Hybrid Electric Bicycle

IPRO 315

Objectives and Goals

- Research both Hybrid and Electric Bicycles
- Publish all research and f ndings
- Build at least one Prototype
- Establish a test bench for comparison
- Explore Sponsorship and donation avenues

Group Organization

- Divide into subgroups for the following research categories
  - Regenerative braking
  - Mechanical Design
  - Motor Research
  - Battery Development
  - Control Devices

Regenerative Braking

What is Regenerative Braking?

- Takes the momentum of a electric vehicle and recharges the battery while braking

Motor switches between
Motor /Generator

Components to turn an E-Bike into a Hybrid Bike

- Motor - motor/generator
- Control box - braking, generator, recharge
- Brakes – 2 stage brakes

Drawbacks

- Expensive
- Extra Possible extra energy storage
- Is it worth it?

Braking Energy

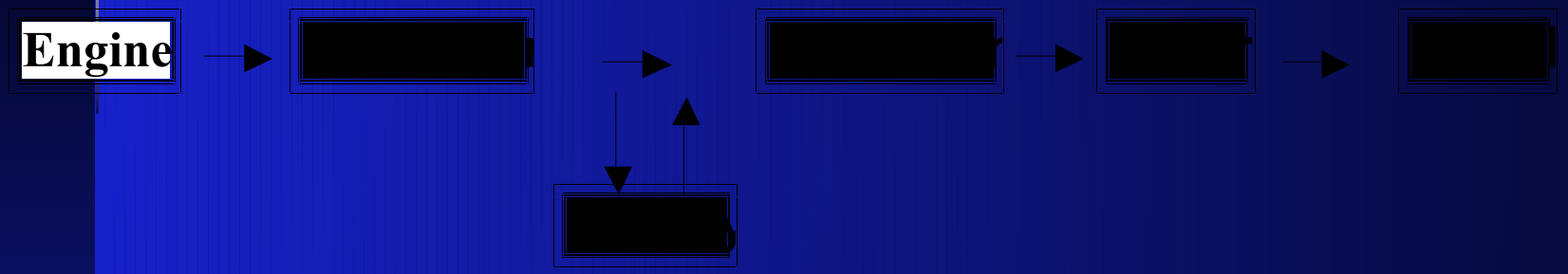
- Convert Kinetic energy into Electrical energy
- Less Energy stored the longer the rider brakes
- Faster braking could lead to friction braking

Problems

- What if the rider does not brake?
- How to store energy so quickly?
  - Ultra-capacitor?
  - Flywheel?

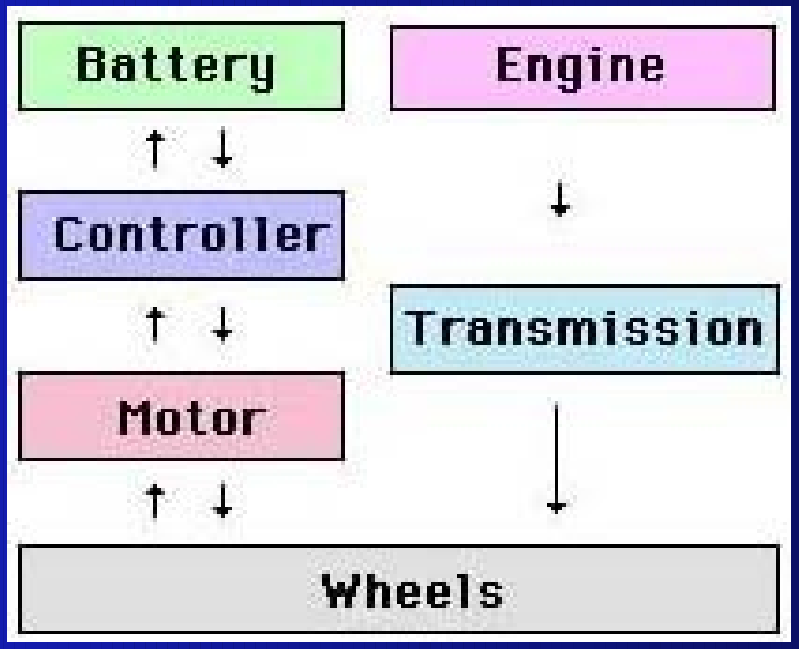
Mechanical Design

Serial Configuration



- Easy Management of power f ow
- Complex mechanical set up for an ordinary bike
- Dead Batteries create problems

