Center for Embedded Networked Sensing

Inverted Pendulum Control: Hardware

Paul Ashla, Andrea Wang, Henrik Borgstrom, Manda Paul, Ivan Pinto, Stoytcho Stoytchev, Jo Tsai, William Kaiser

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Introduction: Implement a "hands-on" project for the UCLA Controls Course (EE141)

EE141: Principles of Feedback Control

- **Introductory controls class**
  - Only controls class required for electrical engineers.
  - Includes instruction in mathematical modeling of systems, root locus, and frequency response.
- **Current lab projects are not ideal**
  - Require expensive machinery which is not accessible to individual students.
  - Inverted pendulum control project is an inexpensive alternative; each student would build and interact with an inverted pendulum device.

The inverted pendulum project and kit

- **A classic controls problem**
  - Inherently unstable system needs to be actively balanced.
  - Feedback from system used to control the motion of the cart to keep the pendulum from falling.

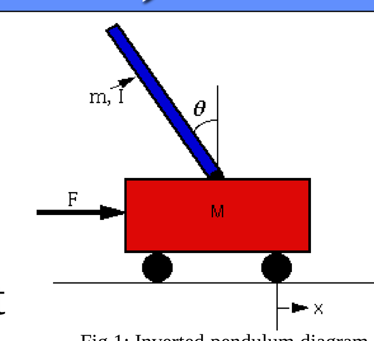


Fig 1: Inverted pendulum diagram (Informatics V, 2008)

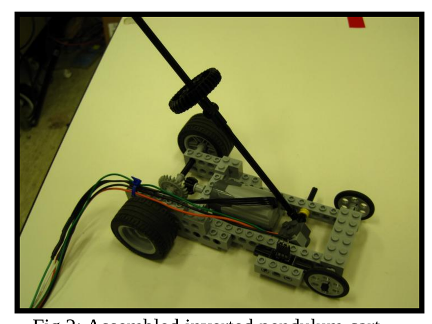


Fig 2: Assembled inverted pendulum cart

Students may build their own inverted pendulum cart

- Cart consists primarily of readily available Lego pieces.
- Students will be given a kit with parts to create the cart, as well as the hardware and software needed to control it.
- Provides hands-on experience in active control techniques.

Problem Description: Kit assembly needs to be simple and accessible

Multiple systems are required

- **Hardware, software and circuitry**
  - Students construct a physical Lego-based cart.
  - They interact with LabView applications to experiment with inverted pendulum control.
  - Some circuitry is required to link the inputs and outputs of the computer software with the physical cart.
- **Building and integrating these systems may be time-consuming**

