Electric Tricycle Project: Appropriate Mobility

Final Design Report

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Daniel Dourte
David Sandberg
Tolu Ogundipe

Abstract

The goal of the Electric Tricycle Project is to bring increased mobility to disabled persons in Burkina Faso, West Africa. Presently, hand-powered tricycles are used by many of the disabled in this community, but some current users of the hand-powered tricycles do not have the physical strength or coordination to propel themselves on the tricycle with their arms and hands. The aim of this project is to add an electric power train and control system to the current hand-powered tricycle to provide tricycle users with improved levels of mobility, facilitating freedom in travel and contribution to the community. The design objectives required a simple and affordable design for the power train and controls, a design that needed to be reliable, sustainable, and functional. In response to the request from an SIM missionary at the Handicap Center in Mahadaga, Burkina Faso, Dokimoi Ergatai (DE) committed to designing and supplying a kit to add electric motor power to the current tricycle design, and we, David Sandberg, Tolulope Ogundipe, and Daniel Dourte partnered with DE in their commitment. Our project was advised by Dr. Donald Pratt and Mr. John Meyer.

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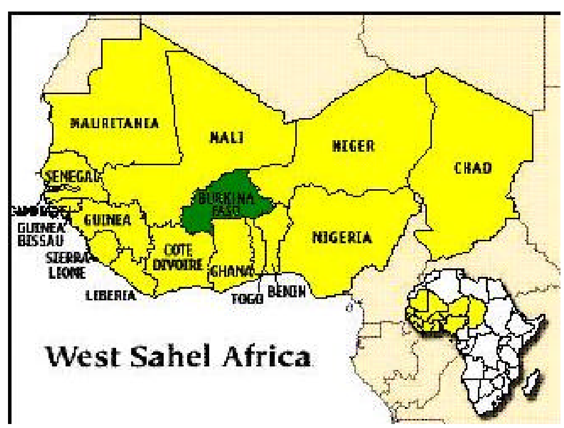
Acknowledgements

We would like to thank Mr. John Meyer for his patient advising and abundant manufacturing assistance and Dr. Donald Pratt for his very thorough advising. We thank Dokimoi Ergatai for partnering with us and providing much project support and information. We are grateful to Dan Elliott and Jim Liebundgut for consulting with us on motor controlling. Finally, we thank our fellow student Brian Wohltmann for his help in editing our presentation video.

1 Introduction

Hand-powered tricycles are presently being used to provide mobility for disabled persons in a rural community in Mahadaga, Burkina Faso. Below is a photograph of a boy in Mahadaga on his hand-powered tricycle. The map on the right shows the location of Burkina Faso (in green).



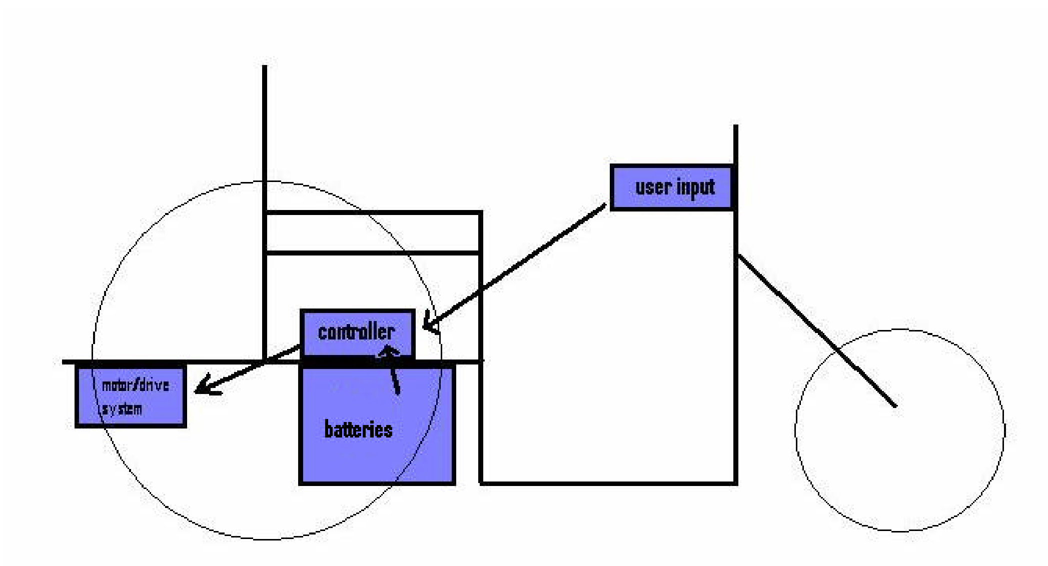
With this project we designed and manufactured a system to convert the hand-powered tricycle to an electric motor powered version. We essentially created an affordable, rugged electric wheelchair for use in a developing country. We have worked to make our design appropriate to the culture where it will be used. This meant designing for the use of locally available parts and manufacturing capabilities. The result is a system that can be almost entirely replicated, with the exception of the motor and motor controller, with familiar parts, tools, and processes. Using the hand-powered tricycle as the basis for our design made the Electric Tricycle more of an appropriate technology because it uses a familiar, locally available platform as a starting point.