Parallel Configuration



- Compact design
- Simple concepts using an ordinary bicycle

Shaft Drive

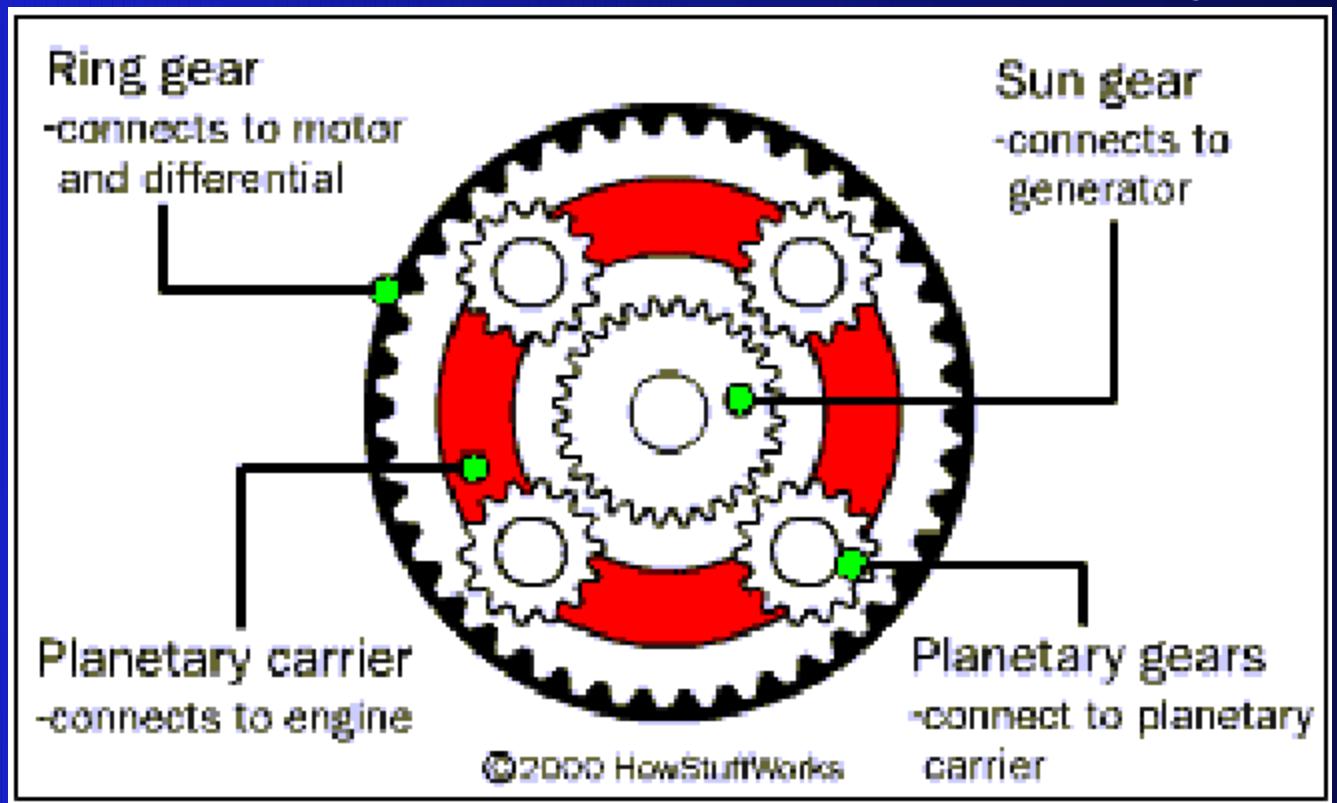
- 95% eff cient on f at and downhill surfaces
- Simple, safe, and clean
- Durable with low maintenance
- No gears make it diff cult for a cyclist

