Low-cost mobile robot arm capable of carrying 2kg using pulley system to reach heights

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Abstract

Current mobile robot platforms capable of carrying weights up to 2kg and reaching heights normally faced within a home are expensive and overly complex for the task. Universities and people in need of at home support, would benefit from a low-cost, open source robot with these abilities.
Development will focus on minimising costs and robot complexity to ensure reproducibility for under £2000.
The resulting system proved capable of lifting 2kg loads to over 1.5m. The gripper design required additional torque to ensure effective load grasp.
In conclusion, a prototype system was effectively developed, with high strength and high simplicity achieved for a low-cost.

Keywords

assistive robot wheelchair pulley

1. Introduction

Access to robots for use in supporting humans is currently limited by cost. Robots are generally highly complex, and require expensive motors to enable the strength to move loads. The open source Katana robot arm used by the assistive ‘El-E’ robot (Nguyen et al., 2008) was reported to cost US$24,900 in 2008 (Robots.net, 2008). The Katana arm was considered open source (Robots.net, 2008), and the El-E robot aimed to be cheaper than carer staff.

In reality, this is not a financially viable option for those who need such a system. This is the primary reason why this issue must be solved. The cost of robotics must be lowered so that both the people them, and the research community, can access them. Through increased user experience, interaction and feedback, the pace of development of such systems can increase. Furthermore, the minimal availability of large scale robots outside of the industrial setting and format at Universities limits education. A truly lost cost robot would even be capable of being introduced at younger education levels.

Robots capable of effective support within the home, or within a care home require the strength and reach to access the array of objects that they may interact with on a daily basis. With this goal in mind, along with the simplicity of implementation targeted by this project, alternative methods of handling heavy weights must be examined.

Both Hillman et al. (2002) and Nguyen et al. (2008), chose to implement vertical arm traversal through a 1-DOF linear actuator. This simplified gripping motions as all objects, regardless of height, could be accessed from the same angle (Nguyen et al., 2008). However, both robots have key issues. First of all the Wilson robot developed by Hillman et al. (2002), is designed for use with a wheelchair and lacks a manipulator capable of handling large loads. The El-E robot meanwhile (aside from cost), uses an additional 5-DOF robot arm as the gripper, also incapable of supporting large and heavy objects.

The novel approach developed by this research will focus on minimising complexity and cost. By using an omnidirectional base for XY movement, and a pulley system to enable vertical traversal (Z-axis), all possible movement axis will therefore be achieved within the robot body, rather than the robot gripper. This design will enable the use of grippers designed to carry heavy loads, with the only required component of the gripper being a clasp to hold the item in place. A rotational ability will exist on the gripper so that items both perpendicular and parallel to a surface may be grasped.

2. Method

The degrees of freedom available to the final design rely on two core components, the base, and the tower.

The robot base consists of three omnidirectional wheels equally spread around the base. The front wheels are 40cm apart from one another, with the rear wheel placed 40cm behind the front wheels (perpendicular).

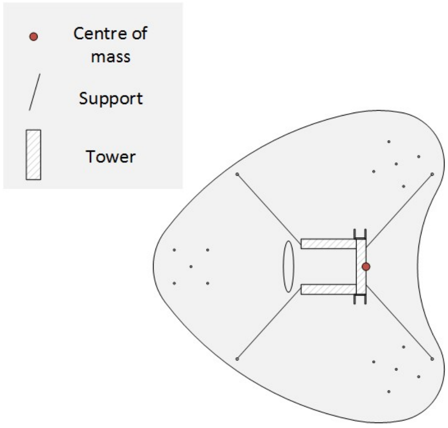

Figure 1 - Base top down view.

All wheels are angled towards the centre of mass at the tower base. Based on the angles towards this centre the required velocities can be calculated to ensure omnidirectional movement in response to XY inputs.

