FINAL SCRIPT: APPROVED FOR FILMING

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Project Page Link: https://review.jove.com/account/file-uploader?src=20858998

Title: High-Precision Electromagnetic Flowmeter with Empty Pipe Detection via Complex Programmable Logic Device-Based Waveform Recognition

Authors and Affiliations:
Zhenxing Wang[1], Zhihan Yang[2]

[1]School of Computer and Information Engineering, Shanghai Polytechnic University
[2]School of Intelligent Manufacturing and Control Engineering, Shanghai Polytechnic University

Corresponding Authors:
Zhenxing Wang zxwang@sspu.edu.cn

Email Addresses for All Authors:
Zhenxing Wang zxwang@sspu.edu.cn
Zhihan Yang 20231513134@sspu.edu.cn

Author Questionnaire

1. **Microscopy**: Does your protocol require the use of a dissecting or stereomicroscope for performing a complex dissection, microinjection technique, or something similar? **NO**

2. **Software:** Does the part of your protocol being filmed include step-by-step descriptions of software usage? **No**

3. **Filming location:** Will the filming need to take place in multiple locations? **NO**

Current Protocol Length
Number of Steps: 7
Number of Shots: 18

Introduction

Videographer: Obtain headshots for all authors available at the filming location.

1.1. **Zhenxing Wang:** We are interested in designing, implementing, and validating a CPLD-driven electromagnetic flowmeter; exploring how waveform recognition elevates measurement precision, ensuring stable empty-pipe detection.

1.1.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera. *Suggested B-roll: 2.4.2*

What are the current experimental challenges?

1.2. **Zhenxing Wang:** Our challenges are suppressing electromagnetic interference, minimizing sensor thermal noise, isolating CPLD switching artifacts, and separating very weak flow signals from ambient noise and make the result more stable.

1.2.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera. *Suggested B-roll: 2.6.1*

What significant findings have you established in your field?

1.3. **Zhenxing Wang**: We found that 50Hz power-frequency interference generates a distinct waveform pattern on the electrodes. When the tube is empty or contains air bubbles, this waveform exhibits specific characteristics. By analyzing these unique patterns, we can determine whether the tube is empty or contains bubbles.

1.3.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera. *Suggested B-roll: 2.7.2*

What advantage does your protocol offer compared to other techniques?

1.4. **Zhenxing Wang:** To meet the requirements of wide-flow-range detection, a variable-gain op-amp circuit is designed to achieve high precision. A multi-stage bandwidth hardware filter enhances the signal-to-noise ratio (SNR), while a software filter further improves system stability

1.4.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera. *Suggested B-roll: 3.1.1*

What research questions will your laboratory focus on in the future?

1.5. **Zhenxing Wang:** We wish to enhance noise-resilient waveform analytics, adapt CPLD algorithms for multiphase and pulsatile flows, and embed self-calibrating, low-power sensors for real-time industrial IoT diagnostics.

   1.5.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera. *Suggested B-roll: 2.6.4*

Videographer: Obtain headshots for all authors available at the filming location.

Testimonial Questions (OPTIONAL):

How do you think publishing with JoVE will enhance the visibility and impact of your research?

1.1. **Zhenxing Wang:** JoVE's video-format publication enables viewers to comprehensively learn our methodology. As an indexed, open-access platform, JoVE amplifies the visibility and citation potential of our work, helping our high-precision, low-fluctuation techniques reach instrumentation researchers, process-control specialists, and grant reviewers worldwide.

1.1.1. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera. *Suggested B-roll: 2.6.4*

Can you share a specific success story or benefit you've experienced—or expect to experience—after using or publishing with JoVE?

1.1. **Zhenxing Wang:** By publishing in JoVE, our lab aims to attract more high-precision detector research projects, particularly those focused on improving signal-to-noise ratio (SNR) through innovative methodologies. The journal's multimedia format will effectively showcase our technical capabilities, helping us secure collaborations and funding for advanced R&D initiatives in this field.

1.5.2. INTERVIEW: Named talent says the statement above in an interview-style shot, looking slightly off-camera. *Suggested B-roll: 2.7.2*

Protocol

Videographer's NOTE: I want to mention that in this shoot, because the subject is a circuit diagram, the majority of the steps can't be filmed in action. The author projected an image on the wall and introduced them in English instead.

2. **Processing of Electrode-Induced Voltage**

Demonstrator: Zhenxing Wang

2.1. To begin, take the induced electromotive force from both sides of the sensor as the input signal **[1]**. Filter the noise using bypass capacitors. Apply a ten X differential amplifier to amplify the input signal **[2]**.