Chain Drive

- 95% eff cient on all surfaces
- Gears allow the cyclist to choose the pedal to wheel ration
- Flexible and absorbs shock
- Cheaper than shaft drive

Planetary Gear Systems

- Gear device with two degrees of freedom
- Diff cult to mount on a standard bicycle



Brushless DC Motors

Brushless Construction

- Often they come in a three phase, four pole conf guration
- Wound Stator (stationary outer member), it helps dissipate winding heat eff ciently
- Permanent magnet rotor (rare earth PM)
- Stator windings are connected in a conventional three phase wye conf guration

Overview

- DC Motor is a three phase synchronous machine
- In the DC motor the rotor chases the Magnetic f eld of the stator windings.
- The revolving f eld is created by sequentially energizing two of the three phases

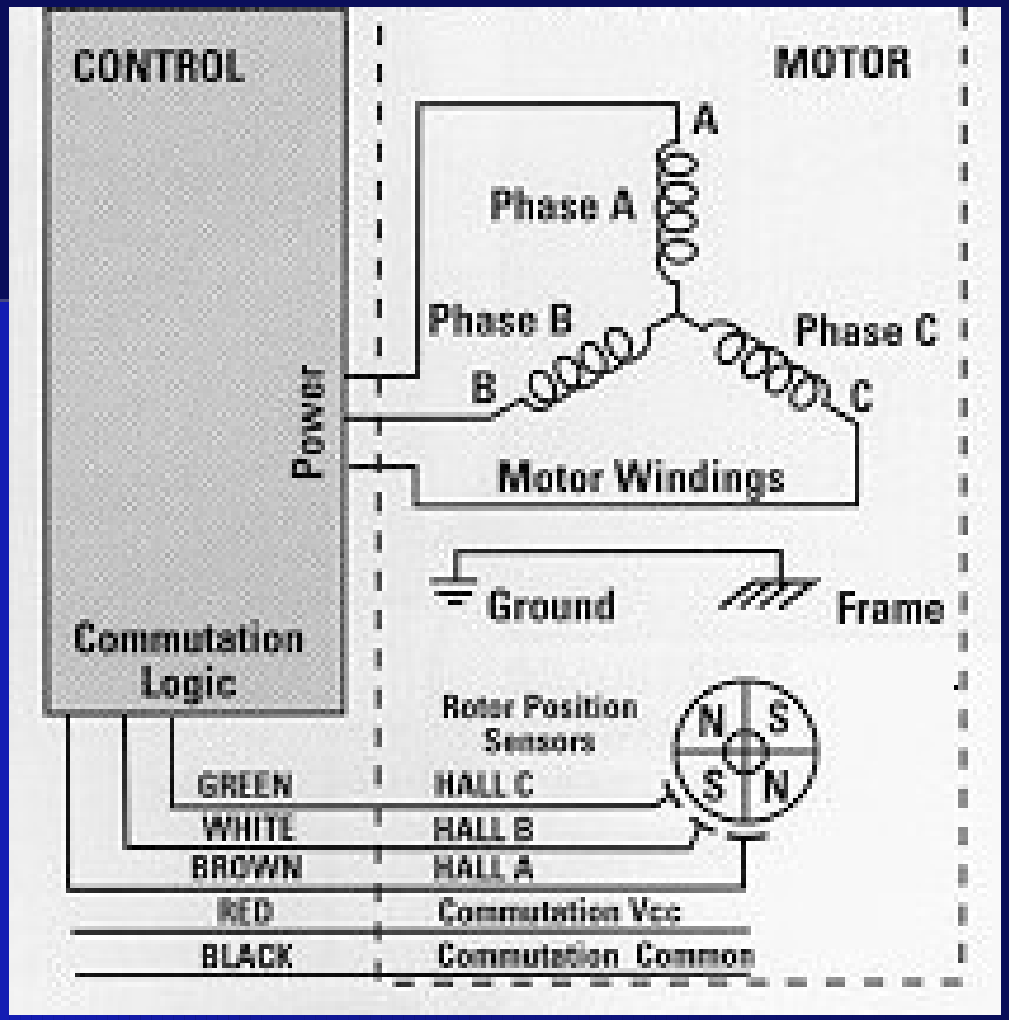
Overview cont'd

- Windings attached to stator, magnets attached to the rotor
- A controller is needed to sense the rotor's position respect to the windings magnetic f eld
- Because of the coils are in contact with the stator, heat dissipation is more eff cient

Brushless motor Advantages

- Less maintenance, long life (brush inspection is not needed)
- Low rotor inertia, improves acceleration/decel.
- Low EMI, and quiet Operation
- More power output per size than shunt wound motors or gear motors

Schematic Representation



Why did IPRO use it?

- Eff cient, long life, low weight
- Small size, easy to interface with an custom designed controller.
- Reliable and moderate in price
- Low maintenance

Battery Group

Specifications

- Size
- Weight
- Energy
- Cycle Life
- Memory
- Applicability

