Bicycle-Powered Attachments: Designing for Developing Countries

by

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Submitted to the Department of Mechanical Engineering
in Partial Fulfillment of the Requirements for the Degree of

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ABSTRACT

There are 550 million smallholder farmers around the world who earn less than $1/day who could benefit from pedal-powered attachments. This project discusses factors to consider in designing for developing countries and highlights experimental methods that help to optimize the power transmission of bicycle attachments.

In comparing power transmission through three main modes off of bicycles, via chain drive and friction drive, this thesis proposes recommendations for design in developing countries, including the advantages of chain-driven attachments and considerations necessary for successful implementation.

Thesis Advisor: David Gordon Wilson
Title: Professor Emeritus of Mechanical Engineering

BIOGRAPHICAL NOTE

This thesis is a culmination of Jodie's experience as a mechanical engineer at MIT. Beginning with her field experience in Tanzania as a D-Lab I: Development student, she returned from the field, struck by the inaccessibility of technology, both physically and financially. She suddenly had an idea of transforming pedal-powered machines into bicycle-powered attachments. From January 2008 until her graduation in June 2009, Jodie spent five months in Tanzania, where she built many friendships and learned of the challenges of working in a developing country. This thesis reflects what she has learned as a field worker, as a designer, and as a lab researcher.

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FOREWORD

This paper presents data and analysis on how to optimize power transmission of bicycle attachments in developing countries. This thesis topic spawned out of the author's work in Tanzania, where she realized that through bicycles, she could bring technology to the people who needed it most—the rural poor. Despite advancements of technology, in developing countries nearly 550 million smallholder farmers still survived on less than $1/day. Due to both financial and physical inaccessibility of industrial technologies, these farmers still relied on manual labor, but without the tools and machines to leverage their human power.

In spring of 2008, the author developed a maize-sheller attachment that was powered by bicycle. The bicycle functioned in two modes—bicycle mode and device mode. As suggested, bicycle mode allowed for the bike to retain its original functionality of transportation while device mode developed a secondary job opportunity in which the bicycle became stationary and pedaling became the mechanical drive of the device.

Bringing this device to the field in summer of 2008, the author soon realized that this device was an income-generating opportunity that earned positive returns within a week. From this emerged Global Cycle Solutions (GCS), a future company that leverages the market of nearly one billion bicycles to create income-generating opportunities for farmers around the world. Central to this start-up is the universal adapter, entitled *Geuza* (GEI-OO-ZA), meaning "change" in KiSwahili. The vision is for *Geuza* to mechanically couple any rotary attachment to a bicycle, transforming the bicycle into a vehicle that can power a multitude of devices.

GCS will not just serve as a business that sells bicycle peripherals, but has a second mission of transferring knowledge to the people to stimulate local innovation. At the core of bringing this knowledge is the need for a handbook that becomes a guide from which local villagers can become the inventors of new pedal-powered inventions.

This thesis presents

- a thorough literature review that justifies the claims of the need for pedal-powered innovations and provides the history of human power,
- a review of prior art and observations from the field,
- a discussion of design as a learning process and discovery through instrumentation, and
- recommendations for design in the developing world.

1 INTRODUCTION

1.1 Objective

The purpose of this thesis is to develop a handbook for power-transmission design for inventors of pedal-powered devices in developing countries. This handbook will serve as a resource to organizations and student initiatives developing pedal-powered appliances and machinery such as corn shellers, depulpers, presses, lathes, and battery chargers for developing countries. By classifying characteristics of these rotary devices, a study was conducted on mechanical couplings and their ability to attain the required speed and torque for a range of rotary devices. Designed for use in developing countries, this handbook quantifies and explains the potential and limitations for two major power-transmission systems: (1) chain drive and (2) friction drive.

1.2 Need

Over 500 million smallholder farmers live on less than $1/day (Polak &Yoder, 2006). According to the Human Development Report 2007/2008 by the UN, over one billion people lack access to electricity. Nearly four billion people, the majority of the world's population, constitute the bottom of the pyramid (BOP) (Hammond et al., 2007). These people are low-income customers, many of whom have been left behind in the technology gap. Despite industrial advancements, the little technology that has been developed to help them rise out of poverty is still difficult to find.

Through D-Lab, MIT students have discovered the value of developing appropriate technology, or intermediate technology. However, many of these technologies are often left just to benefit the community partner rather than becoming a device that penetrates the village.

At the heart of this project is the design for developing countries, especially design for the world's poor. As discussed in *The Fortune at the Bottom of the Pyramid [reference no needed]*, this market of development is promising, especially in understanding the creativity and resilience of the world's poor. There have been many case studies and approaches to development, and common trends of successful projects have been identified by the World Resources Institute:

- Concentration on the BOP with unique products, services, and technologies;
- Localized value creation by building local ecosystems of vendors or suppliers;
- Increased access both physically and financially; and
- Unconventional partnering with governments, NGOs, or groups of multiple stakeholders to bring the necessary capabilities to the table.

It is these four aspects that make product design of both bicycle- and pedal-powered attachments challenging. These four trends translate to the following functional requirements for developing countries:

- Affordability of technology;
- Flexibility in design;
- Local maintenance and use of local materials; and
- Adaptability to various structures and bicycles.

GCS, a business that transforms the bicycle into a vehicle of innovation, plans to bring a multitude of products to farmers in rural areas through NGO partnerships and knowledge resources. The GCS Bicycle Mechanics Handbook (Appendix A) will serve as an onsite resource for dealers and innovators of bicycle attachments.

1.3 Human-Powered Innovations

The basis for this thesis is human-driven power. Human-driven solutions have existed for centuries, from the first hand-cranked devices to levers, treadles, and treadmills, to modern-day pedal cranking (McCullagh, 1973). Many of these methods of human-driven power have failed due to the use of the wrong muscles moving at low speeds with large resistances, leading to low efficiencies in human power.

The bicycle was a revolutionary development in human power as it utilizes the strongest muscles in the body at an optimized motion and speed. Despite the introduction of automobiles and airplanes, the production of bicycles continues to grow.

Pedal power is and can be used to power a multitude of devices including, but not limited to, battery chargers, water pumps and other off-grid power systems It can be used to mechanically drive agricultural and hand tools or generate electricity and store energy for later use. It serves as a form of sustainable development, contributing to the already-existing movement towards a green economy. This thesis explores the potential of leveraging a bicycle as an innovation platform, studying how to meet the demands of devices through human energy and bicycle attachments.

1.4 Leveraging the Bicycle to Bridge the Technology Divide

Today, nearly 130 million bicycles are produced annually in the world, which is nearly three times the annual production of automobiles (International Bicycle Fund, 2009). With GCS, bicycles are not only transportation vehicles; they have the potential to become a human-energy source for innovations. One of the best aspects of the technology is that it requires no fuel (other than the pedaller's food), giving ultimate freedom to the user.

Many devices, such as the grinder and de-huller operate by hand crank, but can be powered more efficiently using pedal power. By optimizing the mechanical transmission design, the future development of pedal-powered prototypes that drive a multitude of devices can be further explored. This project leverages human power, a resource that requires minimal, if any, infrastructure development.

In increasing the potential of the bicycle as a power source with a universal platform, technology becomes mobile, increasing visibility in rural areas. To some, bicycles hold the key to electricity generation. Converting the mechanical input, which is optimized in a bicycle, to electrical output, alternators may be the answer in bringing electricity to the 1.6 billion people who lack access to electricity.

1.5 Power Transmission from Bicycles to Bicycle Attachments

There are two major modes of power transmission for bicycle attachments, chain drive and friction drive. These two drives can be used to meet the power requirements of bicycle attachments, based on necessary speed and torque.

The chain drive holds a number of advantages to friction drive. In a study at Johns Hopkins, chain efficiencies ranged from 81% to 96.8% (Spicer, 2000), which makes chain drives one of the most ideal forms of power transmission in low-speed devices. The chain drive can accommodate a number of loads based on simple adjustments within the gearing ratios of the sprockets. However, it requires multiple tiers of gearing to attain high speeds.