In Mahadaga there are currently four potential users of the Electric Tricycle. Disease or old age has left these members of the community dependent on others for their mobility. Though they own hand-powered tricycles, they are being used like conventional wheelchairs with the motive force coming from a person pushing from behind. Our first user is named Yempabou. He is a 12 year old boy from Burkina Faso who has cerebral palsy. Yempabou is pictured below:

Cerebral Palsy limits his dexterity and severely limits the used of his lower limbs. Currently, he is learning to use a modified type of hand-powered tricycle, but has not been able to power himself consistently. The Electric Tricycle should enable Yempabou, and others in the future, to be independently mobile. Dokimoi Ergatai, a Messiah College service-learning organization that works to improve living conditions for people in developing nations, was an important resource in this project. DE is responsible for the origin of the project, through their partnership with those in the community in Mahadaga, and much of the information gathering that was required to complete the project.

1.1 Description

The design of the Electric Tricycle is adaptable to the current hand-powered tricycles with little modification. The design consists of an electric motor, a drive system, motor and steering controls, and a power supply. See picture below for design schematic:



An electric motor was chosen because high fuel costs prohibited the use of a combustion engine and because of the availability of electricity in Mahadaga. A solar array that provides electricity for the Handicap Center provides the ideal source of electricity for battery recharging.

The first aspect of our design that was addressed was the drive system or means of power transmission. Power must be transmitted from the electric motor to a rear wheel of the tricycle. Second, a method of motor control was decided on. The controls for motor speed and braking were incorporated into a simple mechanical joystick to facilitate operation by users with limited dexterity. The hand-power system was replaced with a steering system that disables the hand-power capability of the tricycle. Third, power is supplied to the motor by a battery pack.

All the above components (motor, transmission, controls, batteries) were designed to be able to be installed on the existing hand-powered tricycles. Everything necessary to convert a hand-powered tricycle to the Electric Tricycle is simple to install, and the conversion is reversible. Our objectives for the project are as follows, in order of decreasing priority:

- Be appropriate for use and replication in Mahadaga, Burkina Faso
- Be able to climb a 10% grade
- Limit top speed to 7 mph
- Have a power supply that will provide a range of 8 miles at maximum speed
- Total cost of power train and controls and power supply will not exceed $300

1.2 Literature Review

Research was done online as well as in magazine articles in search of presently available solutions to our problem. We found many products that were available for purchase, but they didn't entirely meet the requirements of our unique problem. The problem has been solved, and in many different ways, but what we found, or rather didn't find, was a solution to our problem that meets our specific needs of affordability and appropriateness. The advantage of finding these solutions is that we can see what works, what has been tried, and what's available on the market. Then we can more effectively consider how to design a similar product that meets our unique needs.

www.kinetics.org.uk/html/the_motor.html is a website that has Heinzmann motors, which are a type of hub motor (Picture 1). This option is quite an expensive option. It costs over a $1000 and is available in England. Hub motors, although a very good design option, may not be the appropriate technology option that we're looking for. Once the hub motor breaks or needs some maintenance, it becomes useless to the local people. It is a self contained system, but self contained also means more complicated technology as well.

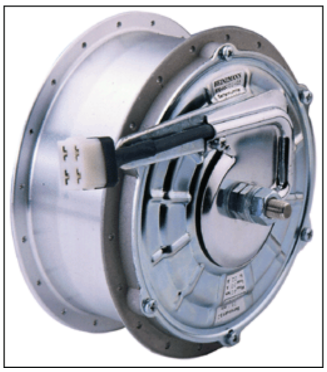
Teftec Mobility (http://www.teftec.com/index.asp0) is a company that produces electric wheelchairs, which is essentially what we're doing. Their more basic and cheapest model is the AlphaTrac and costs $12,495 (Picture 2). This isn't out of the typical electric wheelchair price range which is about $5,000 to $20,000. The amount of engineering that goes into making this machine far surpasses what will go into our Electric Wheelchair. This is a great option and is state of the art, but we believe that we're approaching this art from a much different perspective with very different goals than the typical electric wheelchair manufacturer.

Picture 3 shows different ways, very expensive ways, of hand powering a tricycle. These options may or may not allow for a better design for attaching an electric motor to.

We decided that although these are great designs, their purpose was for recreation and would not suit the needs of the people that we are designing the electric kit for. Their low position doesn't allow a good seating position for a table or clearance enough for the conditions of the area.

Literature Review Pictures:

Picture 1: Heinzmann Hub motor



Picture 2: AlphaTrac (John Deere inspired color configuration, more 'off road')

Pictures 3: These are different options for hand powered operation of a tricycle.

1.3 Solution

We began the design project with three drive options for transmitting power from the electric motor to the drive wheel. First, a hub motor was considered. The hub motor incorporated the motor and transmission into the hub of the wheel. See picture:

This design was very simple and offered the advantage of a sealed, self-contained drive system, but it is the most expensive and least appropriate of the three options.