Lead Acid Battery

- Pros
  - Price
- Cons
  - Weight
  - Size
  - Specif c Energy

Nickel-Cadmium Battery

- Pros
  - Specif c Energy high the Lead Acid
  - Cycle Life
- Cons
  - Memory Effect
  - Power
  - Applicability with Hybrid Electic Bicycles

Nickel-Metal Hydride Battery

- Pros
  - Cycle Life
  - Motor Company usage
  - Price
- Cons
  - Size
  - Weight
  - Specif c Energy and Power

Lithium Ion Battery

- Pros
  - Specif c Energy and Power
  - Size
  - Quickness of Charge
  - Cycle Life
- Cons
  - Cost
- Applicability

Controllers

Why do we need a Controller??

- To accomplish winding Commutation
  - Commutation is the control of current to produce torque. Torque is produced when the magnetic f eld from the winding interacts with the f eld from the magnet. When the motor is moving, the position of the windings changes. This means that the optimal path to channel the current changes, depending on the motor position.
  - Brushless motors require *electronic* commutation. The controller determines how to channel current into the windings.

Common Control Strategies for Brushless Motors

- Control requires knowledge of rotor position and speed.
  - Sensorless
    - Estimation
      - Kalman Filtering
  - Sensored
    - Direct Measurement
      - Position Sensors

Sensorless Control

Why go “sensorless”?

- Simple Design
- Less costly implementation
- Greater reliability of the system.
- Certain applications (compressors) do not allow the use of external position sensors due to ambient conditions.

Sensorless Control

Why Not?

- Poor performance at low RPMs
- Limited accuracy
- Complex D.S.P. needed to perform estimation calculations