Friction drive can be used for high-speed devices, but the design requires care. Friction drive provides added flexibility with regard to orientation of devices, whether vertical or horizontal, but for direct drive of a rear bicycle wheel on a loaded roller, there are numerous factors that should be considered in designing friction drive transmission for developing countries, in particularly, dealing with imperfections of the wheels and tires.

2 LESSONS FROM THE FIELD

2.1 Chain Drives

Chain drives are the most common form of power transmission in the field, stemming from the family of attachments from Maya Pedal, an organization in Guatemala whose mission is to support the local economy through the design and distribution of bicycle machines. The chain drive is durable and robust and yields high efficiency.

At present, there are a number of stationary chain-driven devices.

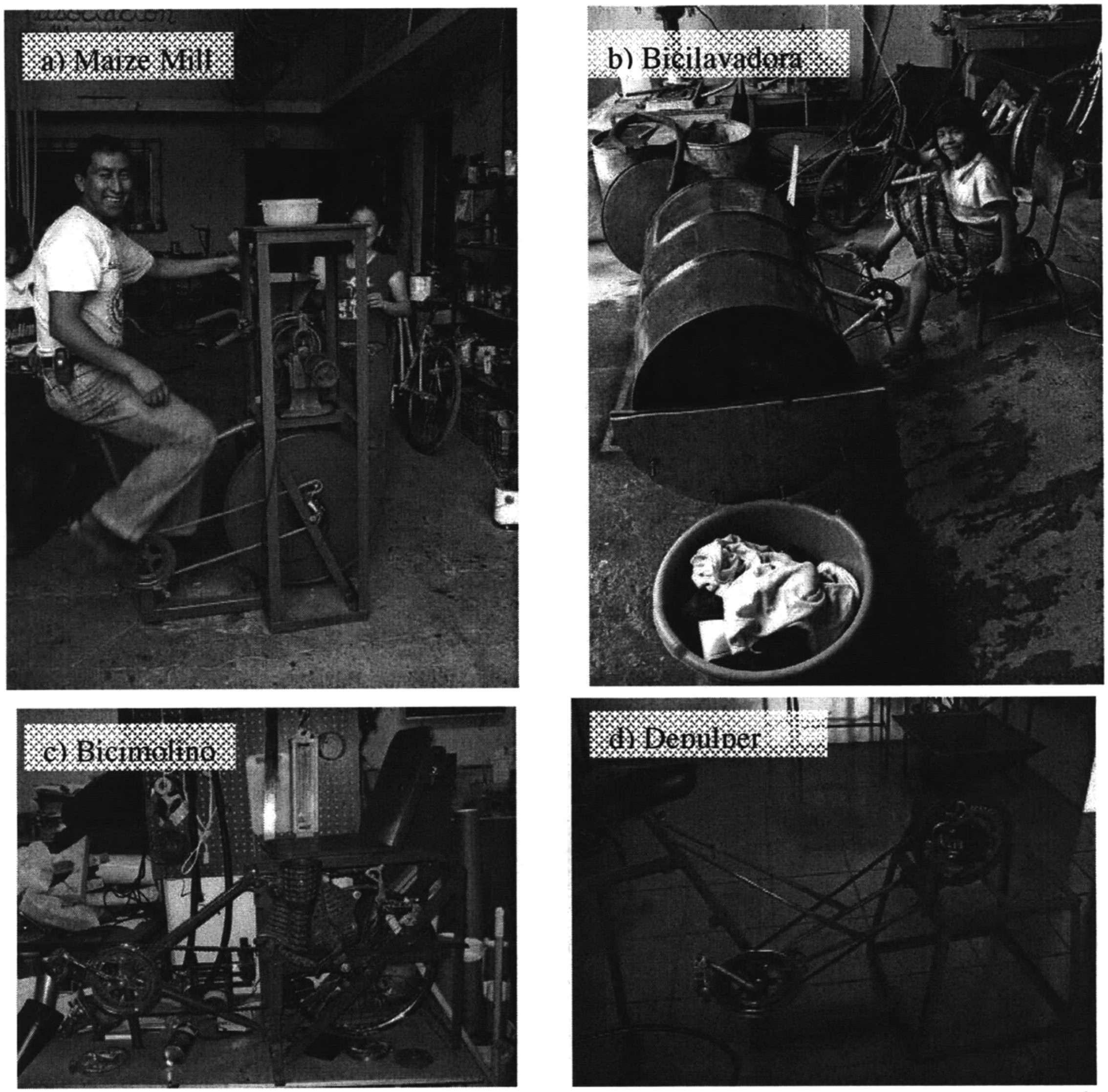


Figure 2.1: *Carlos and Chain-driven Devices Developed by Maya Pedal in Guatemala*

Creativity and pedal-powered inventions and innovations from Maya Pedal are an easily transferable knowledge, which can be seen in Carlos Marroquin's Maya Pedal inspiration on Bernard Kiwia, a bicycle mechanic in Tanzania .

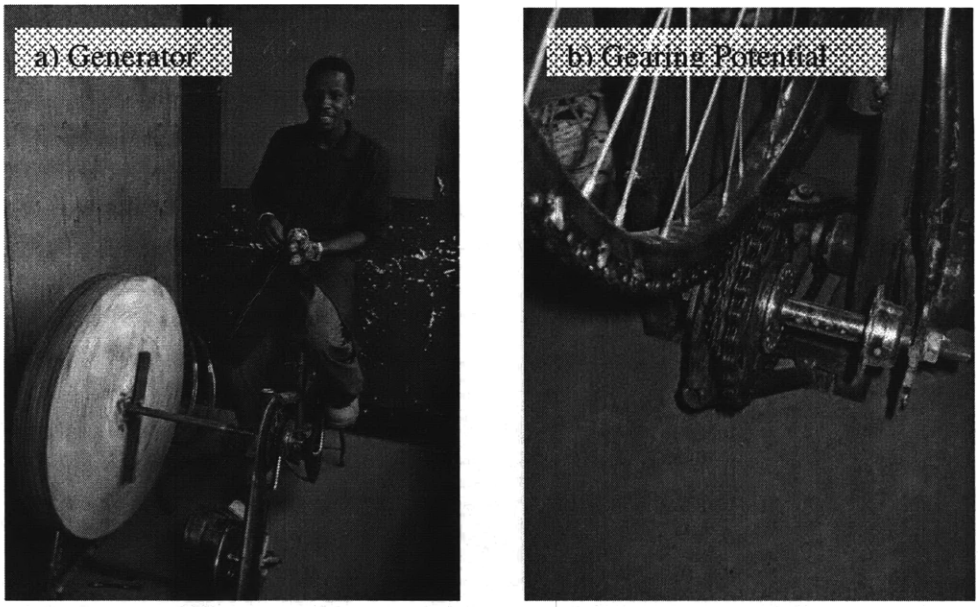


Figure 2.2: *Bernard Kiwia and his Pedal-Powered Generator and Gearing Creativity in Tanzania*

The majority of these devices are too expensive for the rural poor and have only one function. Maya Pedal's bicimolino allows for the attachment of two different devices, the maize grinder, and maize sheller; however, this added flexibility comes at a cost.

To adjust for different devices, the jockey-wheel tensioner from a derailleur gear has been utilized to pick up slack in the chain. When adding and removing devices, the derailleur can quickly lead to entangled chain, rendering the device useless without added expertise.

Figure 2.3: *Common Problems with Adjustable Chain Tensioning—entangled chain and derailleur*

Although derailleur tensioners and gear may seem ideal in the developing world, common feedback indicates a preference away from this added complexity. A derailleur is not only expensive, but when broken, it is difficult to repair. Without chain tools (the most common method use in Tanzania was a steel rod and hammer as a chain tool), derailleurs quickly become a mess to work with, burdening the users of the device.

2.2 Friction Drives

There are two major types of friction drives:


a) Belt Drive

b) Roller Drive

Figure 2.4: *Friction Drives- a) Belt Drive and b) Roller Drive*

Friction drives should be used for driving high-speed devices. These drives provide an added advantage over chain drives in their ability to drive devices at different orientations, as shown in Figure 2.5.