Deciding against the hub motor, we pursued a friction drive system in which torque is transmitted from the motor to the wheel by direct contact between a drive roller on the motor and the tire of the tricycle. See picture:

The main advantage of the friction drive system is that it is capable of very simply providing the large speed reduction because of the difference in diameters of the drive roller on the motor and the wheel of the tricycle. This option was extensively prototyped, and different drive roller sizes and materials were tested, however, we decided against this option because of its limitations on torque transmission. In testing, the friction drive option was shown to not provide adequate friction in wet conditions. See testing results and conclusions below:

on level

note: all velocities in mi/h

wet:

	tire pressure	max. vel. on level	dist. to max. vel.	is there slippage?
trial 1	40	6	90 ft.	yes
trial 2	40	6	90 ft.	yes
trial 3	40	6	90 ft.	yes

on grade

wet:

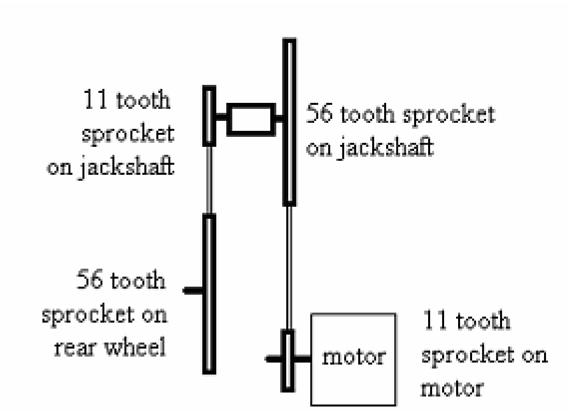
	length of grade (ft)	exact grade (%)	tire pressure	min. vel. on grade	approach velocity	does motor stall?	is there slippage?	start from stop on grade?
trial 1	12	8.3	40	2	5	no	no	no
trial 2	50	8.3	40	0	5	no	yes	no
trial 3	n/a	10	40	0	0	no	yes	no

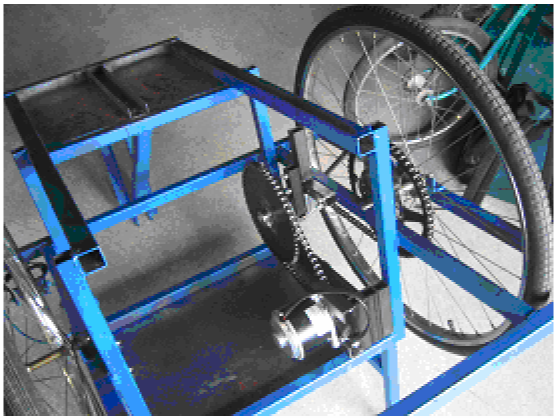
Conclusions: There was little wear on the rubber-tube-wrapped roller even after excessive slipping. Grade climbing objective could not be met in wet conditions. Acceleration on level was unpredictable due to slip under high throttle. See friction drive torque transmission analysis below:

- 406 lb-in of torque required at rear wheel to climb 10% grade (from previous testing)
- T = F*r; radius of rear tire r = 13 in.; F is tangential force applied from friction roller
- F = T/r = 406 lb-in/13 in = 31.2 lb
- μ = F / Fr, Fr = radial (normal) force applied by friction drive mounting, μ = coefficient of static friction between drive wheel and tire
- μ = 31.2 lb / 60 lb = 0.52

Even with a 60 lb load applied, a coefficient of friction of 0.52 is needed to produce enough tangential force to transmit the require torque. This coefficient of friction could apparently not be consistently realized in testing, and it is likely that when dirty (in sandy Burkina Faso) the expected coefficient of friction will drop even further.

After testing of the prototype friction drive system proved that its torque transmission would be too unreliable and too dependent on weather conditions and tire pressure, we decided on our final design option of a chain drive system. The difficulty that the chain drive option presents is getting the required speed reduction when a high speed electric motor is providing power. This is simple if a gearmotor is used, allowing for significant speed reduction, but the prohibitive cost of the gearmotor forced us to use a jackshaft to provide the necessary speed reduction. Two 56 to 11 tooth reductions were used, providing a total speed reduction of 26:1. See section 2 Design Process for speed reduction determination.





The most significant advantage of the chain drive system that reinforces our commitment to it is its ability to transmit large torques without slipping. Also, torque transmission is independent of weather conditions and tire pressure, while the friction drive system was very dependent on those unpredictable factors. A chain drive transmission is also more efficient than a friction drive system. Very high radial forces in a friction drive design put large stresses on bearings and more power is lost to friction than in a chain drive system.

2 Design Process

We needed to decide how much power would be required of our electric motor to achieve our objectives. Some testing and calculation helped us to determine this.

Motor power determination:

- P = F*v
- P = (22 lb)(7mi/h)(5280ft/mi)(1h/3600s)

- P = 257 ft-lb/s = 0.47 hp = 351 Watts

P: Motor power

F: Rolling resistance force = μ_r*N; μ_r is coefficient of rolling resistance; N is weight of tricycle and rider with batteries. F was measured with a force scale pulling the tricycle at a set velocity, and was confirmed by doing deceleration tests.

v: Desired velocity of tricycle

Assuming a transmission efficiency of 80%, our power requirement comes out to be 600W*0.8 = 480W. A slightly larger motor than is necessary was chosen to improve reliability by not running the motor at maximum power all the time. We selected a Currie Technologies 600W, 24VDC, 2600 rpm, brushed electric motor to provide more than adequate power.