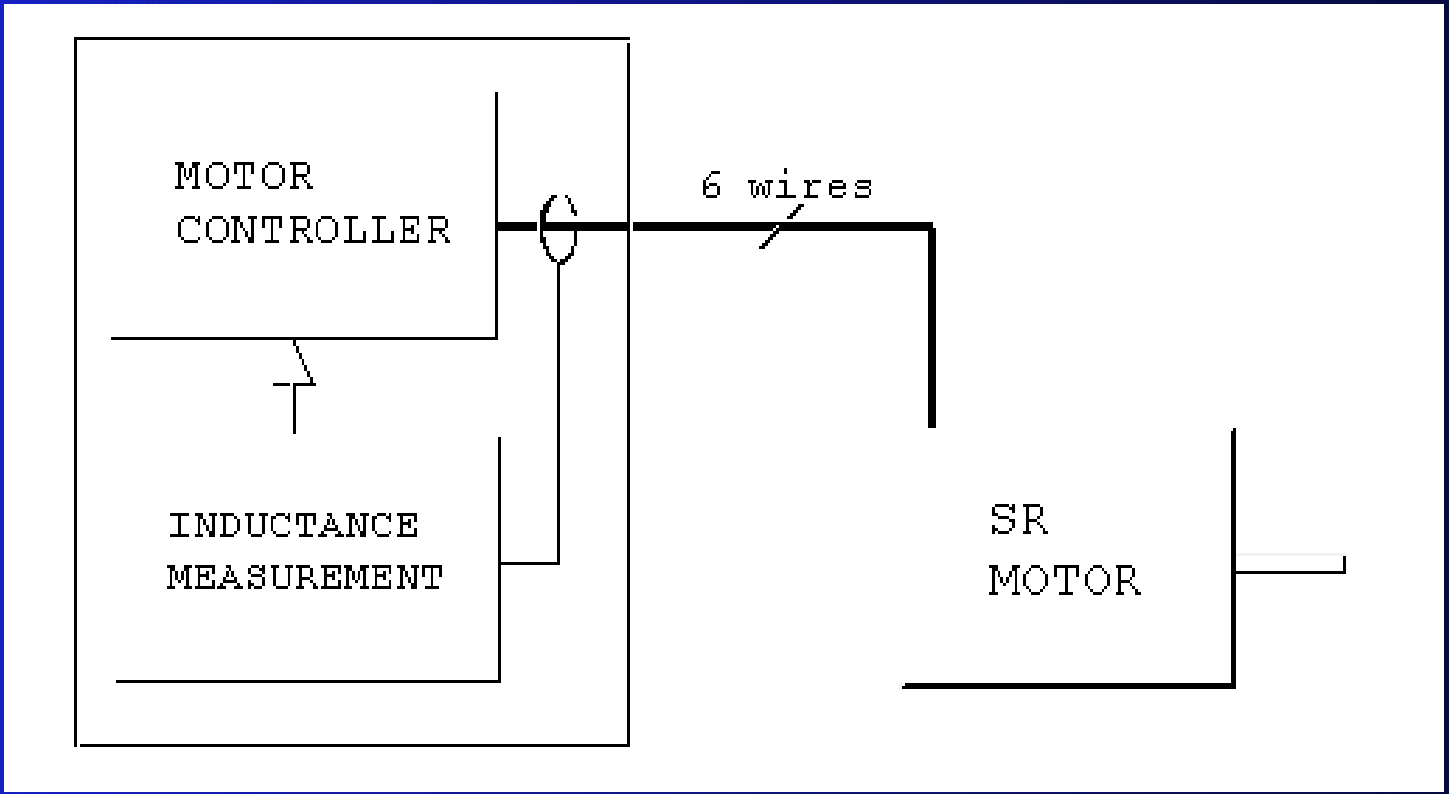
Kalman Filtering

- Relies on estimating the position and velocity of the rotor
- Mathematical description
- Instantaneous measurements of the motor
- Fine-tune the estimates
- Measurements of feedback EMF and currents
- Not position or velocity of rotor