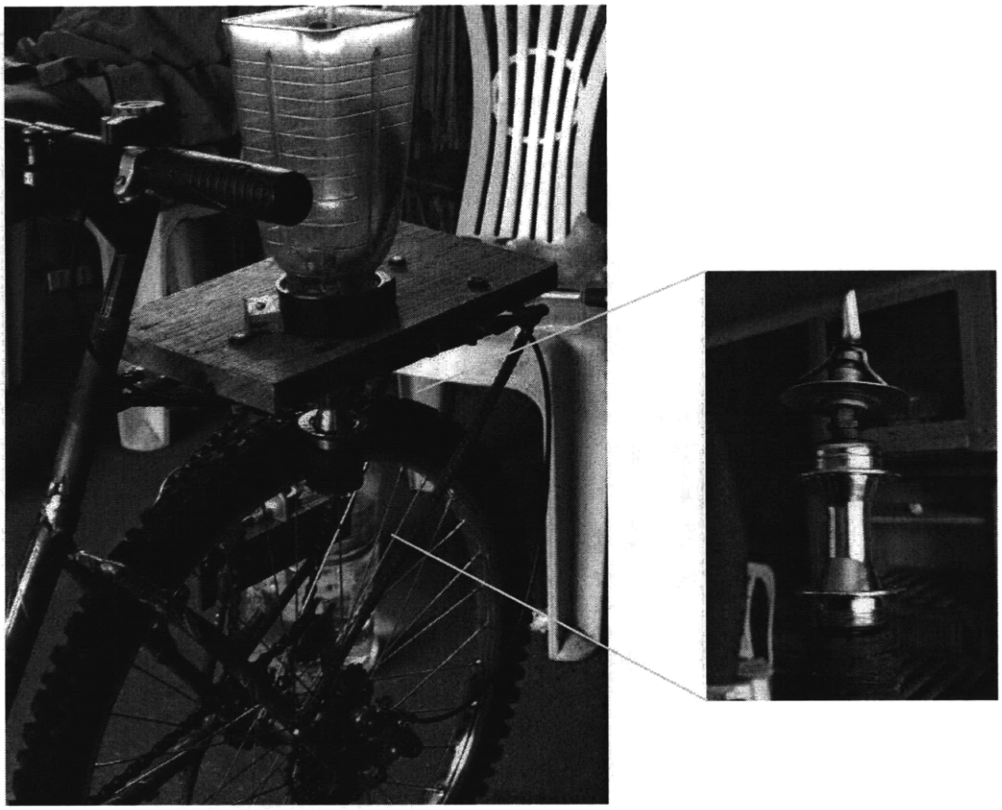


Figure 2.5: *Friction-Driven Bicycle Blender in Peru, Friction Drive from Reused Hub*

Belt Drives

Belt drives are particularly useful in that they can be cheaper and more widely available than chains. Moreover, the drive allows for a wide range of flexibility in that it can be easily engaged and disengaged through tensioning. Its adaptability is shown through Job Ebenezer's Dual-Purpose Bicycle.

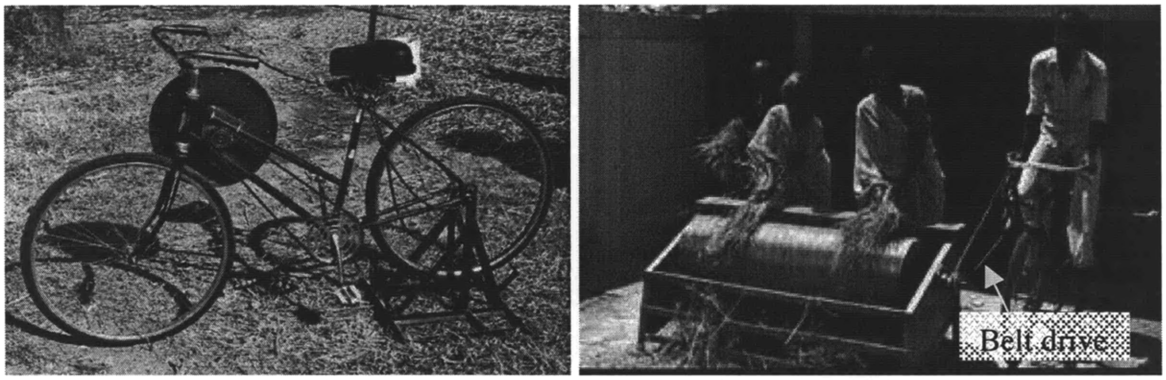


Figure 2.6: *Job Ebenezer's Dual Purpose Bicycle and its Multifunctionality*

In developing countries, belts are often made from scrap tubing, and under weather conditions such as heat and humidity, belts are susceptible to changes in tension and undesired stretching. Therefore, in designing for belt drives, the belt must easily be repaired or be easily tensioned by other methods; otherwise, it loses functionality due to slipping.

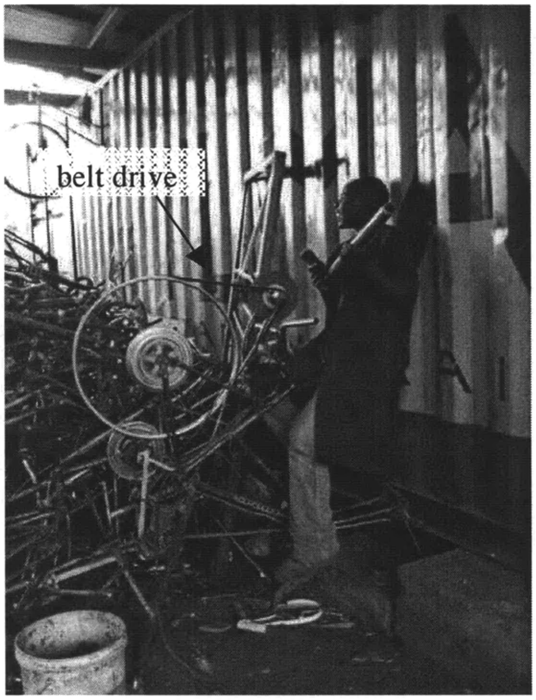


Figure 2.7: *Belt-Driven Grinder in Tanzania*

Although there is a variety of belts available, such as flat belts, round belts, and vee belts, the most common belt seen for homemade pedal-powered devices were flat belts. When making these flat belts, factors such as material and added "teeth" on the belt should be considered.

Roller Drives

Roller drives can be as effective as belt drives, but main disadvantages that make the roller drive non-ideal include: (1) tire pressure, (2) load, (3) wheel imperfections, and (4) slippage. Locals from developing countries have overcome this challenge by using side friction roller drives, as shown in Figures 2.5 and 2.8.

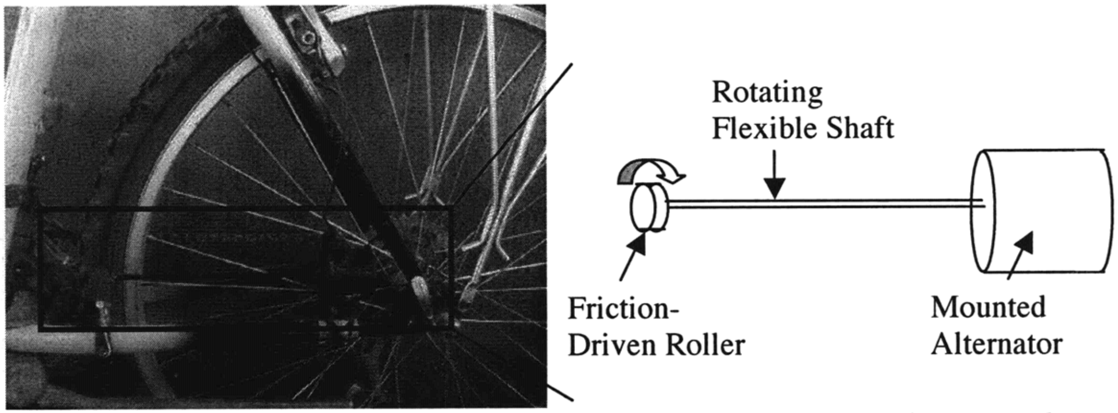


Figure 2.8: *Bicycle-Powered Phone Charger and Design Concept by Bernard Kiwia*

For drive systems in which the rear wheel is resting on a roller, as shown in Figure 2.8, additional challenges arise.