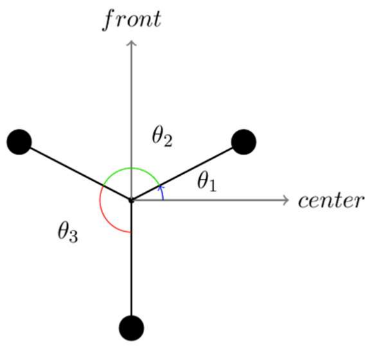

Figure 2 - Wheel placement and angle calculation.

Velocity is calculated for each individual wheel using the following sets of formulas, with θ equal to that of the current wheel, x and y being the result of user input:

$$ta = \arctan\left(\frac{y}{x}\right)$$
$$mag = \sqrt{x^2 + y^2}$$
$$velocity = mag \times \cos(\theta - t\ \ )$$

The resulting velocities allow the base to move in straight lines on the X and Y axis as defined by the X and Y inputs. Applying a fixed velocity directly to all three wheels allows rotation. Sitting on the rear of the base is a large water container acting as a rudimentary counter weight. This avoids the need for any complex counter weighting within the arm.

The robot arm consists of three MDF (medium-density fibreboard) plates. Four structural poles pass through these plates, held in place by metal axles. This allows the poles to freely rotate within the plates. This rotation gives the arm freedom of vertical movement between the front and rear. The centre plate is held onto the tower structure by four sliders. Two sliders are placed on each side and are capable of sliding up and down within the metal "trench" available down both sides of the tower. This ensures a stable base for the front and rear of the arm to rotate around (the centre acting as a fulcrum), while also ensuring parallel raising and lowering of the arm.

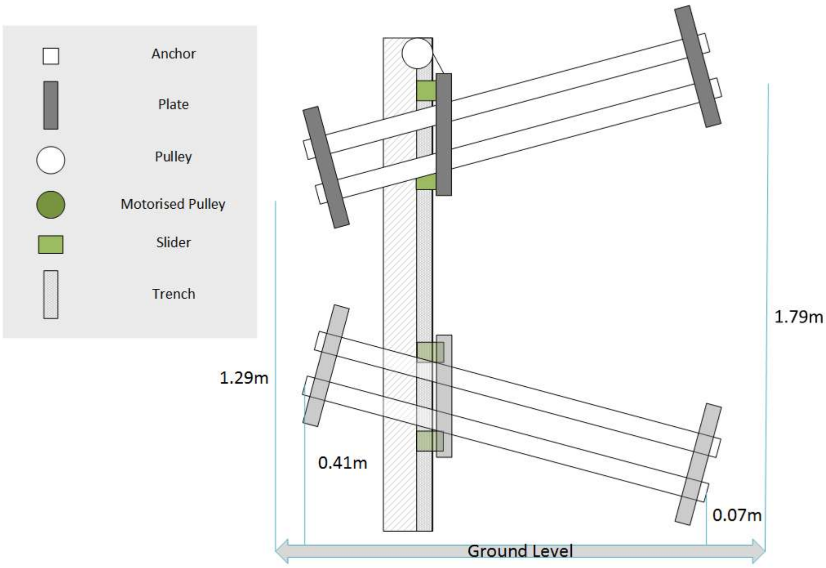

Figure 3 - Arm and tower movement concept and measurements.

Vertical velocity is achieved through the use of a double pulley system. This system applies pulling force to a cable through the use of an MX64 Dynamixel motor. This force results in the robot arm being raised. The pulley directly connected to the motor is considered a double pulley, as the 3D printed component consists of two pulleys. The larger pulley- with a radius of 13mm – is used to raise the robot arm. Meanwhile, the smaller pulley with a radius of 6.5mm, applies force to the rear of the robot arm. This results in the arm rotating at $\frac{1}{2}$ the rate of the vertical traversal of the tower attached portion of the arm.

