Evaluation of LN₂ Dewar Health Using a Weight-based Monitoring System

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Abstract

- Design a weight-based system to continuously monitor dewar (vacuum-sealed tanks that hold cryogenic specimens) weight and changes in liquid nitrogen (LN₂) evaporation rate over time
- Use weight and evaporation rate to quantify dewar “health” (performance), predict when a dewar will empty, and stratify risk among employees & customer segments

Motivation/Market Potential

- There are approximately 480 U.S. fertility clinics, each with at least 12 dewars that hold up to 2,000 samples
- Two recent tank failures involving the University Hospital Cleveland Medical Center in Ohio and Pacific Coast Fertility in San Francisco [1]
  - Legal, financial, and ethical repercussions ($500,000 per individual affected)
- LN₂ dewars also heavily used in industrial manufacturing, research, medical cryogenics, and the culinary industry
  - Collectively constitute a market segment worth nearly $3 Billion USD
- Strong and growing market for improved safety and monitoring tools

Background/Competing Devices

- Specimen stored in LN2 at -196°C
  - Halts molecular process of samples [2]
- Dewars exhibit LN₂ leakage due to imperfect seals/sample handling
  - Must be refilled every 2-7 days
- Low LN₂ from tank failure leads to sample loss
  - Requires real-time monitoring

- Current methods:
  - Yard stick: not real-time
  - Capacitance: imprecise
  - Temperature: non-linear
  - Ultrasound: expensive
- Weight monitoring:
  - Real-time, accurate

Design Criteria

- Functionality:
  - Continuous weight monitoring
  - Real-time calculation of leak rate
  - Data logging in SD card and through Networked Robotics Interface
  - Warning/Alarm through existing system

- Mechanical design:
  - Able to withstand at least 110% of full weight of tank (110 lbs)
  - Can be integrated onto the base
  - Accuracy after extended use
  - To within 5% of definite weight

Final Design

- We created a custom scale (fit to our client’s roller base) capable of continuous weight monitoring
  - Weight is used as a proxy for LN2 volume within the tank and records the level over time
  - Evaporation rate is used as a proxy for tank “health”
- A Raspberry Pi is used to store, output, and graph the change in weight over time in the vaporization rate

Fabrication:

- A Raspberry Pi assembled w/ four load cells interspersed between two 17.5” diameter bevelled, wooden disks
  - Two 2” long bolts and nuts are used to create a view to align sensors for contact
  - Circuit: features an OpenScale, voltage divider (340 & 100Ω resistors) and four 200Ω load cells
  - Replaced breadboard w/ a more robust circuit board

Testing

- Measure change in weight over time (95 ≥ 0.99)
  - Calculate volume, height, evaporation rate
  - Identify patterns for predictive monitoring
- Leak rates calculated for control and exp. conditions: 1 new (<1 yr) and 1 old (>20 yr) dewars tested
  - Control = dewar left undisturbed during monitoring
  - Rate = new: 0.340 lb/day; old: 0.414 lb/day
  - Experimental = dewar’s core access plug was removed
  - Rate = new: 0.954 lb/day; old: 1.38 lb/day
- Differences >10% in evaporation rate could be detected within 3 days of testing

- Our system is able to accurately measure the weight of objects within 5% of their definite weight
- Our system is also able to send a test message alert when weight thresholds are crossed
  - Weight is a preliminary metric that will need to be converted to evaporation rate

Predictive Monitoring

- Estimate time until empty
- Detect impending failure of the tank
  - Compare the real-time evaporation rate to evaporation rates associated with tank failure
  - Experimental evaporation rate correlate to rates indicative of failure
  - Send remotely accessible alerts when a critical weight threshold is reached or when a potential failure is detected

Future Work

- Improve aesthetic and create a circuitry housing unit
  - Evenly distribute five load cells on the five legs of the base and use only one upper (thinner) plate to reduce thickness (eliminate need for guard rail extensions)
- Create a more compact circuit & housing unit
  - Program data logging and interfacing functionalities
  - Alarms at critical thresholds
- Develop predictive algorithm
  - Collect data from simulations to train algorithm
  - Record weight in 0.01 or 0.001 Kg increments
  - Make system more user-friendly
    - E.g. touchscreen or physical buttons
  - AAB & CRB Symposium (May 2019)
    - Share our preliminary findings and find potential clients

Acknowledgements

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- Thank you to our advisor, Ms. Sarah Sandock, for guiding us through this project

References

****Presentation layouts*****

Tong presentation layout

Sections:
- PROBLEM AND MARKET
  - Will
- COMPETITION & INNOVATION AND SOLUTION
  - Jeff
- TESTING & VALIDATION
  - Jake
- COMMERCIALIZATION
  - Quinn

Normal presentation layout

Sections:
- ABSTRACT - BACKGROUND
  - Will
- CRITERIA-FINAL DESIGN
  - Jake
- TESTING
  - Quinn
- THE REST
  - Jeff
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  - A Raspberry Pi is used to store, output, and graph the change in weight over time.

- Fabrication:
  - Scale - Assembled w/ four load cells interspaced between two 17.5" diameter beveled, wooden disks.
  - Two 2" long bolts & nuts are used to create a sleeve to align sensors for contact.
  - Circuit: Features an OpenScale, voltage divider (3kΩ & 10kΩ resistors) and four 200Ω load cells.

Testing

- Measure change in weight over time:
  - Calculate volume, height, evaporation rate
  - Identify patterns for predictive monitoring

- Compare to concurrent temperature readings:
  - Does changes in temperature correlate to specific changes in weight?
  - Figure 5 shows an increase in temperature but no change in weight: current scale only measures up to 0.1kg accuracy
  - Increase the sensitivity to identify patterns
  - Need to increase the precision of weight readings to get more comprehensive and ‘continuous’ data.

General results: linear change in weight over time: temperature remains relatively constant for any amount of LN2 (Figure 4) - changes in temperature might be identified by changes in weight with more precise readings.

Figure 3: The custom scale features a Raspberry Pi connected to an OpenScale used to read the output from four load cells.

Figure 4: SolidWorks rendering of the fully assembled roller base and integrated scale with the LN2 tank placed directly on the assembly.

Figure 5: Graphs produced by MR’s TempMonitor upon addition of a single 0.023kg (20g) specimen (data taken by Dr. Jeffrey Jones).
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