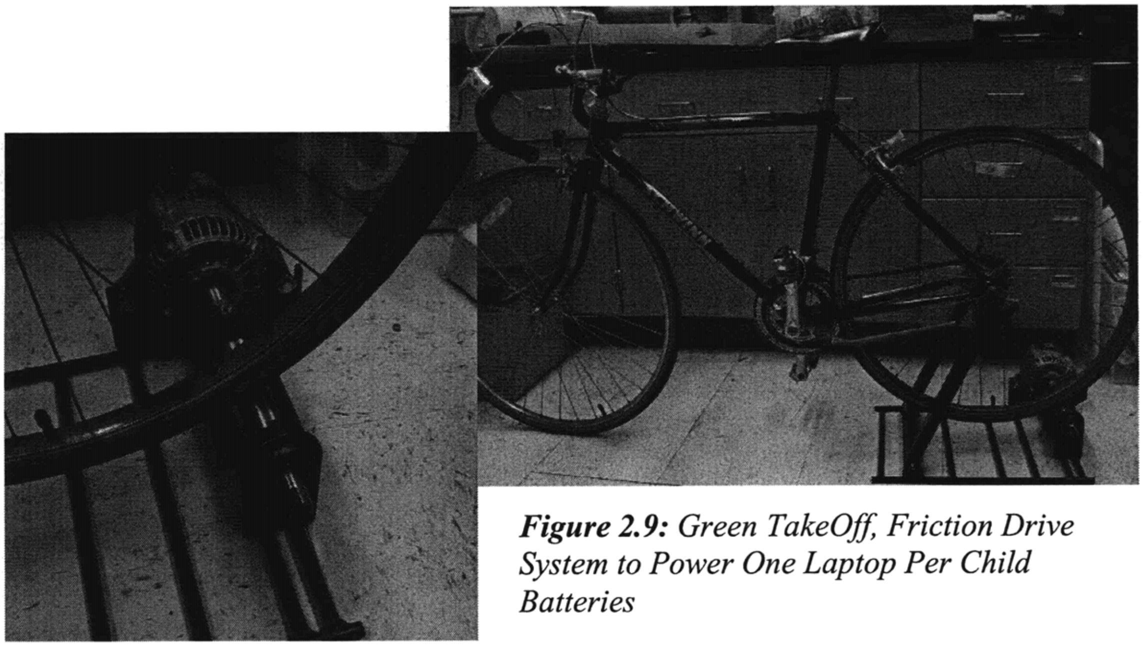


Figure 2.9: *Green TakeOff, Friction Drive System to Power One Laptop Per Child Batteries*

In developing countries, most terrain for travel is non-paved roads. These make tires susceptible to continual tire punctures. Rather than being replaced, tire tubes are often mended by gluing an extra layer of rubber on top of the tube. This adds even more imperfections to an already off-centered tube.

With non-optimally pumped tires, the forces to move the roller become rather high, as the roller is essentially a moving intrusion as the rear wheel is pedaled, pushing air around the tube. This less-than-ideal pressure also leads to added friction from the greater contact area.

It is important that the roller tube have a larger radius, as this helps displace the pumped air. With friction drive, continual bicycle maintenance is necessary, and slippage is to be expected. Another problem that may arise is a non-concentric outer tube, which causes added energy losses.

3 DESIGN AS A LEARNING PROCESS

3.1 Chain Drive for Added Flexibility

To address the challenges emerging from the derailleur and stationary devices, the *Geuza*, or universal adapter, was developed to allow for added mobility and flexibility. In targeting developing countries, the following functional requirements were made.

Functional Requirements	
Requirement	*Description*
Modular	Able to adapt to the most commonly used bicycles in developing countries
Adaptable	Variety of devices can attach to it
Low Cost	Cheap
Low weight	Light enough to not effect bicycle riding and maneuverability
Low skill	Requires minimal tools and skills (or no more than screw driver and wrench) for use
Easy and quick to use	Device changeability within a few minutes ~5 minutes
Reliable	Drive does not fail often (i.e. chain fall off)
Stable	Supports devices and chain tensions
Multiple drive systems	Incorporates most common drive systems of available devices
Chain tensioning	Does not require derailleur (an expensive item) for chain tensioning

These functional requirements directly correlated with benefits for the user.

Applications and Benefits to User
Multifunctional drive system; enables user to customize to meet needs by allowing attachment of diversity of devices
Ability to cultivate entrepreneurship and alleviate poverty by fostering small businesses and income generation
Maintains original function of bicycle as primary form of transportation
Manner of providing technology to previously inaccessible locations (user does not need to seek technology at specific location; technology can travel to them)
Does not require electricity
Low cost solution to everyday agricultural tasks
Increases productivity
Able to adapt to diverse markets

The result was the *Geuza.* This device allows for devices of different gear ratios to be attached to a mount. With interchangeability, it yields the missing flexibility. However, there are major error sources, including tensioning and misalignment.

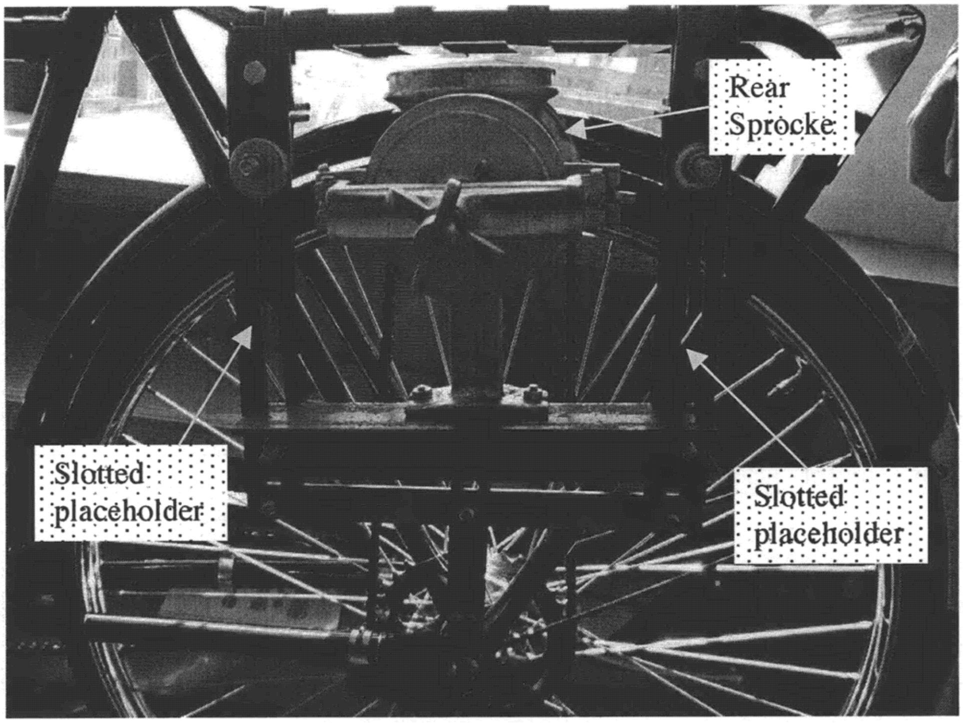


Figure 3.1: Geuza. *GCS' Geuza allows for devices to be interchanged. Two slotted placeholders on the side of the device allow for the user to decide the appropriate tensioning of the device. Tensioning plays a critical role in the chain's ability to stay on the sprocket as well as the ease of driving the device. Other sources of error emerge from misalignment of the sprocket on the device*

By building this device, a number of lessons were learned. Though there were definite benefits of making this mount chain-driven, main challenges stemmed three major areas: (1) chain tension, (2) structural support for mount, and (3) alignment of the chain drive.

The chain tension played a critical role as a loose chain would often cause the chain to fall off between the drive and the device. A derailleur gear, which always includes a chain tensioner, used on the rear wheel of a bicycle, would serve as a simple solution in providing the necessary play in the chain to cope with chain misalignment, but as discovered in the field, derailleurs were strongly discouraged, mainly due to the high cost, unavailability, and complexity of the device. The need for the tensioner is evident, so an alternative chain tensioner system should be explored. Design elements that should be incorporated include guides and restraints that would prevent the chain from falling off.