Motor Modif cation

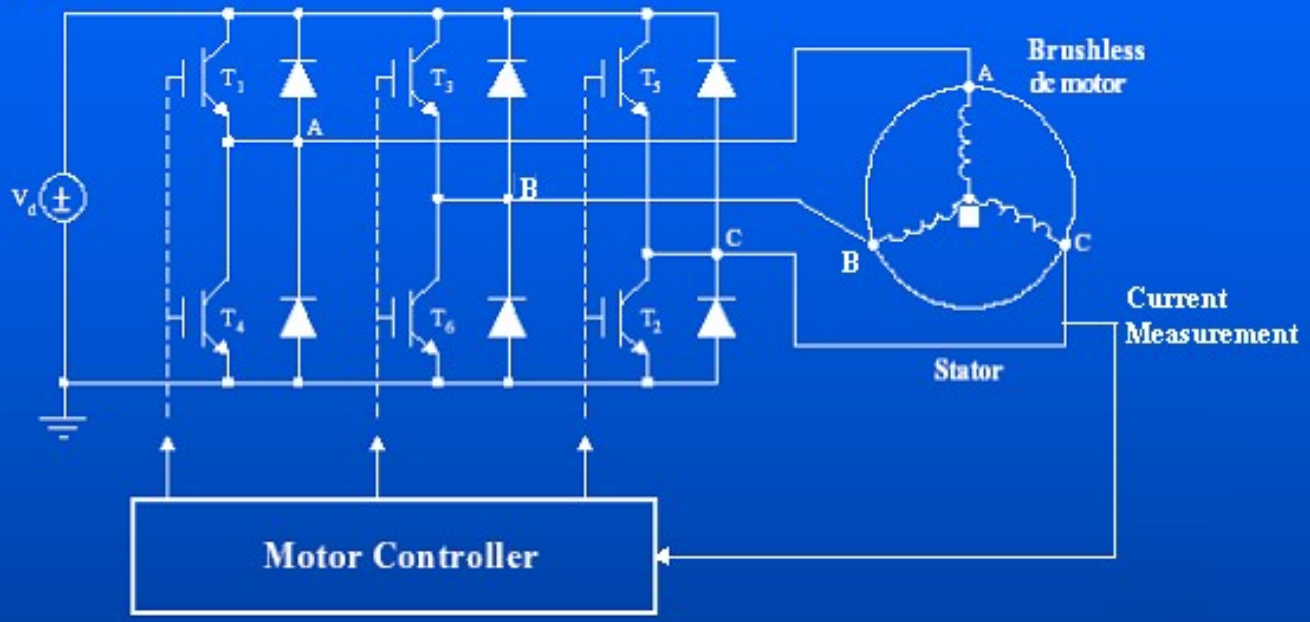
- No physical changes
- EMF and current probes
  - Implemented within controller
- Commutation Logic
  - Estimation
    - Feedback EMF
    - Phase Current

Sensorless Block Diagram



ROTOR POSITION ESTIMATION

- **Back emf Integration**



- **Use three integrators**

$$\int v_A dt \;,\; \int v_B dt \text{ and } \int v_C dt$$

Sensored Control

Why go “sensored”?

- Accurate control at all speeds
- Easiest way to commute winding current
- Easy starting of motor
- Fewer mathematical calculations so only simple integrated circuits needed.

