.

VI. References

[1] M. Li and X. Xie, "An Improved Architecture and Implement of Rescue Robot," in *International Conference on Anti-Counterfeiting Security and Identification in Communication (ASID)*, Chengdu, July 2010.

[2] K. Harihara, S. Dohta, F. Zhang and T. Akagi, "Development of a Search Type Rescue Robot Driven by Pneumatic Actuator," in *SICE Annual Conference 2010*, Taipei, Taiwan, August 2010.

[3] B. Doroodgar and G. Nejat, "A Hierarchical Reinforcement Learning Based Control Architecture for Semi-Autonomous Rescue Robots in Cluttered Environments," in *6th annual IEEE Conference on Automation Science and Engineering*, Toronto, Ontario, Canada, August, 2010.

[4] W. Chuanjiang, S. Xiujuan, Z. Z. Zhixian and Z. Jixiang, "Virtual Prototype Realization and simulation for Small-Caliber Deep Well Rescue Robot," in *Third International Conference on Measuring Technology and Mechatronics Automation*, Shangshai, January, 2011.

[5] T. GUO, C. Zheng, Z. Du and F. XU, "Research on Obstacles Avoidance Technique of Mine Exploration and Rescue Robot Based on Fuzzy Reasoning," in *Sixth International Conference on Fuzzy Systems and Knowledge Discovery*, Tianjin, August, 2009.

[6] M. Hongwei, . T. Hao and . L. Xiaopeng, "Research on Motion Control System of Mine RescueRobot," in *IEEE International Conference on Automation and Logistics*, Shenyang, China, August, 2009.

[7] M. Hatano, "Research on Rescue Robots with Force Sensors on the Fingertips for Rubble Withdrawal Works," in *SICE, 2007 Annual Conference*, Takamatsu, September 2007.

[8] S. Miyama, M. Imai and Y. Anzai, "Rescue Robot under Disaster Situation:Position Acquisition with Omni-directional Sensor," in *InU. Conference on Intelligent Robots and Systems*, Las Vegas. Nevada, October, 2003.

[9] R. Masuda, T. Oinuma and A. Muramatsu, "Multi-sensor Control System for Rescue Robot," in *International Conference on Multisensor Fusion and Integration for Intelligent Systems*, Washington, DC, Dec 1996.

[10] N. G, G. G, V. G and N. S, "Design and Simulation of borewell rescue robot - advanced," *ARPN Journal of Engineering and Applied Sciences,* vol. 9, no. 5, pp. 608-611, May, 2014.

[11] S. K, V. S and M. J. Louis, "Bore-Well Rescue Robot," *International Journal Of Research In Aeronautical And Mechanical Engineering,* vol. 2, no. 4, pp. 61-80, April, 2014.

[12] L. ". O. Arivazhagan, "The Minitab Blog," 19 08 2014. [Online]. Available: http://blog.minitab.com/blog/statistics-in-the-field/using-the-g-chart-control-chart-for-rare-events-to-predict-borewell-accidents. [Accessed 25 01 2015].

[13] [Online]. Available: http://www.deccanchronicle.com/content/tags/borewell-accident.

[14] NDTV, [Online]. Available: http://www.ndtv.com/video/player/news/borewell-robot-to-the-rescue/98310. [Accessed 08 02 2015].