The structure supporting the chain driven device is the other critical aspect. The *Geuza* shown above lacks a sturdy structural support in that the slotted placeholders are flat steel bars that flex under high loads. Another problem is in finding the perfect tension. If the chain is too tensioned, the sprocket immediately wants to misalign itself, as shown below. This cantilevered sprocket quickly leads to the chain getting off the gear teeth. If the chain is not tensioned enough, the chain easily falls off because it cannot handle the slack in the chain.

Structurally, it' is imperative to have a sturdy support, as the device is actually undergoing oscillating forces, as seen with the incoming pedaling force. Moreover, a flexible support makes the device vulnerable to vibrations.

Alignment is the other major factor as misalignment results in unnecessary shear forces in the chain; however, this challenge can be addressed by creating device mounts for shifting the device inwards or outwards for the purpose of aligning the sprockets. The other important factor is reducing the play within the bearing shaft of the device, as a wobbling driven sprocket directly leads to disengaged chains.

3.2 Friction Drive for High-Speed, High Torque

High-speed, high torque mechanical transmission is the most challenging of power transmission categories as the main limiting factor is the amount of feasible human power output. The idea for Green TakeOff, a friction-drive system for providing electricity through an car alternator, grew from a motivation to generate electricity from a bicycle. Green TakeOff's first challenge was tackling the One Laptop Per Child (OLPC) Battery Charger.

Green TakeOff was designed in response to the limitations of solar power and hand-cranked power. Solar power proved effective, but unaffordable. Hand-cranked power proved difficult to sustain for long periods of time.

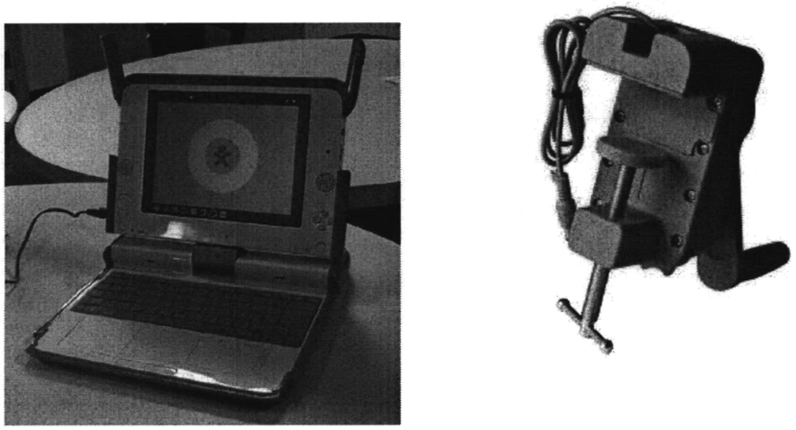


Figure 3.2: *OLPC Laptop and the handcrank device.*

With a target market in developing countries, OLPC developed a platform which could take DC input from an alternator. These fifteen batteries hold thirty watt-hours each and charge at up to fifteen watts. The unique feature of this battery charges is its ability to charge in spill-over mode. For example, if eight empty batteries are inserted but the cyclist only outputs thirty watts, it will charge the first two batteries over two hours, then start charging the next two.

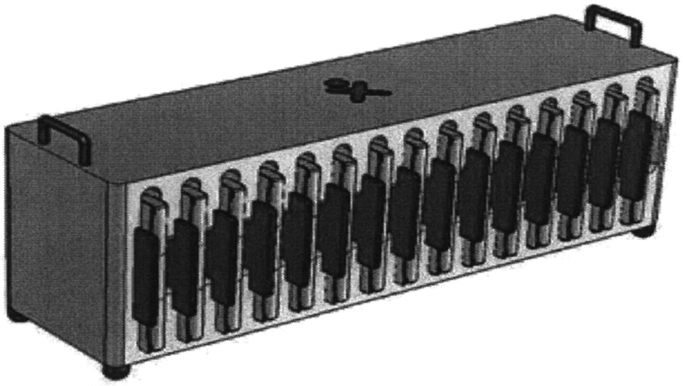


Figure 3.3: *OLPC Battery Charging Platform*

As the charger is able to take inputs ranging from 10 volts to 30 volts to charge the battery, this ready-made charger has already been designed for power fluctuations from the bicycle rider. Green TakeOff considered these specifications, which led to the design shown in Figure 3.4.

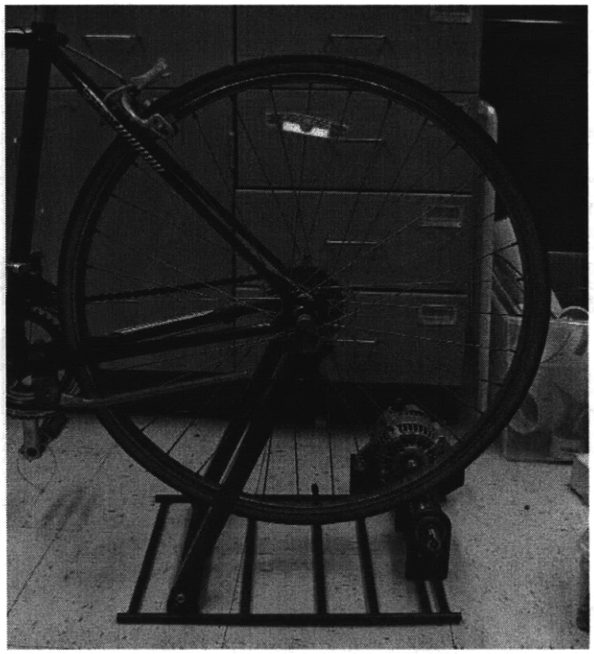


Figure 3.4: *Green Take-Off*

This design ultimately failed, driving the need to develop instrumentation for improving this system.

4 INSTRUMENTATION FOR UNDERSTANDING

4.1 Instrumentation

This experiment was centered on power transmission of a frictional wheel between a bicycle wheel and a steel roller. Efficiencies were taken by conducting power comparisons between the input and output. To measure power transmission losses in a bicycle attachment system, four major pieces of information were necessary: input torque, input rotational velocity, output torque, and output rotational velocity. These four sets of data were found through the use of tachometers and force sensors. To resist high loads and reduce the number of hands needed for this experiment, rotary motion sensors and load cells were used.

Rotational velocities could be consistently measured through the photosensor of a tachometer or through the use of a rotary motion sensor. For the case of the photosensor, by placing a piece of reflective tape on the rotating object, the rotational velocities were instantly obtained on the tachometer. To measure torque, two major methods were developed and used.

4.2 Pedaling Concepts

Obtaining the input pedaling torque from each pedal stroke is one of the most difficult parameters to measure, as instrumentation must be needed to summarize both normal and shear forces on the pedal, as shown in Figure 4.1.

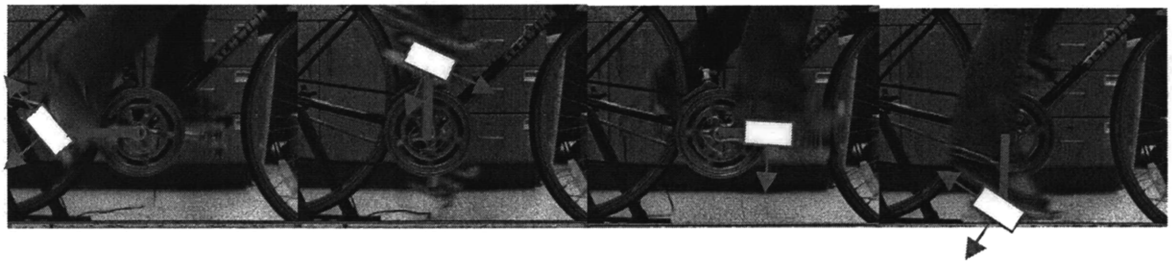


***Figure 4.1**: Dilemma of Using Pedaling Torque. The pedal angle and direction of shear for changes with each pedal stroke.*