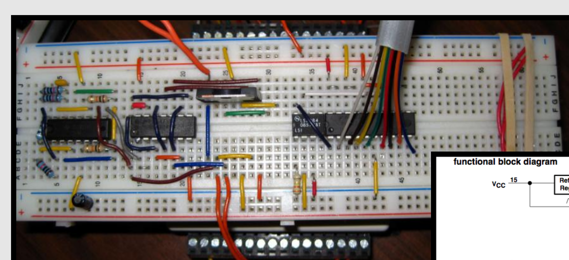


Fig 3: An example of the completed circuitry for the inverted pendulum cart

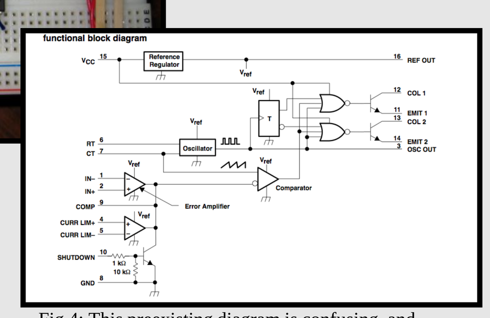


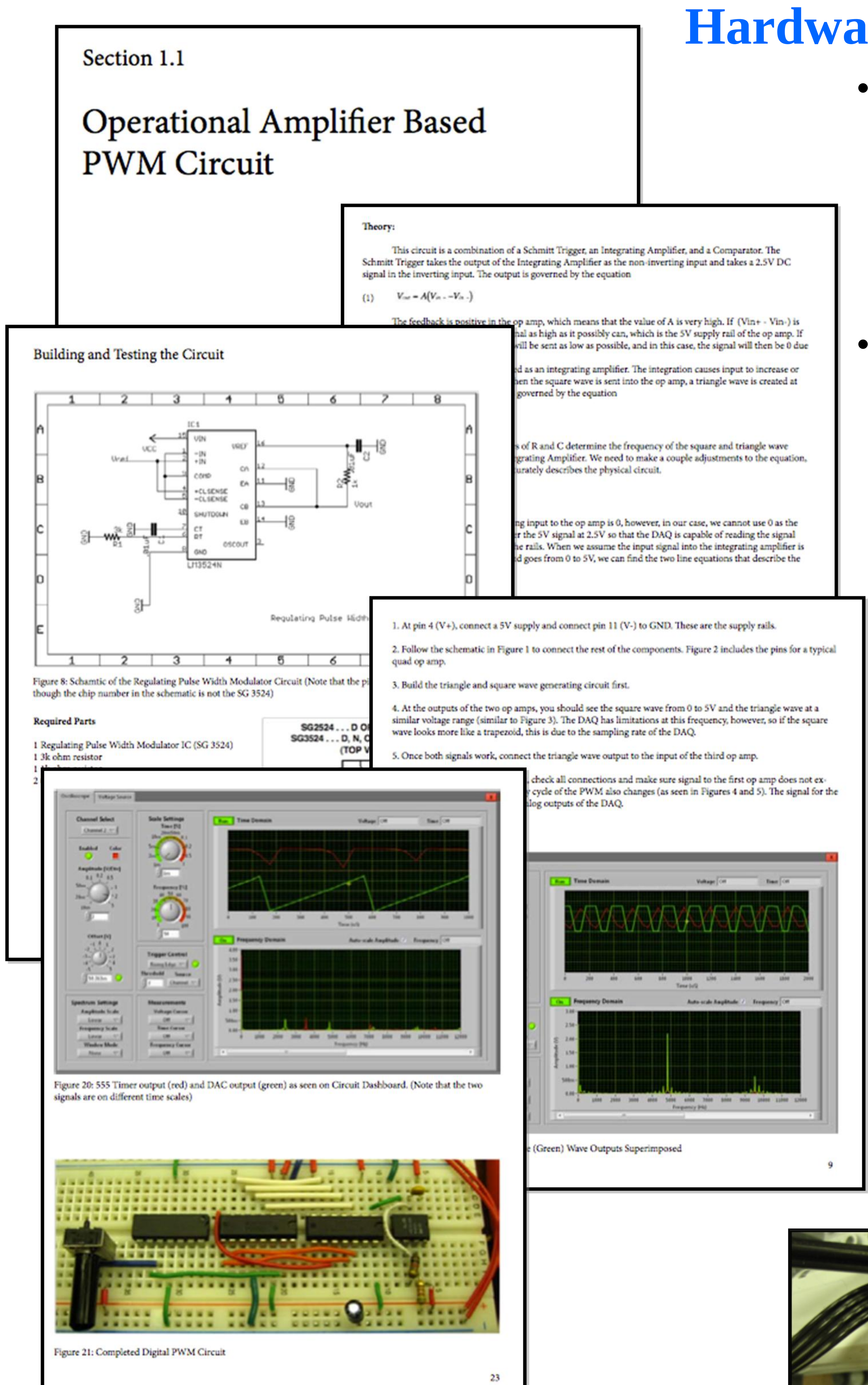
Fig 4: This preexisting diagram is confusing, and would not be sufficient to assemble a working circuit

Difficulties with circuit assembly

- **Progress for some may be slowed by lack of circuitry experience**
  - A circuitry class is not a reinforced prerequisite for EE141.
  - Existing information of on proper assembly of the circuits was confusing.
- **Assembling and troubleshooting these circuits is difficult and frustrating**

Students should be working with the controls aspect of the system, not struggling with the circuits!