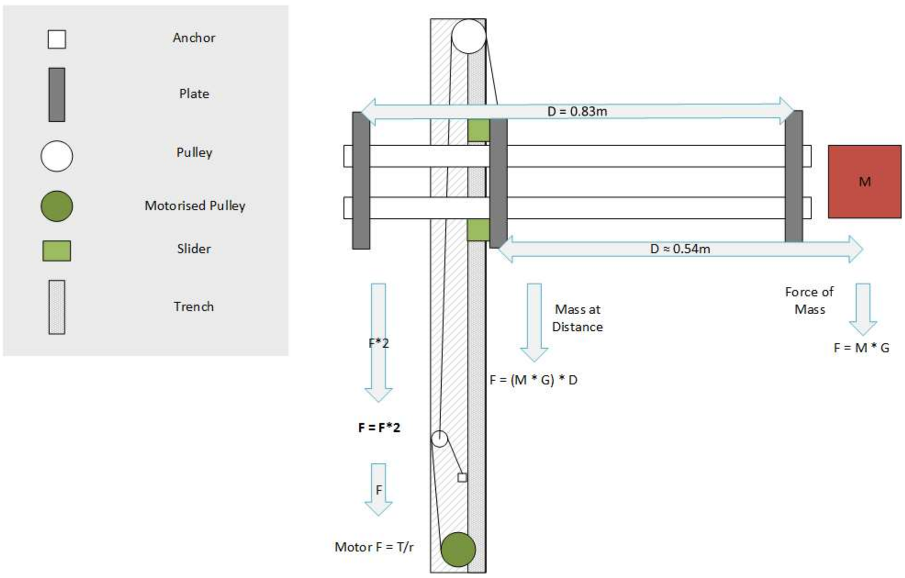

Figure 4 - Available and required force. Only one pulley ecosystem is visible.

Additional pulling force is achieved through the addition of free-floating pulleys. Both pulley systems are directly attached to smaller free-floating pulleys (i.e. not held in place). The returning cables from these pulleys are then anchored within the tower. The cables responsible for applying force to the arm are actually tied to the tops of these free-floating pulleys. The result of this mechanical advantage is a drop of $\frac{1}{2}$ in the force required to lift a load.

The gripper design also relied on simple pulley systems. To avoid putting undue weight and strain on gripper motors, the gripper was attached to the forward plate using a large metal axle. Therefore, and mass applied to the gripper was carried by this axle directly through to the arm, rather than the motor. The motor rotated the gripper through the use of a pulley built into the rear of the gripper.

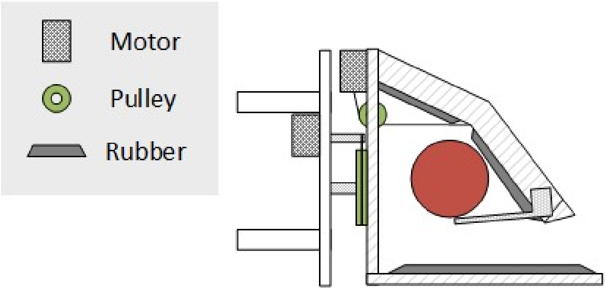

Figure 5 - Gripper design. Using both knuckle and finger components.

Similarly, the rotation of the “knuckle” portion of the gripper also operated through a pulley, with a motor located on the rear of the gripper, tightening a rope in order to pull the knuckle closed. A spring them act to return the knuckle to it’s default location. The final component was a finger, this was simply a motor with a plastic plate attached to its end as a rudementary manipulator. This “finger” was added to manipulate smaller items, hold items in place, and pull items towards the gripp. The bottom the gripper was simply a metal plate and ensured a strong carrying platform. A thin rubber layer over all internal portions of the gripper ensured a reasonable degree of friction coefficient throughout the design (note this did not include the finger component).

3. Results

Testing of the robot was accomplished through the use of a pilot study followed by three recorded experiments. During each of these experiments no issues were found with the base or tower systems. The robot was capable of carrying all weights attempted, ranging from 100g to 2kg, and lifted these over 1.5m from ground level.

Figure 6 - Robot prototype used during testing.

A failure in the control system resulted in the base being incapable of rotating, but otherwise was capable of full omnidirectional movement. This feature was especially used by the participants for side-to-side strafing, removing the need for complex navigation when aligning the robot with a target point.

The gripper was tested for its ability to handle objects of different shapes and sizes. Experimentation required three objects be picked up and moved a short distance.