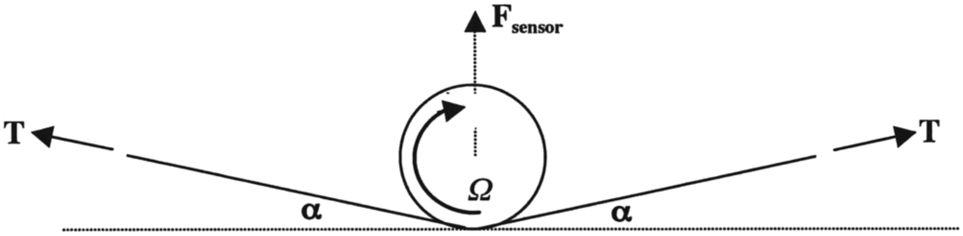
As the rider makes a full stroke, the shear forces involved are changing directions as it makes one revolution. Moreover, the forces change significantly with the pedal stroke, which is sensitive to many parameters:

- person who is riding
- rider position
- rider fatigue
- potential weight shifting from side-to-side when pedalling
- placement of foot on pedal
- shoe worn by rider

These parameters demonstrate how sensitive measurements are to slight alterations. One may wish to use force sensors on the pedal, but the researcher must keep in mind that unless the sensor can measure both shear and normal forces, one's technique is only measuring one force among the big picture, rendering the technique useless except for making qualitative comparisons of pedaling input.

4.3 Torque through the Chain Drive

Because of the insufficiency of measuring torque input through the pedals, this section presents methods for measuring torque through the chain drive. This method does not account for any bearing losses caused by the pedals or the crankshaft, but this method does allow for ease of measurement in deriving the tension from the normal force of the chain. By measuring the force on a sprocket that deflects the tension side of the chain and the speed of the sprocket, the tension and power transmitted can be found as shown in Figure 4.2.



$$2T\sin(\alpha)=F$$
$$T=F / (2\sin(\alpha))$$

Figure 4.2: *Chain Tension Derivation*

4.4 Torque Output of Shafts and Rollers

To measure the output torque, the best method was using the Prony Brake set-up as depicted in Figure 4.3 to function as an alternative torque-meter.

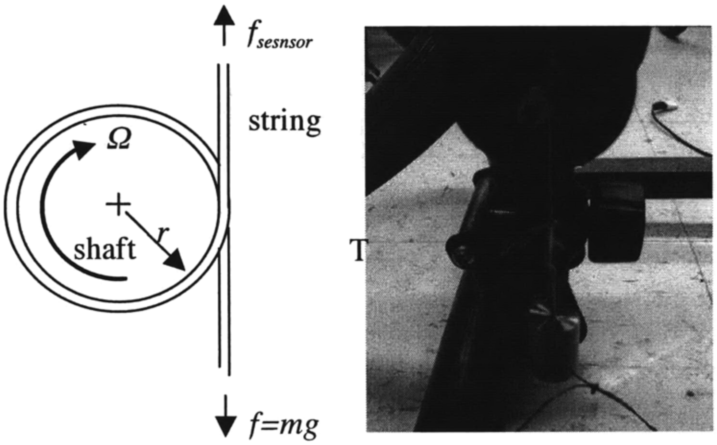


Figure 4.3: *Using a Prony Brake as a Torque Dynamometer*

From the Prony Brake, force was determined by taking the difference of the two forces of the string.

$$\tau = (f - mg) * r \qquad (3)$$

4.5 Application

With tachometers and the above apparatus set-ups, the power input and output can be derived from the torque and rotational velocity to find the efficiency of any system.

$$Power = \tau \ x \ \Omega \qquad (4)$$

$$Efficiency = Power\ Output\ /\ Power\ Input \qquad (5)$$

The presented instrumentation allows for a multitude to tests to conduct to optimize power transmission to bicycle attachments. Through these set-ups, a number of experiments can be conducted to optimize bicycle-attachment design, including but not limited to the effect of:

- rider position on power transmission,
- moment of inertia on energy expenditure,
- added loads on power transmission efficiency,
- wheel imperfections on input power, and
- air pressure of tires on power losses.

With these tests, one might find that the recumbent bicycle design is ideal for the future of bicycle attachments.

5 DISCOVERY THROUGH EXPERIMENTATION

5.1 Green TakeOff

Green TakeOff is an electromechanical system that translates mechanical energy to electrical energy. With the use of a car alternator, the desired output is was \12V and 70amps.

The experimental setup consisted of three main components: the bicycle, the electromechanical power transmission element (friction-driven roller with alternator), and the OLPC multi-battery charger

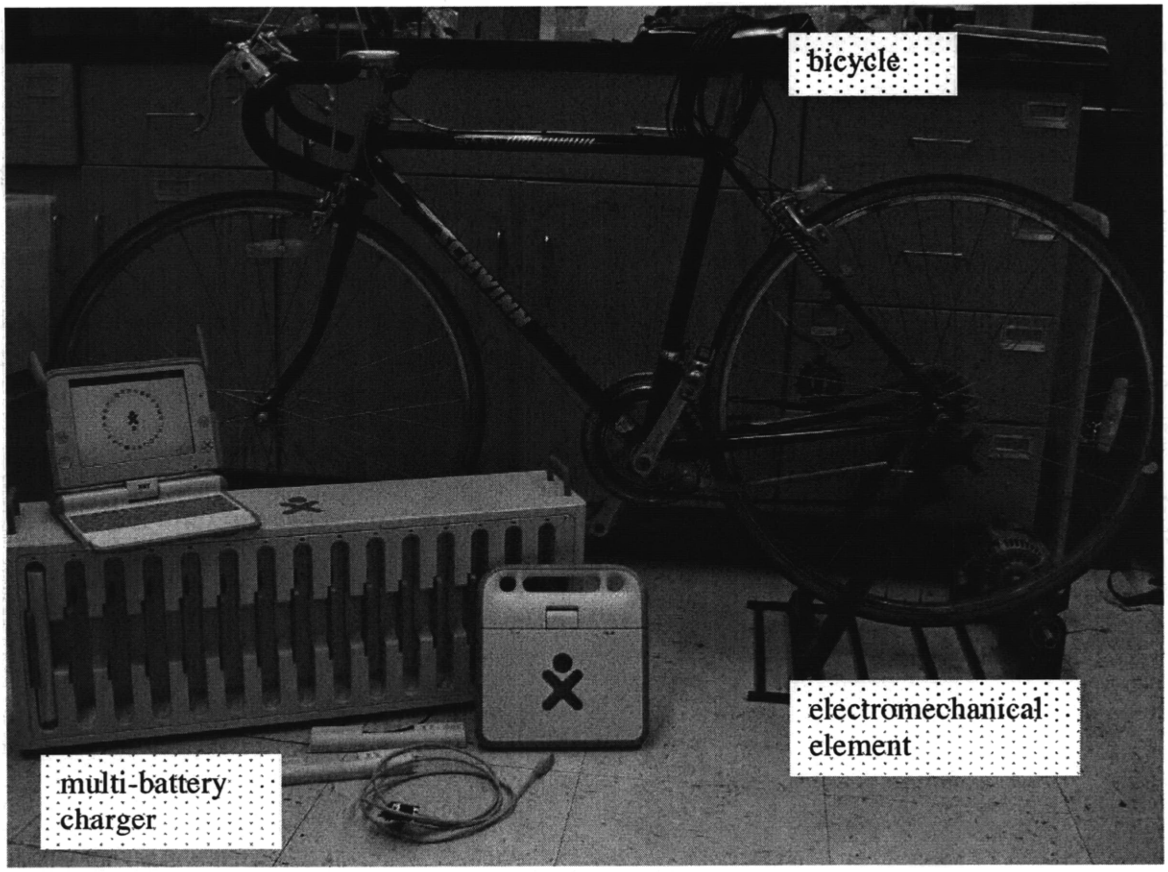


Figure 5.1: *System Elements*

The alternator yielded a DC output that could be hooked up using a simple circuit system.

