Evaluation of LN_2 Dewar Health Using a Weight-based Monitoring System

UW BME Design

Team Members: Jake Andreae, William Guns, Yiqun Ma, Jeffrey Tsai
Client: Dr. Jeffrey Jones, *Generations Fertility Care*
Advisor: Sarah Sandock, *Department of Biomedical Engineering*
University of Wisconsin - Madison

Abstract

- Design a weight-based system to continuously monitor dewar (vacuum-sealed tank that holds 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 across 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 ($350,000 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

Figure 1: Worthington VHC35 LN2 Storage Tank With Roller Base

Image taken by Dr. Jeffrey Jones

- 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

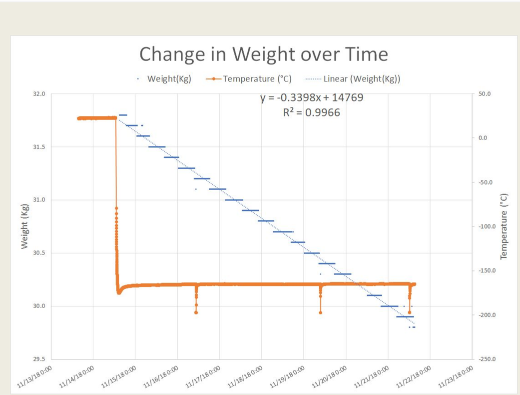


Figure 2: Temperature vs. time chart showing non-linear change in temperature w.r.t. amount of LN2

Image taken from: Networked Robotics

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

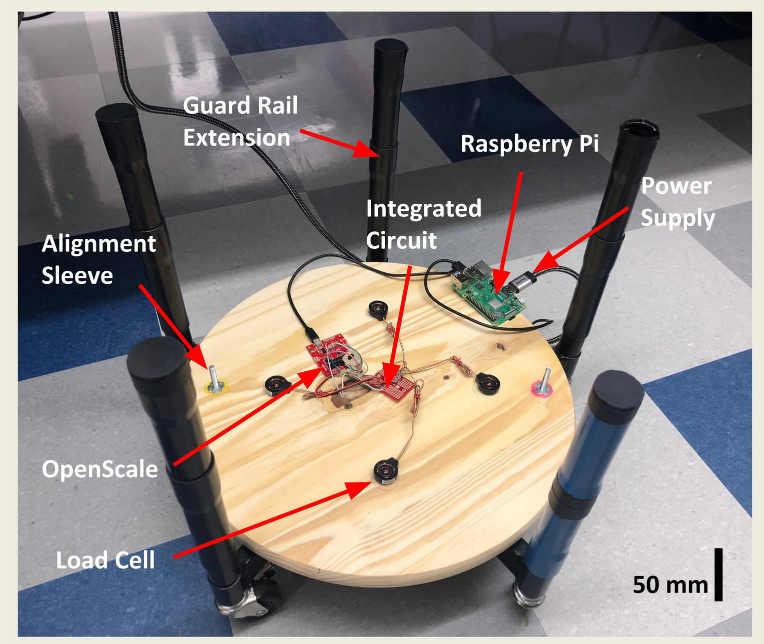


Figure 3: The custom scale features a Raspberry Pi connected to an OpenScale used to read the output from four load cells

Image taken by: BME Team

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

SolidWorks Image by: Jake Andreae

- 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 levels 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 as well as the evaporation rate

Fabrication:
- Scale - Assembled w/ four load cells interspaced between two 17.5'' diameter beveled, wooden disks
  - Two 2'' long bolts and t-nuts are used to create a sleeve to align sensors for contact
- Circuit: Features an OpenScale, voltage divider (3kΩ & 10kΩ resistors) and four 200lb load cells
  - Replaced breadboard w/ a more robust circuit board

Testing

- Measure change in weight over time ($R_2 \geq 0.99$)
  - 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 yrs.) dewar tested
  - Control = dewar left undisturbed during monitoring
    - Rate = new: 0.340 L/day ; old: 0.414 L/day
  - Experimental = dewar's core access plug was removed
    - Rate = new: 0.954 L/day; old: 1.38 L/day
- Differences (>10%) in evaporation rate could be detected within 1 hour of testing