- Task 1: Roll of wire (200g)
- Task 2: 500ml bottle of water (600g)
- Task 3: Book (400g)

	Task		
	1	2	3
Pilot	Fail	00:02:40	Fail

P1	00:02:18	00:02:50	00:03:52
P2	00:03:43	00:04:07	Fail
P3	00:03:20	00:00:40	Fail

During the pilot study the gripper failed multiple times due to overload errors in the knuckle, and occasionally the finger. As a result, the main experiments required the researcher to be ready to power cycle the specific motors upon failure.

4. Discussion

The experiments showed strengths and weaknesses in the robot design. The base and tower operated as expected, however the gripper showed areas were improvements were needed.

The key issue discovered within the gripper was that both the knuckle and finger were underpowered for the tasks, with the knuckle having the greatest need for redevelopment. The knuckle portion lacked the torque to effectively clasp, or hold items. Items that could be held in place, would not be releasable due to a motor overload. If collecting a larger bottle, the knuckle would fail just prior to applying enough force for a successful clasp. Items that were picked up occasionally slipped out of the gripper as the knuckle began to fail. An increase in power supply or motor size would solve these issues. The currently used MX28 is rated for a max stall torque of over 7N·m when supplied with 14V. However, at 11V this is limited to 5.3N·m.

Task 3 of the experiments resulted in a 75% failure rate. This was due to the slippery surface of the book. Neither the gripper plate – designed to be moved under an object – nor the gripper finger, were able to grasp the object. The simplest solution would be the addition of high friction coefficient materials on the gripper finger, to enable it to pull items towards the gripper effectively.

As can be seen in Figure 4, the available force of the motor can be calculated as the given torque of the motor divided by the radius of the pulley. As the main pulley has a radius of 13mm, and the motor a torque of 5.3N·m at the supplied 11V, the following force can be calculated as:

$$\begin{aligned} F &= \frac{T}{r} \\ &= \frac{5.3N \cdot m}{0.013m} \\ &= 407.69N \end{aligned}$$

With the effects of the pulley system, this would in fact result in a total available perfect (frictionless) force of 815.38N. A load weight of 2kg, or 5kg at the extreme - once the weight of the arm and gripper are accounted for – results in a force of 49.033N, discoverable through:

$$\begin{aligned} F &= M \times G \\ &= 5kg \times 9.80665m/s^2 \\ &= 49.033N \end{aligned}$$

So to simply counter the effects of Earth gravity only 8.3% of the available torque is theoretically needed. However, in reality a 2-3kg load is the maximum safe load for this arm currently.

The reasons for this can be seen as two fold. First of all, the low cost materials used throughout resulted in structural weakness when faced with excessive weights. More substantially however is the clear loss of force. This can be explained by the design of the arm's slider system. The slider components were 3D printed and will be applying friction to the trench walls. To compensate for this, stronger, frictionless components such as ball bearings would be required to replace the slider components.

While the use of a single large mass on the robot base is an effect counter weight, it does remove an otherwise useful feature. If a counterweight system was directly implement into the arm, this would balance the pull applied to the sliders by any carry weight, and would limit the applied friction.

5. Conclusion

The developed system effectively used low cost materials and motors while outputting the required lifting force to carry 2kg loads at up to 1.5m. With seven motors used throughout the arm and base, and each motor costing approximately £200, this mobile robot arm can be expected to cost, at least £1400 if constructed from scratch. Furthermore, if the base Dynamixel motors were replaced with PWM motors, this could cut the cost of the robot drastically, as Dynamixel motors are priced due the amount of on-board data and parameters available – usable as joints or wheels.

The quality of the materials may limit the amount of force reaching the arm from the motor, this is also a limitation of a pulley system, with friction being applied at multiple points. The main weakness of the robot design is the motors used to supply torque to the knuckle component of the gripper. The output of the motor is limited by the power supply used by the robot, and should be increased prior to further changes.

The completed robot arm represents an effective prototype in the move towards low-cost worldwide availability of support robots. Through open sourcing this research, it is hoped that the design will be used as the basis for further research development.

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7. References

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