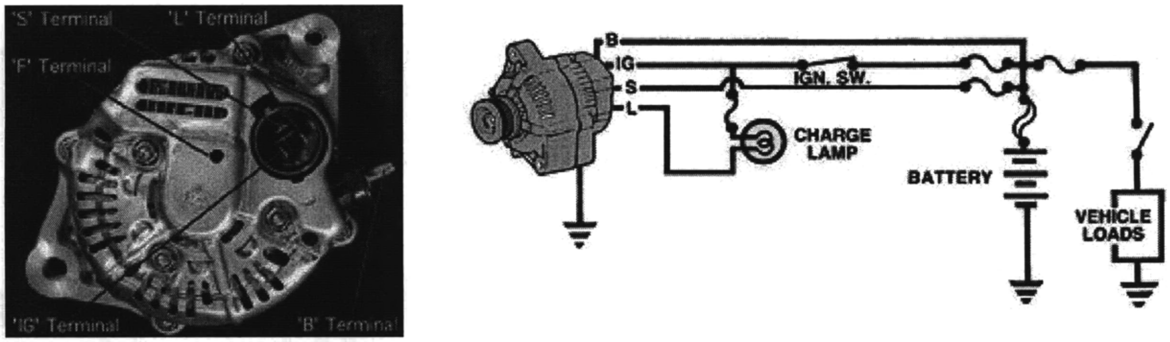


Figure 5.2: Alternator Hook-Up

This device showed a high-speed, high torque mechanical transmission, one of the most challenging of power transmission categories as the main limiting

5.2 Experimental Setup

To find the speed and torque, five instrumentation devices were used: load cell, force sensor, two rotary motion sensors, and the OLPC communication device as shown in Figure 5.3.

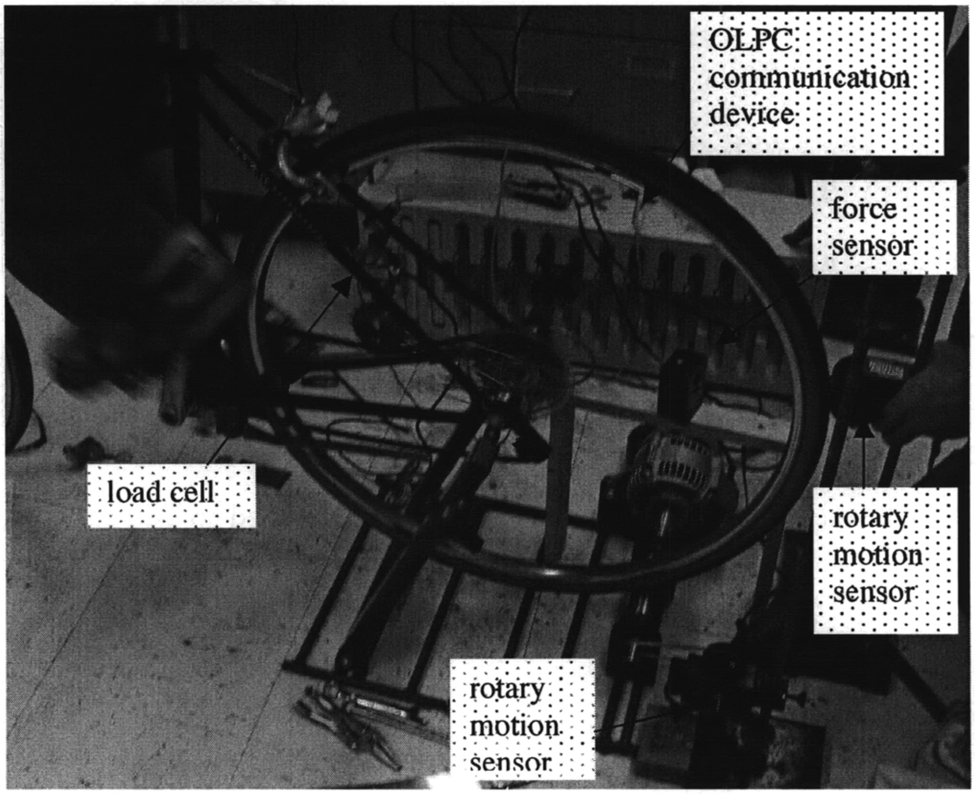


Figure 5.3: Experimental Set-Up

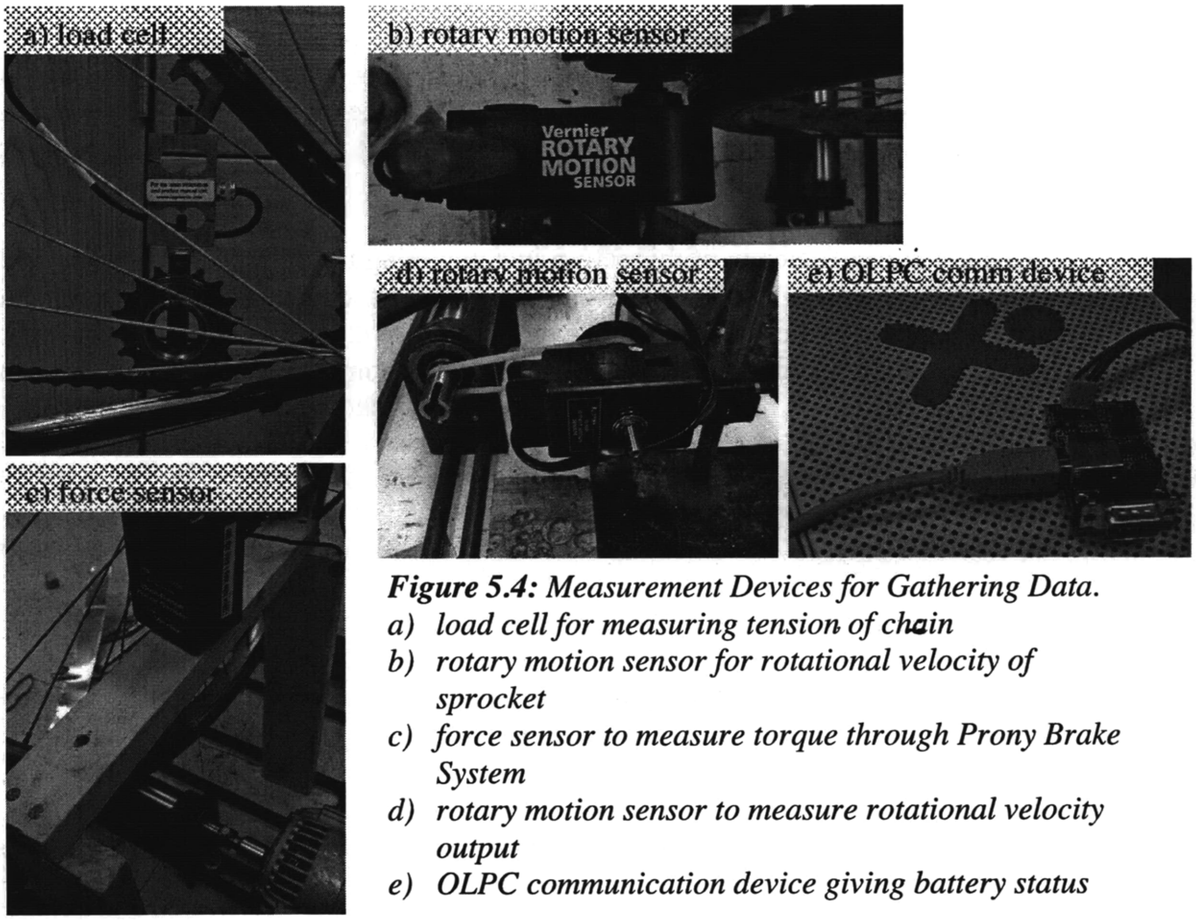


Figure 5.4: *Measurement Devices for Gathering Data.*
a) load cell for measuring tension of chain
b) rotary motion sensor for rotational velocity of sprocket
c) force sensor to measure torque through Prony Brake System
d) rotary motion sensor to measure rotational velocity output
e) OLPC communication device giving battery status

All of the outputs of these devices were sent directly to a computer for analysis using Vernier Software and LoggerPro.