Sensored Control

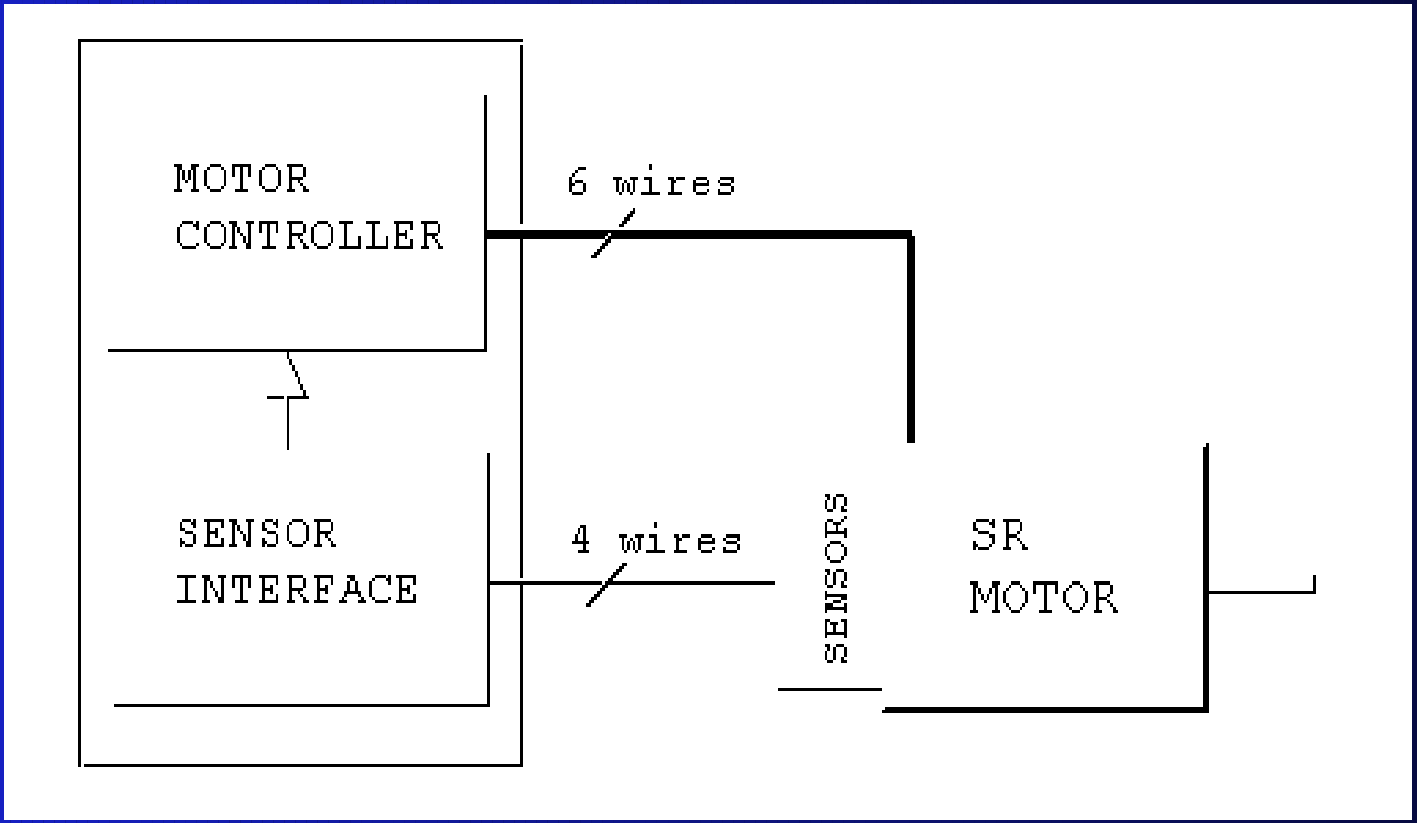
Why Not?

- More components
- Larger packaging
- Questionable reliability
- Costs more to implement

Motor Modif cation

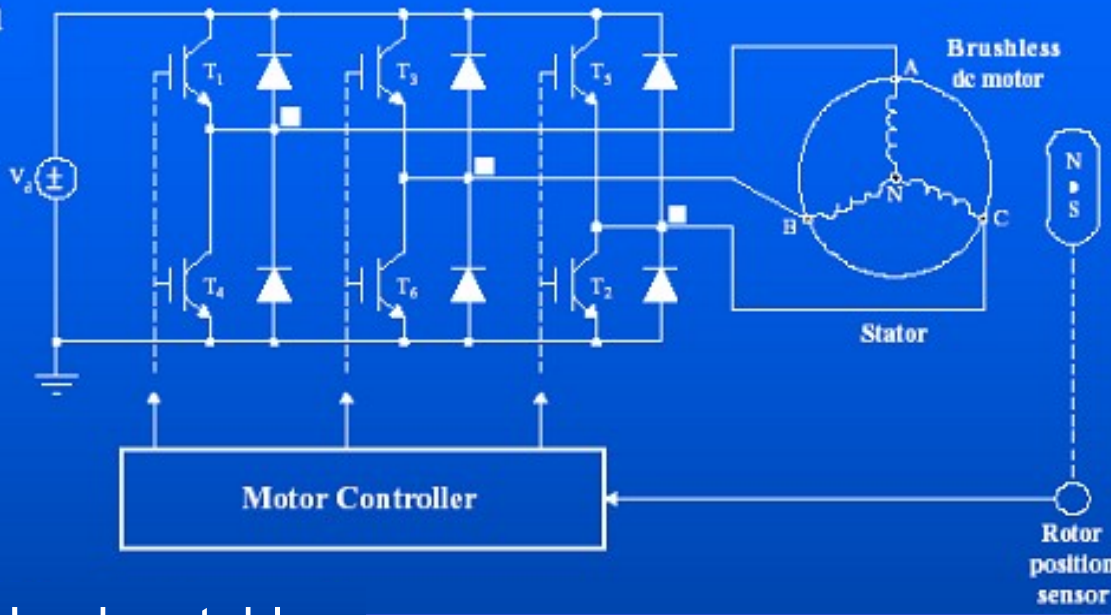
- Position Sensors
  - Hall Effect
    - Displacement of 60 degrees
    - Digital high/low for 120 degrees
- Commutation Logic
  - Sensor data
    - Lookup table