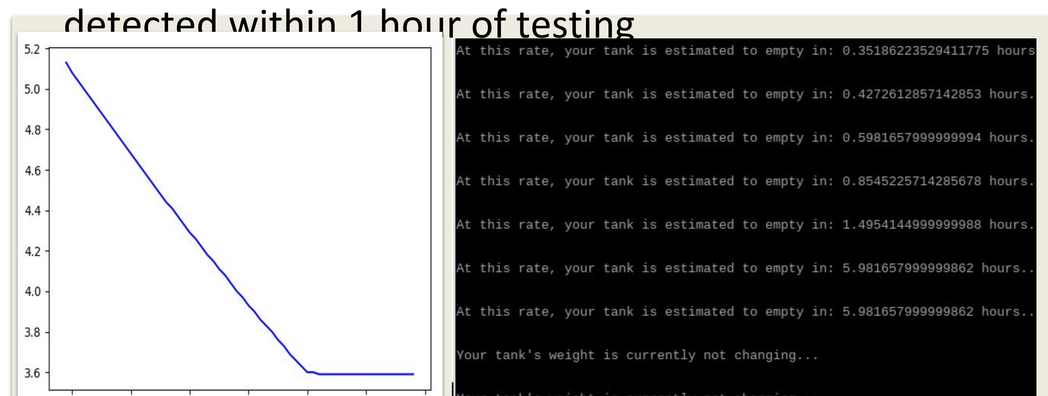


Figure 5: (left) Graph of weight of a leaking water tank. Leaking is stopped at timestamp 120. (right) Predicted time until empty during the time up until the leaking is stopped

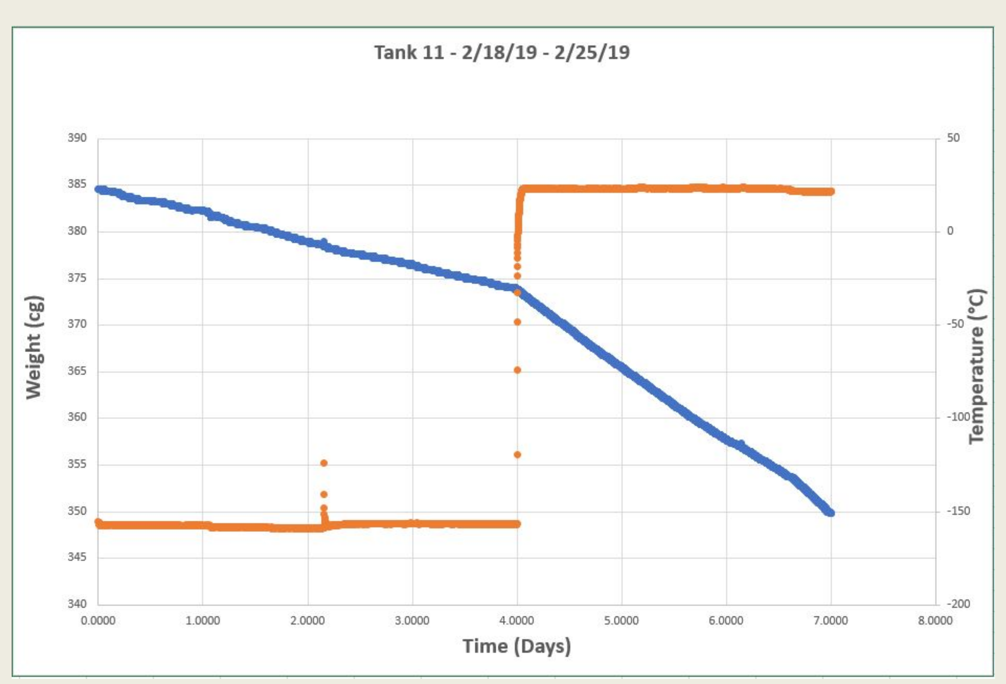


Figure 4: Graphing Weight and Temperature of our client's new 1 year old dewar used to calculate evaporation rate

Data collected by: Dr. Jeffrey Jones

- 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 text 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 evap rates 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
  - Eg. touchscreen or physical buttons
- AAB & CRB Symposium (May 2019)
  - Share our preliminary findings and find potential clients

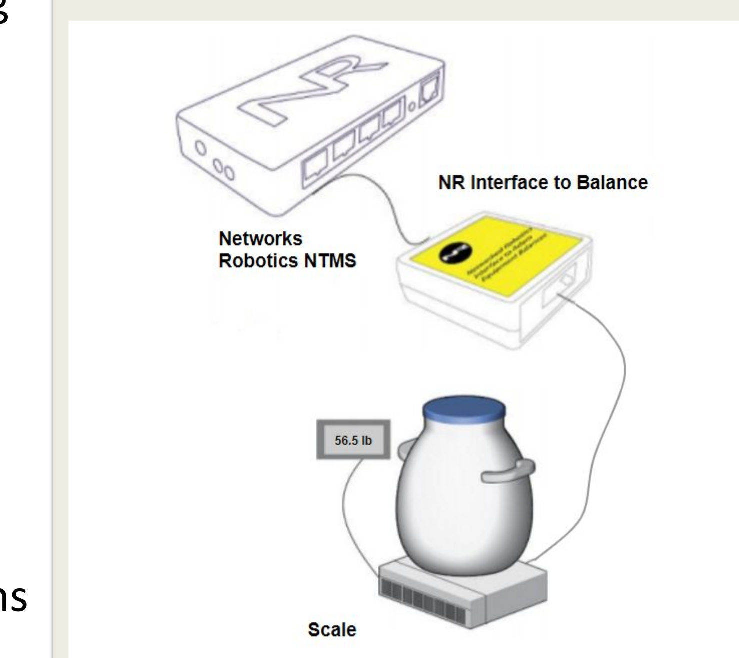


Figure 6: NR interface to custom scale

Image taken from: Networked Robotics

Acknowledgements

- Thank you to our client, Dr. Jeffrey Jones: for offering this project, help with data collection, and his supportive feedback
- Thank you to our advisor, Ms. Sarah Sandock, for guiding us through this project

References

[1] C. Hauser, "4,000 Eggs and Embryos Are Lost in Tank Failure, Ohio Fertility Clinic Says," The New York Times, 28-Mar-2018. [Online]. Available: https://www.nytimes.com/2018/03/28/us/frozen-embryos-eggs.html.

[2] Cohen J, Inge KL, Wiker SR, Wright G, Fehilly CB, Turner TG, Jr. Duration of storage of cryopreserved human embryos. J In Vitro Fert Embryo Transf 1988;5:301-3.

******Presentation layouts******

Tong presentation layout

Sections:

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

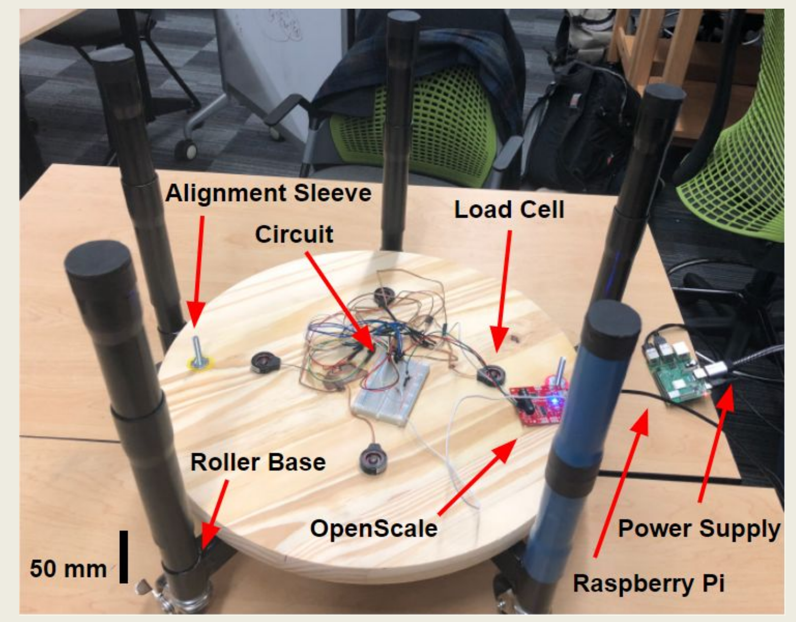
Normal presentation layout

Sections:

- ABSTRACT - BACKGROUND
  - Will
- CRITERIA-FINAL DESIGN
  - Jake
- TESTING
  - Quinn
- THE REST
  - Jeff

Old testing section

Final Design



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Testing

- Measure change in weight over time
  - Calculate volume, height, evaporation rate
  - Identify patterns for predictive monitoring
- Compare to concurrent temperature readings
  - Do 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

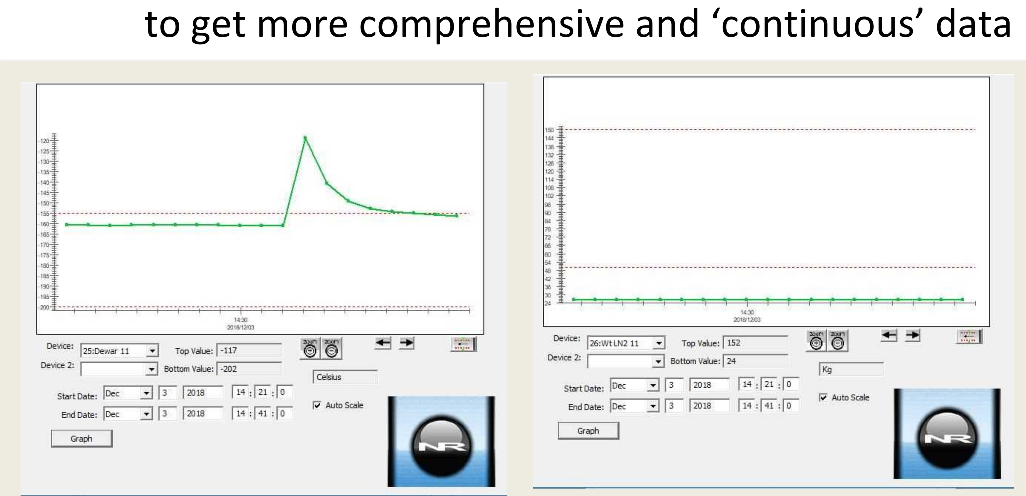

Figure 5: Graphs produced by NR's Tempurity Monitor upon addition of a single 0.02kg (20gm) specimen

Data collected by:
Dr. Jeffrey Jones

Figure 4: Graphing Weight and Temperature of our client's VHC35 LN2 tank from November 14th to November 21st

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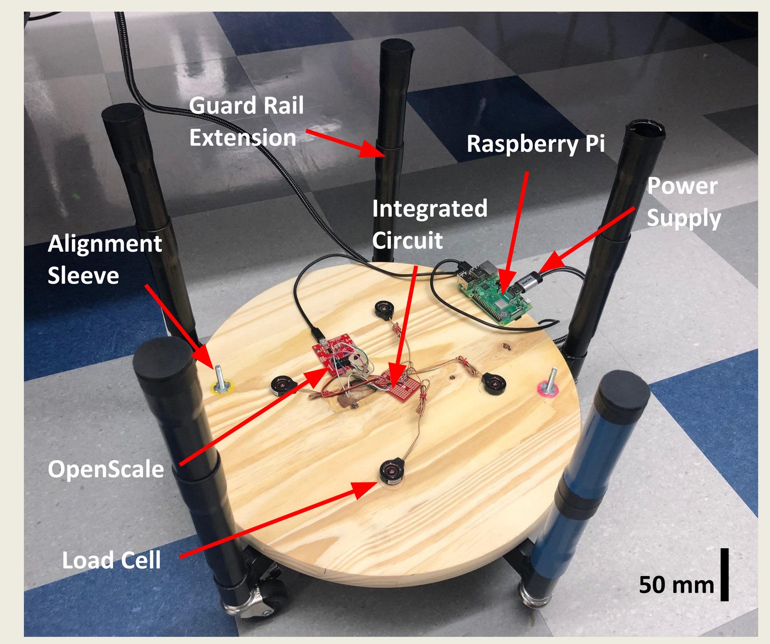
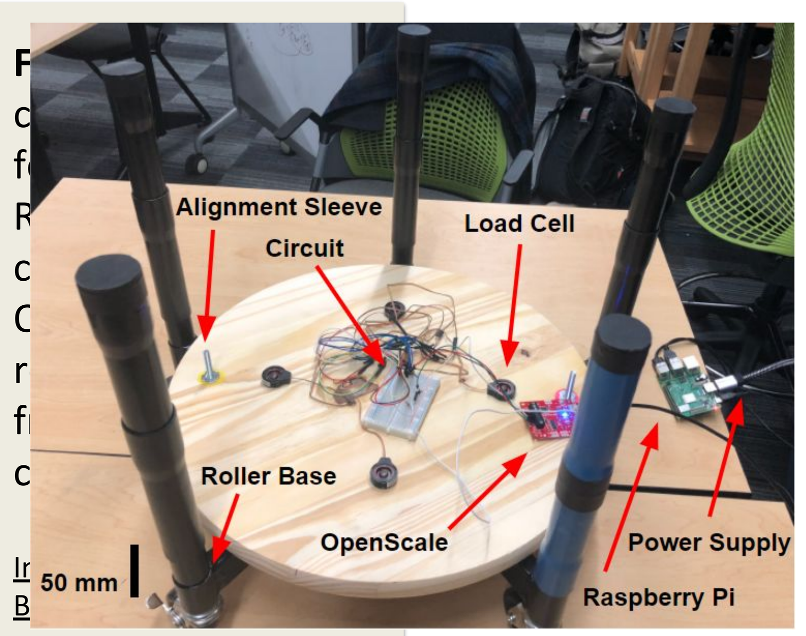
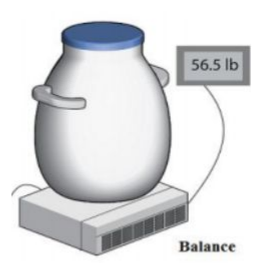
- General results: **linear change in weight over time; temperature remains relatively constant for any amount of LN2 (Figure 4)** - changes in temperature might be identified by changes in weight with more precise readings







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