Measurements were for five scenarios:

- no electrical hook-up
- 0 batteries charging
- 1 battery charging
- 2 batteries charging
- 3 batteries charging

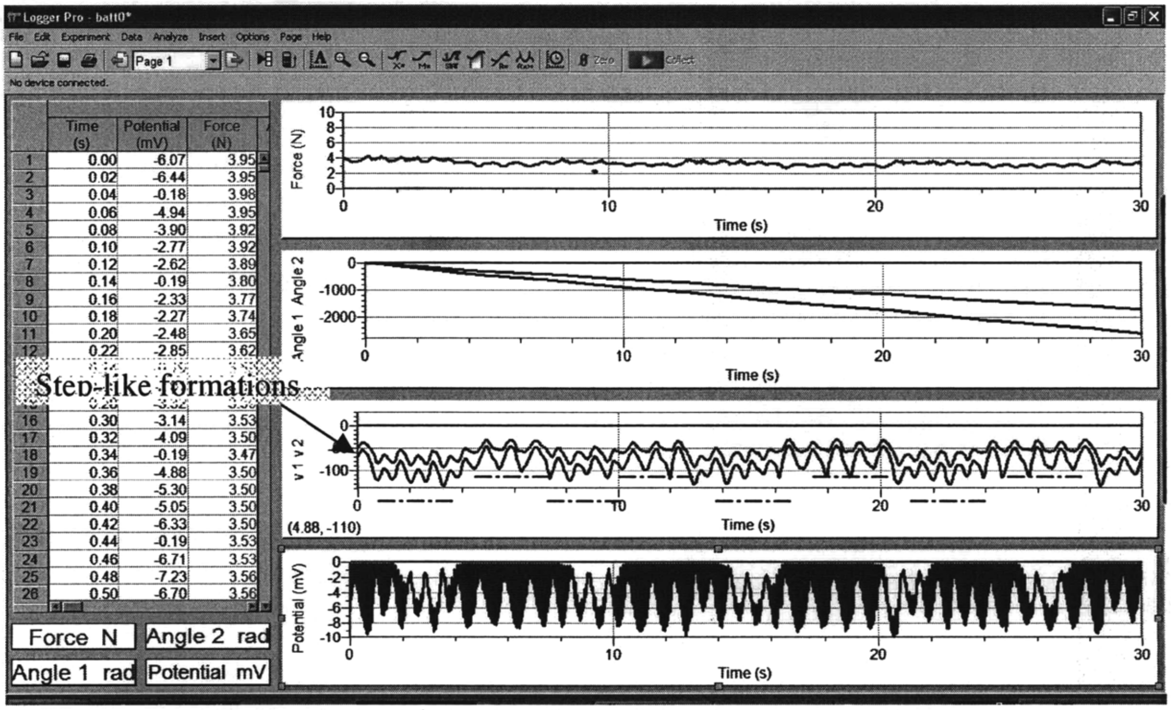
5.3 Experimental Results and Conclusions

Collecting the data from all five devices, efficiency and slippage were calculated for all five scenarios. Results revealed constant amounts of slippage, reaching only 95% of the expected velocity output given no slippage at all.

Despite the addition of battery loads, there were no significant changes in efficiency. Rather than getting the full power output, including the power losses from the alternator in addition to the prony brake, only the output of the prony brake was found, yielding data that only told a fraction of the story.

In the future, the efficiencies between the wheel and the roller output should be isolated. Data showed efficiencies close to 6%, which can directly be attributed to the inclusion of the alternator, which functioned as an additional brake on the roller. However, these results do show that a great amount of power was lost through the added resistance of the electrical load.

Despite the insufficiency of this set-up in completing the entire picture of power losses, there were a number of discoveries, just from the raw data alone. In Figure 5.5, one can see how the natural oscillations in power input and velocity as one is pedaling each pedal stroke. Figure 5.5 additionally demonstrates a phenomenon caused by the alternator, in which load seems to oscillate in a step-like form as shown by the dotted lines of Figure 5.5.



	Time (s)	Potential (mV)	Force (N)
1	0.00	-6.07	3.95
2	0.02	-6.44	3.95
3	0.04	-0.18	3.98
4	0.06	-4.94	3.95
5	0.08	-3.90	3.92
6	0.10	-2.77	3.92
7	0.12	-2.62	3.89
8	0.14	-0.19	3.80
9	0.16	-2.33	3.77
10	0.18	-2.27	3.74
11	0.20	-2.48	3.65
12	0.22	-2.85	3.62
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	0.28	[illegible]	[illegible]
16	0.30	-3.14	3.53
17	0.32	-4.09	3.50
18	0.34	-0.19	3.47
19	0.36	-4.88	3.50
20	0.38	-5.30	3.50
21	0.40	-5.05	3.50
22	0.42	-6.33	3.50
23	0.44	-0.19	3.53
24	0.46	-6.71	3.53
25	0.48	-7.23	3.56
26	0.50	-6.70	3.56

Figure 5.5: *Visible Pedal Strokes shown through Velocity and Power Inputs*

Moreover, there was noise in the load cell that measured the tension in the chain, as shown in Figure 5.6. This noise directly related to the force from each gear tooth, demonstrating how this set-up can quantify imperfections in the measurement sprocket itself.

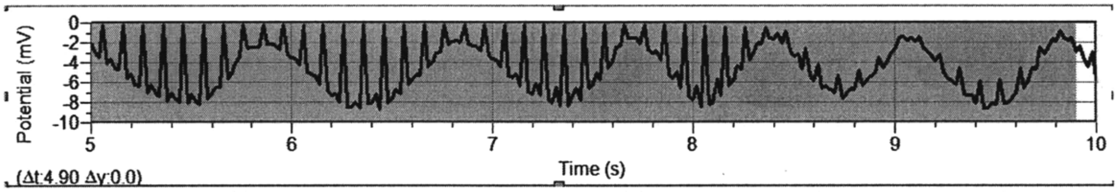


Figure 5.6: *Spikes caused by the Sprocket Engagement of the Load Cell Set-Up*

6 RECOMMENDATIONS

6.1 Further Exploration

For the case of Green TakeOff, future studies should include breaking down the system. Each component should be investigated individually, from the bicycle to the electromechanical element to the multi-battery charger itself. However, much was gained from the instrumentation itself.

With the techniques mentioned in the instrumentation section, one is now equipped with the skills needed for design in developing countries. In conducting controlled experiments, extra care should be taken to ensure that aside from the variable being investigated, all other aspects of the system consists of the most ideal of situations, beginning with a close-to-perfect wheel that maintains consistent load as the back wheel rotates, frictionless bearings, and proper alignment when assessing isolated conditions.

As bicycle dynamics are far from ideal in developing countries, further exploration should be conducted to quantify the bicycle challenges faced in developing countries, such as the accessibility of repairing one's bicycle, the range of bicycle problems faced by riders, and the cultural and gender acceptance of the future bicycle attachments to come.

6.2 Designing for the Developing World

This thesis outlines a number of lessons learned, highlighting the various transmission systems as well as the need in developing countries. In future bicycle-powered attachments, the most essential part of design begins with experimentation. Does the device work consistently?

If yes, then the next steps are optimization for manufacturing, especially in the local context. If not, then experimentation should be conducted to isolate factors that can contribute to improved performance. Moreover, lessons should be taken from the field, learning from the people who know the needs best.

For the case of the *Geuza* and Green TakeOff, both of these devices need extensive work. The *Geuza* needs increased reliability, beginning with increasing the ease of adding and removing devices while maintaining proper alignment and tensioning. One solution is inventing a simple system that functions as a chain tensioner without the added complexity of the derailleur. As for Green TakeOff, identifying the sources of the key inefficiencies is the first step to optimizing this system. Other parameters include changing the roller design as well as the biker position to power the alternator.

6.3 Disseminating Technologies into the Developing World

Beyond the laboratories of the Massachusetts Institute of Technology, the final aspect of design is the iterative process that emerges from disseminating technologies into the field. By taking these technologies to countries in the developing world, one can observe customer interaction and begin to customize these technologies to meet customer needs. Though many of the devices developed for the developing world may seem "lowtech," it is important that just as much diligence be taken in inventing and developing new devices. If anything, the developing world provides greater challenge in bringing longer-lasting products with reduced materials and manufacturing costs, and MIT students should rise to meet this challenge.

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