Sensored Block Diagram



ROTOR POSITION MEASUREMENT

- **Block Diagram**



- Commutation Lookup table

Motor Rotation								
Clockwise*					Counter Clockwise*			
Hall Sensor Output			Phase Current			Hall Sensor Output			Phase Current		
A	B	C	A	B	C	A	B	C	A	B	C
0	0	1	+	OFF	−	0	1	1	OFF	−	+
0	0	0	+	−	OFF	1	1	1	+	−	OFF
1	0	0	OFF	−	+	1	1	0	+	OFF	−
1	1	0	−	OFF	+	1	0	0	OFF	+	−
1	1	1	−	+	OFF	0	0	0	−	+	OFF
0	1	1	OFF	+	−	0	0	1	−	OFF	+

So what designs shall be used?

- Parallel Conf guration
- Chain Drive
- Permanent Magnet Brush less Motor
- Lithium Ion Battery
- Sensor Less Controller
- Regenerative Braking is still an issue to be pursued

Now that the design is decided upon, where shall we start?

- $ $ $
- Proposals monetary grants, product donations, and sponsorship
- Purchase of a small e-bike kit

E-bike Kit

- NYCeWheels kit
  - Included battery, motor, and controller
- Built on loaned bicycle
- Massed, measured and ridden

THANKS ! To…

- Santa Cruz Bicycles
  - Light weight mountain bike frame
- Argonne National Laboratory
  - Hosted a f eld trip to the HEV division
- TREK bicycles
  - Promise for a few simulation products and a f eld trip to the engineering facility in Madison, WI
- Dr. Al-Hallaj – IIT Chemical Engineering
  - Li-ion battery design and product
- Dr. Emadi – IIT Electrical Engineering
  - Expertise with controllers

A Look To The Future

The Next Semester

Further Research and Plans

- Research on Alternative Technologies (motors,batteries, etc…)
- Simulation and Testing of different hybrid models.
- Build a Working Prototype of an electric hybrid bicycle.
- New Sponsorship (Grants, Donations and Advisement).

Research of Alternative Technologies

- Different forms Regeneration (via Breaking, Solar, fuel cells etc..)
- Battery Technology (Lithium vs. Nickel Hydride Battery technologies)
- Controller Conf guration and type

Simulation,Testing and Building of Prototype

- Simulations of different hybrid bicycle models.
- Building Prototype
  - parallel conf guration
  - brush-less motor
  - Sensor-less Controls
  - Lithium ion Battery
- Testing Prototype (Trek)

New Sponsorship and Grants/Donations

- Acquiring new Sponsors for:
- Parts (includes motor drives, batteries etc)
- Grant Money (cover some expenses in yearly budget)
- Use of testing Facilities
- Provide Advisement (new direction)

Members

- Francis Carrera
- Darius Dubanski
- George Derrick
- Jeongwoo Lee
- Kitae Kim
- Kylie Klint
- Lee Nelson
- Mike George
- Ryan Lim
- Sam Choi
- Shaun Diggs
- Sungwoo Min
- Waqas Jamal
- Phillip Felber

Questions