Motor torque determination:

Testing done on a 10% (5.7º) grade using torque wrench on hand crank axle:

- Front axle torque = 26 lb-ft = 312 lb-in = 35.5 N-m
- Rear axle torque = 34 lb-ft = 406 lb-in = 46.2 N-m
- Required gear ratio > rear axle torque / motor stall torque
- Motor stall torque = 4*P/?; P is motor power, ? is motor free speed in rad/s
- Motor stall torque = 78 lb-in

Speed reduction determination:

- For 7 mph top speed, rear wheel rpm should be about 91 rpm.
- Therefore, speed reduction = motor speed (rpm) / 91 rpm
- With Currie 600W motor, free speed = 2600 rpm, necessary gear reduction is 2600/91 = 28. We used a 26:1 reduction as this was the largest reduction that

could be achieved using the locally available (in Burkina Faso) moped sprockets and only two reduction stages. In testing, this setup has achieved but not exceeded our objective of a 7 mi/h top speed.

Making the switch from friction drive to chain drive in January left us with little time to design, prototype, and test the chain drive system. However, the decision to implement the chain drive design had to be made in light of the shortcomings of the friction drive system. After finding gearmotors too costly, we chose to essentially make our own "gear" motor through the use of a jackshaft to provide the necessary speed reduction. Our testing of the chain drive system has significantly reinforced our decision to choose this option.

Battery capacity determination:

- Stall current is 35 amps (tested)
- Current at top speed is 8.3 amps (tested)
- Estimating average current from testing in typical start/stop use to be 15 amps
- Assume average speed of 4 mi/hr
- Objective requires 8 mile range

Capacity = average current * run time

Capacity = 15 amps * (8 mi / 4 mi/hr)

Capacity = 30 Ah

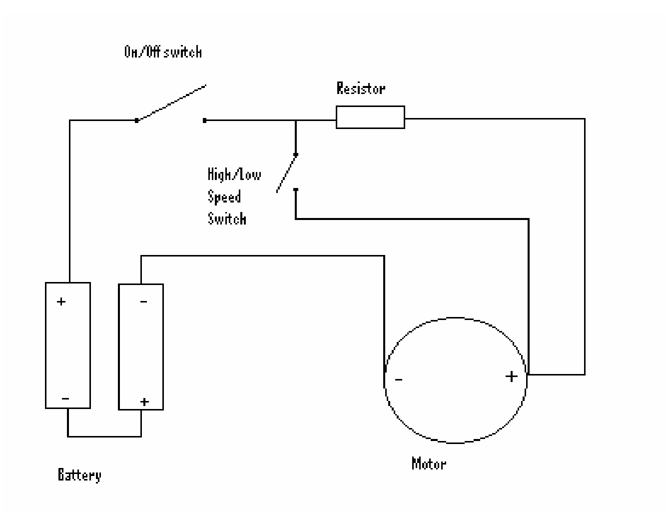
We selected a 98 Ah, 12V, sealed lead-acid battery that can be obtained locally. It is a deep cycle battery that has been used in solar array designs by Dokimoi Ergatai teams.

Motor Control

Electric tricycles already do exist with different control systems. The purpose of the control systems is to act as an On/Off switch and as a speed controller. Our system consists of a 24VDC (2 X 12VDC) battery and a 24V brushed DC motor. We had to decide if we wanted to use a more common and efficient Pulse Width Modulation (PWM) controller or come up with another design to meet our objectives.

In an effort to avoid using a PWM controller to make a more rugged system, we designed a resistive motor control option that consisted of two switches. One switch operated the motor at a slow speed, running current through a power resistor, and the second resistor shorted out the resistor, giving full speed. Knowing the voltage and current we wanted to limit in slow speed, a value for resistance was calculated using Ohms law.

Ohms Law states V = IR, therefore, R = V/I, where V = Voltage, I = Current, R = Resistance. Below is our original test schematic:



In some limited testing, the design was shown to be effective. Our main problem with it was that there wasn't enough initial torque at slow speed. With this we, decided we would have to decrease our resistance, initially 1.7 ohms.

When trying to decide on what resistance we should go for, we thought it would be useful to come up with a way to make a resistor from local materials that are readily available in Mahadaga, Burkina Faso. So we decided to go for thin stainless steel metal. Since stainless steel is widely used and has relatively high resistivity, it seemed appropriate to pursue making a resistor.

The major factors involved in resistor design are the electrical resistivity of the stainless steel, the length, and the area of the cross section. Since the electrical resistivity varies with each stainless steel, we decided that a resistance range of 0.4 O – 1.1O resistance would be good. To get a resistance within this range, it can be calculated by

? = ?V*A/(L*I)

Where

? = Resistivity

L = Length

A = Area

I = Current

?V = Voltage drop.

We this formula, we can estimate how long, how wide, and how thick the stainless steel will need to be to get a resistance within our range.