Proposed Solution: Simple, step-by-step documentation of the circuitry


Section 1.1

Operational Amplifier Based PWM Circuit

Building and Testing the Circuit

Fig 5: Documentation sample

Hardware Documentation

- **Documentation for each circuit is broken up into three sections**
  - *Theory:* background information on the principles of operation behind the circuit.
  - *Building and Testing the Circuit:* Step-by step instructions on how to build the circuit and relevant diagrams.
  - *Expected Results:* Includes information on how the finished circuit should function and what it might look like.
- **Designed to be easy and informative**
  - Written for people with limited circuit building experience.
  - Conveniently collects all important information in one place, including excerpts on basic functionality and pin attributes from datasheets.
  - Students can use provided hardware and software to compare the output from their circuits against sample output waveforms included in the documentation.
  - It is possible to exactly duplicate the sample circuit from the picture, so a frustrated student can move on from a difficult circuit.

Other Work: Encoder-Less Design

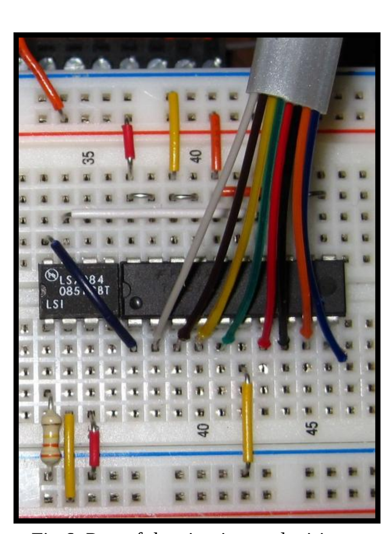


Fig 6: Part of the circuitry and wiring for the optical encoder

- **The cart currently uses an optical encoder to get data on pendulum position**
  - *Advantages:*
    - Quite accurate, with 256 digital positions.
    - Does not introduce much friction.
  - *Disadvantages:*
    - Somewhat expensive.
    - Requires substantial circuitry, wiring and programming to operate.
- **It may be possible to use a variable resistor instead**
  - *Advantages:*
    - Accurate in a small range, giving analog position data.
    - Significantly lower cost than an encoder.
    - Simpler to operate, eliminates an entire circuit.
  - *Disadvantages:*
    - Produces more friction, which may be problematic
    - Loses accuracy in larger angles.

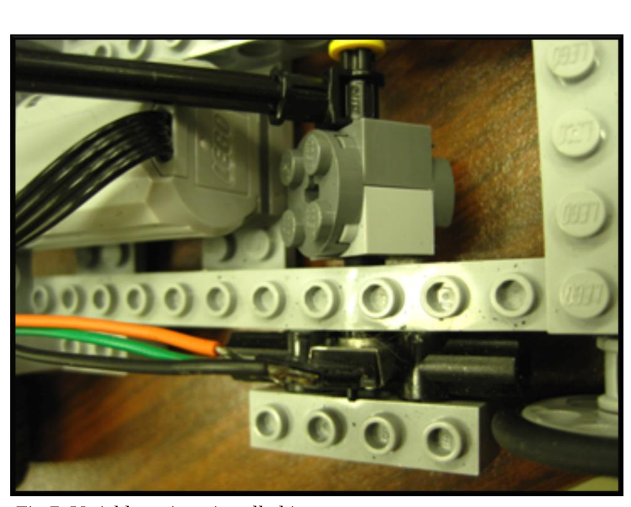


Fig 7: Variable resistor installed in a cart