2.1.1. WIDE: Talent connecting both sensor leads to the input terminals of the circuit.

2.1.2. Talent adjusting the gain control for the differential amplifier.

2.2. Feed the amplified signal into a second-order bandpass filter, starting with a high-pass filter to remove low-frequency components **[1]**. Then, channel the filtered output through a coupling capacitor into the low-pass filter stage **[2]**.

2.2.1. Talent pointing to the signal through the high-pass filter on the circuit module.

2.2.2. Talent showing the position of the coupling capacitor and the waveform on the screen before and after the low-pass filter stage.

2.3. Using an inverting amplifier, amplify the denoised signal **[1]**. Then, apply a gain of negative one through the inverting amplifier to convert the negative-polarity signal into positive polarity, preserving the amplitude **[2]**.

2.3.1. Talent configuring the input and feedback resistors on the inverting amplifier circuit.

2.3.2. Talent connecting the signal output and the shot of polarity inversion on the oscilloscope.

2.4. Direct the positive and negative half-cycle signals to two separate channels of the analog switch **[1]**. Simultaneously, input both signals into the comparator **[2]**. Process the output signals from the comparator using a complex programmable logic device to detect pipeline vacancy and determine fluid flow direction **[3]**.

2.4.1. Talent wiring the signal outputs to two separate channels of the analog switch.

2.4.2. Talent connecting signal paths into the comparator inputs.

2.4.3. SCREEN: Show CPLD programming interface where logic is configured to detect pipeline vacancy and interpret flow direction from the comparator output. **Videographer's NOTE**: the author provided a Word document of the coding

2.5. After signal gating via the analog switch, feed the signal into a third-stage amplifier **[1]**. Process the amplified signal using an integrating low-pass filter **[2]**. Transmit the final filtered signal to the microcontroller unit for computational processing **[3]**.

2.5.1. Talent connecting the analog switch output into the third-stage amplifier.

2.5.2. Talent inserting a capacitor-resistor network for the integrating low-pass filter.

2.5.3. SCREEN: Show microcontroller interface receiving input from the analog-to-digital converter channel. **Videographer's NOTE**: the author provided a picture. I've included them in the folder

2.6. Position the signal amplifier near the bandpass filter **[1]**. Connect the amplifier to the output of the bandpass filter **[2]**, followed by the secondary amplifier to receive the bandpass output **[3]**. Configure two comparators below the analog switch **[4]**.

2.6.1. Talent positioning the amplifier module on the test bench next to the bandpass filter.

2.6.2. Talent connecting wires from the bandpass output to the amplifier input.

2.6.3. Talent placing and wiring a secondary amplifier downstream of the first.

2.6.4. Talent mounting two comparators beneath the analog switch and linking them with wires in ECAD platform.

2.7. Finally, input the rectified signal from the analog switch into a variable-gain amplifier **[1]**. Route the output through a low-pass filter and into the analog-to-digital conversion channel of the processor **[2]**.

2.7.1. Talent connecting the rectified signal line into a tunable amplifier and adjusting the gain.

2.7.2. Talent wiring the low-pass filter to the processor board and observing the input to the analog-to-digital channel on screen.

Results

3. Results

3.1. The flow rate measurements from three repeated experiments using the same device showed highly consistent results across the entire measurement range, confirming strong data reproducibility and intrinsic linearity **[1]**.
  3.1.1. LAB MEDIA: Figure 6A.

3.2. When comparing the four experimental devices to the standard instrument, all devices showed high measurement consistency at identical standard flow rates, as well as excellent linearity over the full range **[1]**.
  3.2.1. LAB MEDIA: Figure 6B.

3.3. After applying linearity correction, the measurement deviations of the four devices from the standard values were significantly reduced, enhancing the system's accuracy **[1]**.
  3.3.1. LAB MEDIA: Figure 6C.

3.4. At low flow velocities, the relative error was noticeably higher and gradually decreased with increasing velocity, reflecting the influence of signal-to-noise ratio on measurement accuracy **[1]**.
  3.4.1. LAB MEDIA: Figure 6D.

Pronunciation guide :

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1. Electromotive Force

- **Pronunciation link**: https://www.merriam-webster.com/dictionary/electromotive%20force
- **IPA**: /ɪˌlɛk.troʊˈmoʊ.tɪv fɔːrs/
- **Phonetic Spelling**: ih-lek-troh-moh-tiv force

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2. Bypass Capacitor

- **Pronunciation link**: https://www.merriam-webster.com/dictionary/bypass (for "bypass"); https://www.merriam-webster.com/dictionary/capacitor (for "capacitor")
- **IPA**: /ˈbaɪˌpæs kəˈpæsɪtər/
- **Phonetic Spelling**: bye-pass kuh-pas-ih-ter(merriam-webster.com, merriam-webster.com, merriam-webster.com)