Since we have a DC power source, we needed DC switches that would last a fair amount of time and be relatively cheap. DC circuit breakers met our specifications but we had a problem with availability and cost in Burkina Faso. Another problem we had was that they are not really designed to be turned an/off on a regular basis. The circuit breakers have a cycle of over 10,000 switches at a 6-switch/min rate, meaning that the switches would likely last less than a year with the expected intense use of the tricycle.

Finding a PWM controller for $35, about $10 more than the price of a single switch, meant that this more efficient method of motor control was also cheaper than the resistive motor control option. Considering all the factors involved, we carefully evaluated the pros and cons of the resistive and PWM motor control options. See chart:

Resisitve Control

positive	negative
understandable/ simple	not efficient in low speed
potentially more reliable	hot resistor
	jerky motion

PWM Controller

positive	negative
smoother operation	questionable reliability
more efficient	
	possibly fragile
easy to integrate into lever	
cheaper	

Cost:

switches:	$58
resistor:	$3
joystick:	$10
total:	**$72**

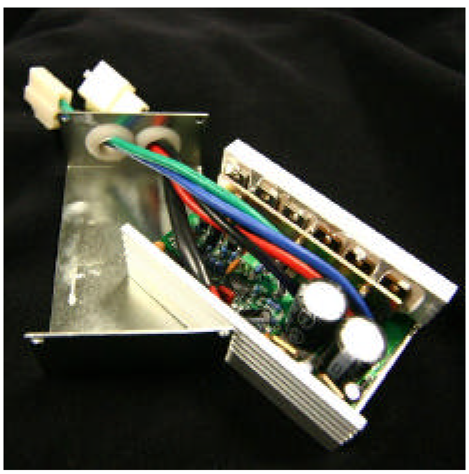
Cost:

controller:	$35
throttle:	$3
joystick:	$6
total:	**$44**

Conclusion:

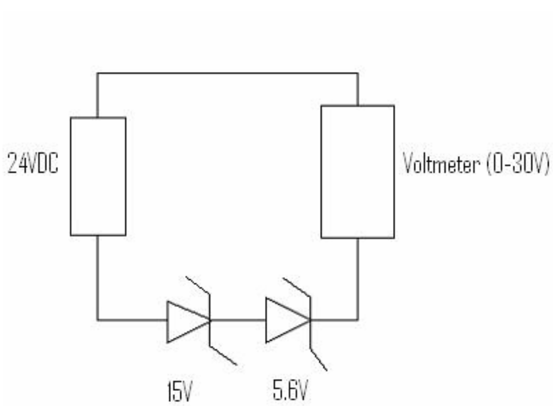
Efficiency, simplicity in lever design, and reduced cost are gained by choosing the PWM controller. The main reason in choosing the resistive control option would be to gain reliability, and we can't be sure that it will indeed be gained. Both options are about equal in appropriateness. The question of reliability will have to be tested to be answered. We chose the PWM controller option because it is being used the way it is designed to be used, possibly offering greater reliability, while the switches will be seeing use for which they were not designed. Also, the controller offers better performance (smoother speed control and improved efficiency).

The Currie Technologies motor controller that we selected for our final design has a 0-5V throttle input that could be achieved through the use of either a Hall effect throttle or a 5k potentiometer. It is a 24V controller with a 40 amp current limit and 20V cutout, meaning that if battery voltage drops to 20V the controller will no longer provide power. This helps prevent battery damage from over discharge. See picture of controller:



In February we received some much needed information about our intended user in Burkina Faso. Yempabou's severely limited dexterity, due to cerebral palsy, meant that control inputs (throttle, brakes, steering) had to be simplified greatly. We did this by combining the throttle control and brakes into a single-axis joystick. The joystick consists of a simple lever that operates a slide potentiometer (5k), giving a throttle input to the motor controller. The lever has a spring return that applies the brakes in the off position. To ensure throttle application does not require excessive force (to overcome the return spring), a tug back on the lever is necessary for full brake application. See picture of joystick below:

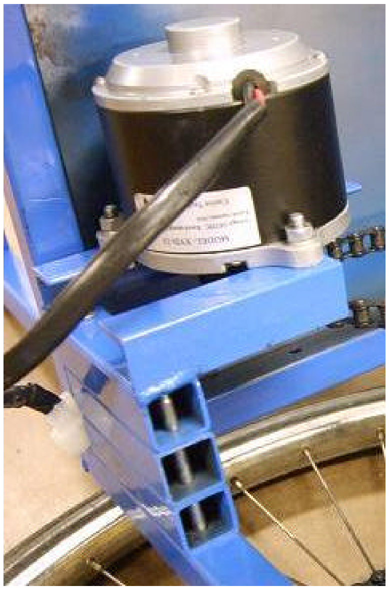
Once we had everything all set up, we decided to add a voltmeter to the system. The voltmeter would act like a fuel gage to warn the user that he needs to recharge the batteries at a certain point. A 0-30VDC panel meter was used. It was designed in such a way that once the battery had been run to a minimum of about twenty volts, it would read empty (0 volts indicated). To make this possible, a 20.6V zener diode was put in series with the voltmeter. Knowing that the motor controller would also not run the motor if it has an input voltage of twenty volts, it was an educated decision to make the voltmeter read zero at that point. Below is a schematic of the voltmeter with the diodes

