The commuter scooter re-engineered

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Abstract
Public transportation is a popular option for city commuters. However, it is limited to specific routes which rarely bring riders directly to their final destinations. The aim of this project is to develop a faster and easier way to travel the distance between public transportation stops and individual locations. A bicycle or scooter could be used; however, most current models are not sufficiently portable and convenient enough to carry.

A Version 1 concept for a folding, pedal powered adult scooter was devised and prototyped by a previous Capstone team, but its transmission was not operational, and did not meet targets for size and ease of deployment. This project re-engineers the Version 1 Commuter Scooter. Simple testing was performed to determine more attainable specifications, so the new prototype will be designed to meet a different set of goals from the Version 1 team. The re-engineered proof of concept includes a more robust transmission incorporating a planetary gearbox that converts human power to propulsion. This concept was chosen after thorough testing and systematic decision making. The Version 1 frame was re-designed to decrease the folded volume, strengthen weak points, and accommodate the new transmission. The overall folded volume of the prototype is 456 in$^3$, 200 in$^3$ less than the Version 1, and the weight is 7.8 lbs.

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The Need for Project

The commuter scooter allows commuters to reach destinations beyond public transportation drop-off points quickly and efficiently. Public transportation is limited to specific routes with set pick-up and drop-off locations. Riders whose start and end points are not close to these locations must travel an additional distance by walking or other means, which adds time, effort, and/or cost to their daily commute. The commuter scooter will allow commuters to reach destinations beyond the limits of public transportation more quickly and efficiently. An adult sized, lightweight, foldable, pedal-powered scooter can conveniently be carried in a backpack and quickly unfolded and folded for riding.

The Design Project Objectives and Requirements

Design Objectives

The commuter scooter must support and comfortably fit an adult rider up to 250 lbs. The final design should weigh 5lbs and be portable enough that it can easily be carried in a backpack. The frame must be simple to fold and unfold. The scooter must allow an individual to travel faster than walking, but with no more effort.

Design Requirements

For convenience of carrying, the commuter scooter should be lightweight and fit inside a backpack, as seen in Figure 1. The scooter will include a foot powered pedal with a transmission providing 50 inches of travel per pedal stroke that can maintain a speed of 5.5 mph. Testing of user characteristics, such as desired input pedal force, rolling friction, and comfortable riding speed, was performed to determine the optimal specifications. (Rep. 5.1.4-5.1.6)

Design Concepts Considered

To achieve the project goals, a step-up transmission that converts a high torque input at the pedal into a high speed output at the rear wheel must be incorporated into the commuter scooter. Development of the transmission was the primary focus of the project since it differentiates the commuter scooter from a typical scooter. Three concepts—a Chinese windlass, pulley cable drive, and planetary gearbox—were prototyped and tested before choosing the final design concept.
The Chinese windlass includes a cable wound in opposite directions around a rotating drum with two slightly different diameters and through a translating pulley, as seen in Figure 2. As the pulley translates away from the drum, the larger drum loses cable while the smaller drum gains cable resulting in many rotations of the drum. The Chinese windlass bench-top model was 66% efficient based on testing (Rep 5.1.7.1).

The pulley cable drive was incorporated into the Version 1 design but failed due to high friction. An improved pulley system was tested, including a string wound around three pulleys on a translating shaft and three pulleys on a rotating shaft, as seen in Figure 2. With this configuration, a small travel distance of the input translating shaft results in many rotations at the output shaft. The pulley cable drive bench-top model was 87% efficient based on testing (Rep 5.1.7.2).

A planetary gearbox can be driven in reverse to achieve many, high speed rotations at the output from a high torque input. A planetary gearbox transmission from a cordless drill was tested as a potential concept for the commuter scooter. The planetary gearbox bench-top model was 70% efficient based on testing (Rep 5.1.7.3).

Alternate folding schemes for the scooter frame were also brainstormed, but after modeling and structural analysis it was determined that the Version 1 folding design was the strongest option. The alternative consisted of a three piece deck, shown in Figure 3, which folded within the dimensions of a textbook, rather than the long and narrow shape of the Version 1 design.

**Recommended Design Concept**

The commuter scooter will use a planetary gearbox transmission to drive the rear wheel. This is a robust, compact option. The Version 1 frame was redesigned to be stronger and fold smaller.

Based on the comparison of the three transmission bench-top models, the planetary gearbox was chosen for the final transmission design. For the final frame design, the Version 1 design was improved to decrease the folded volume, strengthen weak points, and accommodate the planetary gearbox transmission.

**Design Description**

The planetary gearbox tested for the commuter scooter transmission consists of three stages, with a high gear setting with a gear ratio of 45.9:1 and a low gear setting with a gear ratio of 14.25:1. The low gearing was used for the commuter scooter transmission with a belt connecting the gearbox output to the rear wheel, increasing the
gear ratio. Two gears connect the input pedal shaft to the gearbox input shaft to reverse the direction of the gearbox output and drive the scooter forward.

The scooter frame includes a telescoping and hinged steering column that collapses shorter by adding an additional stage. The front wheel joint was improved for better wheel axle support by thickening the support. The hinged deck folds at a 3° offset angle, as seen in Figure 4, increased from the 2° angle in Version 1, to fit the redesigned wheel joint. The folded scooter is 16”x4.75”x6” and the overall folded volume was reduced by about 200 in³ from the Version 1 design. The end weight is 7.8lbs, which is 0.5lbs less than the Version 1 scooter.

**Experimental Investigations**

Initial experiments were performed on a bench-top model, by placing a load on a lever attached to the input shaft and measuring the torque required to raise and lower the load at the output shaft. The measured torque was compared to the ideal torque calculated from the gear ratio.

Next, a mock-up was built to test the functionality of the gear box in propelling a scooter forward. This mock-up included all of the necessary components, including the two added gears to reverse the output direction and a belt connected to the wheel. The mock-up proved that this setup worked in driving the scooter forward.

**Analytical Investigations**

The frame design was modeled in SolidWorks and analyzed for structural integrity using SolidWorks simulation. Modifications were made based on simulation results.

**Key Advantages of Recommended Concept**

Although the planetary gearbox was not the most efficient option, this concept has many advantages over the Chinese windlass and pulley cable drive. This option is compact and durable. The pedal can be used as a direct rotational input rather than incorporating it into a linkage to create a translating input, as seen in Figure 5. Most importantly, there is no risk of cables slipping off pulleys or tangling during pedal retraction.

The final frame design is the strongest design option considered by both the Version 1 and 2 teams. This folding scheme best accommodates the steering column and has the smallest folded volume.
Financial Issues

The prototype was fabricated for $500 not including labor. There was no target cost for this product as it aimed to be a proof of concept. The prototype was built with $500 worth of parts. Labor is not included in this figure. As with all mass produced products, costs can be decreased considerably with suppliers developing one off parts in large quantities for lower per unit cost.

Recommended Improvements

The scooter design would need to be modified for mass production. The next phase of this project would be an improved design for manufacturability. A smaller, custom planetary gear box could be designed to occupy less space within the frame. The deck could consist of multiple welded/attached components rather than machined from solid to decrease cost and material scrap. High precision tubing could be purchased for the steering column to avoid turning the outer diameters to size.