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3. Differential Amplifier

- **Pronunciation link**: https://www.merriam-webster.com/dictionary/differential (for "differential"); https://www.merriam-webster.com/dictionary/amplifier (for "amplifier")
- **IPA**: /ˌdɪfəˈrɛnʃəl ˈæmpləˌfaɪər/
- **Phonetic Spelling**: dif-uh-ren-shul am-pluh-fy-er(merriam-webster.com, merriam-webster.com)

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4. Bandpass Filter

- **Pronunciation link**: https://www.merriam-webster.com/dictionary/band-pass%20filter
- **IPA**: /ˈbændˌpæs ˈfɪltər/
- **Phonetic Spelling**: band-pass fil-ter(merriam-webster.com, merriam-webster.com)

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5. High-Pass Filter

- **Pronunciation link**: https://www.merriam-webster.com/dictionary/high-pass%20filter
- **IPA**: /ˈhaɪˌpæs ˈfɪltər/
- **Phonetic Spelling**: high-pass fil-ter(merriam-webster.com, merriam-webster.com, merriam-webster.com)

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6. Low-Pass Filter

- **Pronunciation link**: https://www.merriam-webster.com/dictionary/low-pass%20filter
- **IPA**: /ˈloʊˌpæs ˈfɪltər/
- **Phonetic Spelling**: low-pass fil-ter

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7. Coupling Capacitor

- **Pronunciation link**: https://www.merriam-webster.com/dictionary/capacitor (for "capacitor")
- **IPA**: /ˈkʌplɪŋ kəˈpæsɪtər/
- **Phonetic Spelling**: kuh-pling kuh-pas-ih-ter(merriam-webster.com)

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8. Inverting Amplifier

- **Pronunciation link**: https://www.merriam-webster.com/dictionary/invert (for "invert"); https://www.merriam-webster.com/dictionary/amplifier (for "amplifier")
- **IPA**: /ɪnˈvɜːrtɪŋ ˈæmpləˌfaɪər/
- **Phonetic Spelling**: in-ver-ting am-pluh-fy-er(merriam-webster.com)

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9. Analog Switch

- **Pronunciation link**: https://www.merriam-webster.com/dictionary/analog (for "analog"); https://www.merriam-webster.com/dictionary/switch (for "switch")
- **IPA**: /ˈænəˌlɔg swɪtʃ/
- **Phonetic Spelling**: an-uh-log switch(merriam-webster.com)

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10. Comparator

- **Pronunciation link**: https://www.merriam-webster.com/dictionary/comparator
- **IPA**: /kəmˈpærətər/
- **Phonetic Spelling**: kuhm-pair-uh-ter(merriam-webster.com, merriam-webster.com)

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11. Complex Programmable Logic Device (CPLD)

- **Pronunciation link**: https://www.merriam-webster.com/dictionary/complex (for "complex"); https://www.merriam-webster.com/dictionary/programmable (for "programmable"); https://www.merriam-webster.com/dictionary/logic (for "logic"); https://www.merriam-webster.com/dictionary/device (for "device")
- **IPA**: /ˈkɒmplɛks proʊˈgræməbəl ˈlɒdʒɪk dɪˈvaɪs/
- **Phonetic Spelling**: kom-plex proh-gram-uh-bul loj-ik dih-vise

12. Integrating Low-Pass Filter

- **Pronunciation link**: https://www.merriam-webster.com/dictionary/integrate (for "integrate"); https://www.merriam-webster.com/dictionary/low-pass%20filter (for "low-pass filter")
- **IPA**: /ˈɪntəˌɡreɪtɪŋ ˈloʊˌpæs ˈfɪltər/
- **Phonetic Spelling**: in-tuh-gray-ting low-pass fil-ter(merriam-webster.com)

13. Microcontroller Unit

- **Pronunciation link**: https://www.merriam-webster.com/dictionary/microcontroller (for "microcontroller"); https://www.merriam-webster.com/dictionary/unit (for "unit")
- **IPA**: /ˈmaɪkroʊkənˌtroʊlər ˈjuːnɪt/
- **Phonetic Spelling**: my-kroh-kuhn-troh-ler yoo-nit

14. Variable-Gain Amplifier

- **Pronunciation link**: https://www.merriam-webster.com/dictionary/variable (for "variable"); https://www.merriam-webster.com/dictionary/gain (for "gain"); https://www.merriam-webster.com/dictionary/amplifier (for "amplifier")
- **IPA**: /ˈvɛriəbəl ɡeɪn ˈæmpləˌfaɪər/
- **Phonetic Spelling**: vair-ee-uh-bul gain am-pluh-fy-er