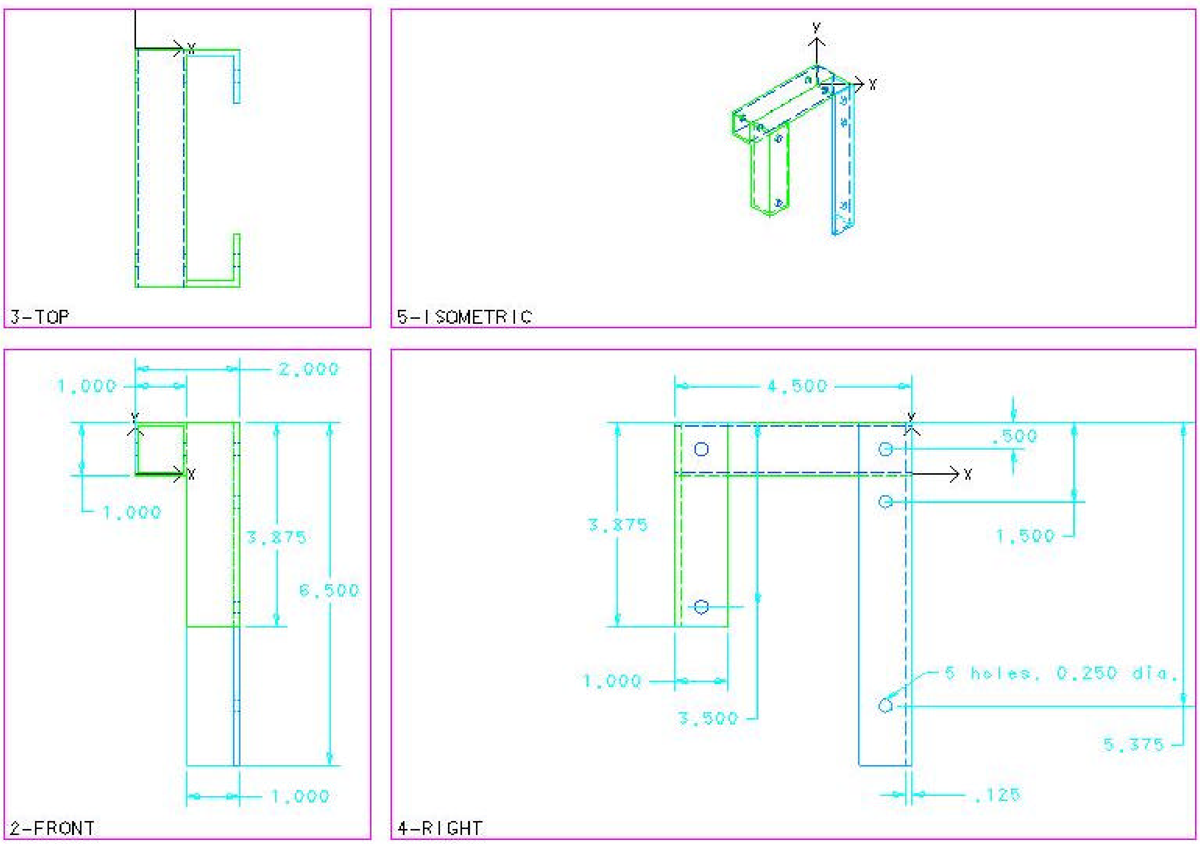


Also, a power interrupt switch was made accessible so that in the event of a runaway condition, power could be shut off. See picture of voltmeter and power cut-off switch:

Motor Mount

The motor mount was designed and made using materials that we know are available to the community in Mahadaga, square steel tubing and angle iron. Two pieces of angle iron are welded to section of square steel tubing. Two other sections of square steel tubing are used as spacers between the tricycle frame and the motor mount to position the motor to align with the jackshaft sprocket. The motor mount is bolted to the frame, making installation easily reversible. See picture and CAD drawing of motor mount below:

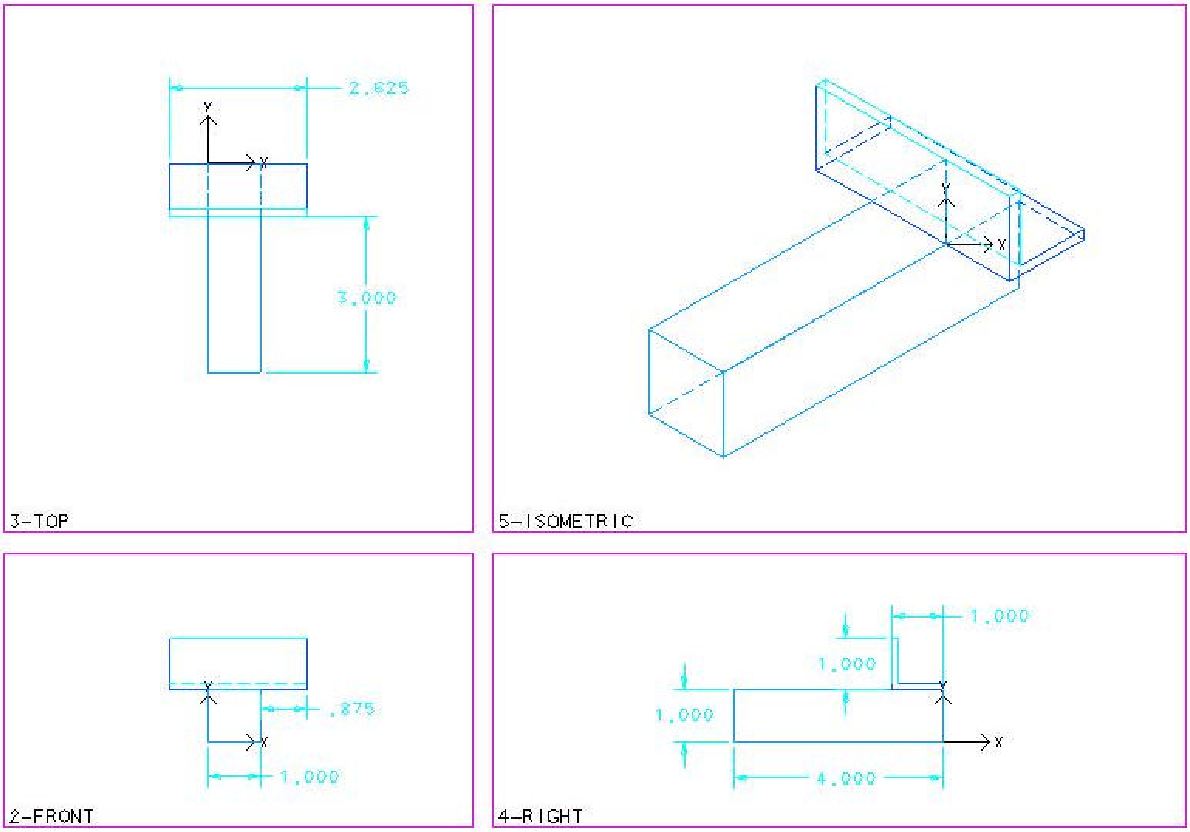




Jackshaft and Sprocket Mounting

As mentioned in section 1.3, motor speed reduction is achieved through use of a jackshaft that provides two 56 to 11 tooth reductions. The jackshaft and entire transmission is designed using only locally available materials. A bicycle bottom bracket is used for the jackshaft. The jackshaft is mounted to the frame by welding a section of angle iron to the bottom bracket and then welding a section of square tube to the angle iron. An L-bracket of square tubing is bolted to the frame and the jackshaft is then bolted to the bracket. See pictures below of jackshaft and complete drive system:

It can be seen in the pictures above show how the sprockets were attached to the jackshaft axle. A short section of a bicycle crank arm is sawed off and welded to the sprocket (welding fixtures were designed and fabricated to ensure alignment); the sprocket is then attacked to the axle by using the crank arm bolt that would be used to attach a typical crank arm. The sprocket on the rear drive wheel is attached by welding the threaded collar of a freewheel sprocket to the 56 tooth drive sprocket. The sprocket can then be threaded onto the hub of the rear wheel that replaces the traditionally used front wheel on the tricycle. Jackshaft mount CAD drawing:



Steering

In an effort to approximate Yempabou's current tricycle design, we designed and made a simple tiller type steering bar that allows one handed steering operation while leaving the other hand free for throttle and brake application. In testing the steering initially seemed awkward, but it proved to work remarkably well after only a few minutes of familiarization. See steering bar picture:

3 Implementation

Construction

We encountered a few difficulties while constructing our prototype. Something that was important for us to keep in mind while designing our drive system was that we use only locally available materials and construction methods. Welding was one of those processes that we had to keep in mind since those in the area where our design will be implemented are only able to stick weld. Designs requiring milling or turning operations for construction were not options.

Stick welding became a problem because of the amount of heat that was dissipated through the parts. This became a problem when our weld was close to threads of our sprocket and slightly changed the exact opening. Again we encountered this problem when welding the motor sprocket to the female end of the motor axle. Some minor design changes that we made were more in the procedure then in the actual changing of the design.

We learned a lot about being sensitive to a culture that doesn't have the abundance of materials and opportunities as we have. We had to keep in mind what was available and still make a very simple and robust system that would be able to withstand substantial environmental abuse. Even though our design was of the more simple nature, we think it was more difficult since we had to reverse engineer things to make them more user friendly and appropriate. A complicated design solution is often much easier than a simple one.

Operation

Testing was a huge part in our overall project. Since we were designing for a very real client, it was important that our system be tested to be reliable. Maintenance needs had to be at a minimum since we could not count on it being pampered in its use. As the chart below shows, operation of the Electric Tricycle met or exceeded 4 out of 5 of our objectives. Grade climb testing showed that we could start from a stop on a maximum of a 16% grade. We measured a 7 mph top speed on level ground, and we calculated that its range would exceed our 8 mile goal by monitoring motor current and knowing the battery capacity of the implemented design. We made a subjective evaluation of the design's appropriateness, and we decided that only the necessary items of motor and controller are not locally available. Even the single-axis joystick can be made of locally available parts (with the possible exception of the potentiometer). Considering the use of available parts and based on the reliability that the system has shown, we decided our design had met the objective that it be appropriate for implementation in Mahadaga, Burkina Faso. Adding up the cost of materials for the design puts us over our desired $300 limit. Some early optimistic battery cost estimates are to blame for our failure to meet our cost objective.

Objectives	**Results**	**Success?**
Appropriate	**Some exceptions**	**YES**
10% grade	**16% grade**	**YES**
$300 cost	**$365**	**NO**
7 mph top speed	**7 mph**	**YES**
8 mile range	**8 mile range**	**YES**

4 Schedule

See updated Gantt chart and team member resumes in appendix:

Cooperating with Dokimoi Ergatai in the completion and implementation of this project puts a small twist in how our team is organized and forces us to think about our partnership and the mission of DE when making design decisions. Since we are all part of this club and also doing our senior project, many things overlapped. A lot of work had already been done regarding the actual tricycle as well as research on materials that are locally available and other tricycles that are in use. We had club meetings every Monday night which gave our project group a chance to get together to go through our weekly task sheet and to discuss problems encountered and successes achieved during the week before. In the advisor meetings we reported on the weeks accomplishments and asked for help on any problem areas we discovered.

Tasks were assigned weekly and for the most part kept on task. Some things were unforeseeable since we did make some big design changes. Our Gantt chart helped a lot the first semester when we were more on task with the original idea. But things changed and there was a three month period where we had to make up what tasks needed to be done in order to get back on track with the last three months of our Gantt chart. The last parts on our chart included an extensive testing period which stayed the same.

Some things that impacted our schedule of progress were, as mentioned earlier, receiving specific information about the particular user. That set us back a few weeks since we had to redesign a few things and change our final objectives. It was a challenge to have to yield all of sudden to a design need that was overlooked or left out. Nevertheless we had to make the necessary changes with just as much zeal. Earlier on the decision to pursue the chain drive system also impacted our schedule. We had to find out if it was worth it to drop all the work we had done on the friction drive system or to stick with it through further evaluation. At that time we needed to gather enough information in order to make the right decision that would best suit the needs of the user. This was a stressful time for us since it was a time we were sitting on the fence and we couldn't keep going back and forth. We had to make the educated engineering decision to go with the design and prove why it was a better choice. During the time of testing the friction system, we felt we haven't exhausted the possibilities which made it harder for us to make that final decision. This period of indecision set us back a couple weeks from our original schedule.

As the chain drive system was coming together, we neglected to address local availability of chains and sprockets. We designed a system that used materials that were available to us and would produce a more compact system instead of being of a more appropriate mind in design. After a group meeting about materials we realized it would be wise to again redesign the drive system only using locally available parts, sprockets and chains. Two options came up between bicycles or mopeds. Bicycle sprockets didn't allow us to get the desired gear reduction, so we decided on the moped sprockets. By using locally available moped sprockets we were able to get the desired gear reduction while using a bicycle's bottom bracket for our jackshaft. Now we had a final design using only parts that were locally available and relatively cheap. The only parts we supplied were the motor and controller. Even the batteries are locally available.

5 Budget

See cost tabulation:

Prototype

Component	Unit Cost	Quantity	Total Cost
Motor Products Owosso BDC motor, 24V, 200W	65	2	130
Curtis Motor Controller	45	1	45
Potentiometer, wires, connectors	5	n/a	5
Mounting materials and roller materials	10	n/a	10
Batteries	Borrowed	2	0
Battery Charger	Borrowed	1	0
			190

Production

Component	Unit Cost	Quantity	Total Cost
Currie BDC motor, 24V, 600W	85	1	85
Motor Controller	35	1	35
Potentiometer, wires, connectors	5	n/a	5
56 tooth moped sprocket	8	2	16
11 tooth moped sprocket	2	2	4
Moped chain	5	1	5
Bottom bracket	10	1	10
Rear wheel	40	1	40
Mounting materials	15	n/a	15
Batteries (estimated cost)	75	2	150
			365

Despite being over our budget objective of $300, we are pleased with our efforts to keep costs to an absolute minimum. We see the biggest potential for further cost reduction in transmission simplification and possibly using lower capacity batteries.

6 Conclusions

We would say our project has been a success considering the changes we had to make in the spring once we actually found out who the electric tricycle was for. We achieved four out of five of our objectives, and we believe that we have a system that will be effective in providing mobility for persons in Burkina Faso who have disabilities. One of the major lessons we have learned is that designing an appropriate technology is a huge challenge. Appropriate is more than just availability for replication, it considers longevity, reliability, and efficiency.

7 Future Work

Now that we have come this far in our project, the next thing that has to be done is to do enough testing to be able to accurately evaluate the reliability of our design. We should make sure that the tricycle can handle abuse and inclement weather. Further weather proofing of the battery box, motor controller, and joystick needs to be considered and implemented. Much of this future work will commence this summer in preparation for the implementation trip to Mahadaga, Burkina Faso that begins 12 July, 2004.

Appendix

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Gantt chart: