Detecting LN2 Tank Failure with a Digital Scale Alarm Monitoring System

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Abstract

- Design a system to monitor and record the weight of LN2 tanks
  - Integrate with client's current temperature monitoring system to log data and send alerts about LN2 levels and leak rate
- The monitoring system should continuously monitor the weight of the tank, calculate the rate of loss of liquid nitrogen in real time, log data onto a remote platform, and send warnings regarding critical liquid levels, excessive leakage, and potential failures

Motivation

- Two recent tank failures involving the University Hospital Cleveland Medical Center in Ohio and Pacific Coast Fertility in San Francisco [1]
  - Serious legal, financial, and ethical repercussions
- Storage tanks for the cryopreservation of eggs, embryos, and sperm are the largest segment of the cryogenic equipment market based on product type
  - Expected to grow from USD 16.18 billion in 2016 to USD 22.42 billion by 2021, at a CAGR of 6.74% [2]

Background

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 [3]
- Health of tank crucial to specimen survival
- Insufficient LN2 from tank failure leads to loss of specimen
  - Requires real-time monitoring
- Current methods:
  - Yard stick: not real-time
  - Capacitance: imprecise
  - Temperature: non-linear
  - Ultrasound: expensive
- Weight monitoring:
  - Real-time, accurate

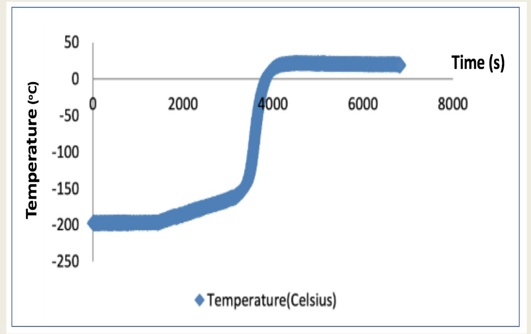

Figure 2: Temperature vs. time chart showing non-linear change in temperature w.r.t. amount of LN2

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

Final Design

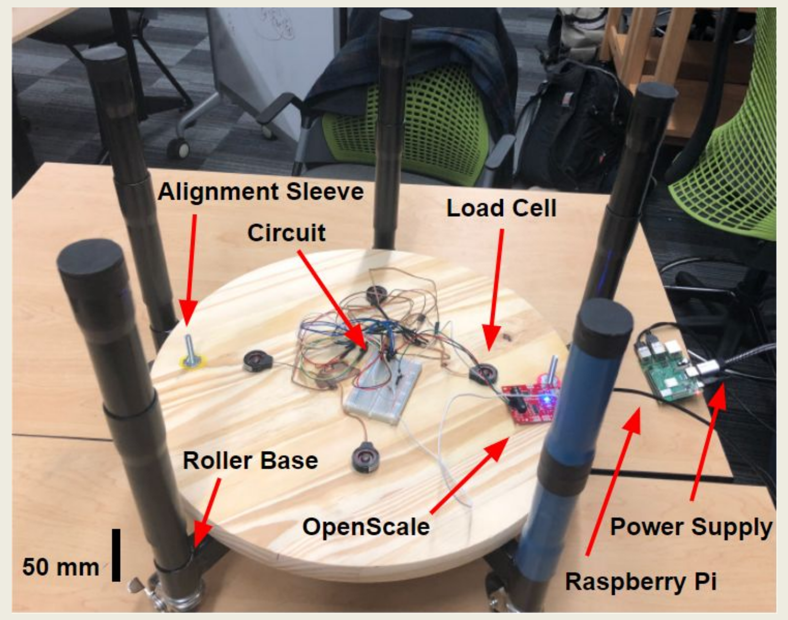

Figure 3: The custom scale features a Raspberry Pi connected to an OpenScale used to read the output from four load cells

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
- 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 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

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

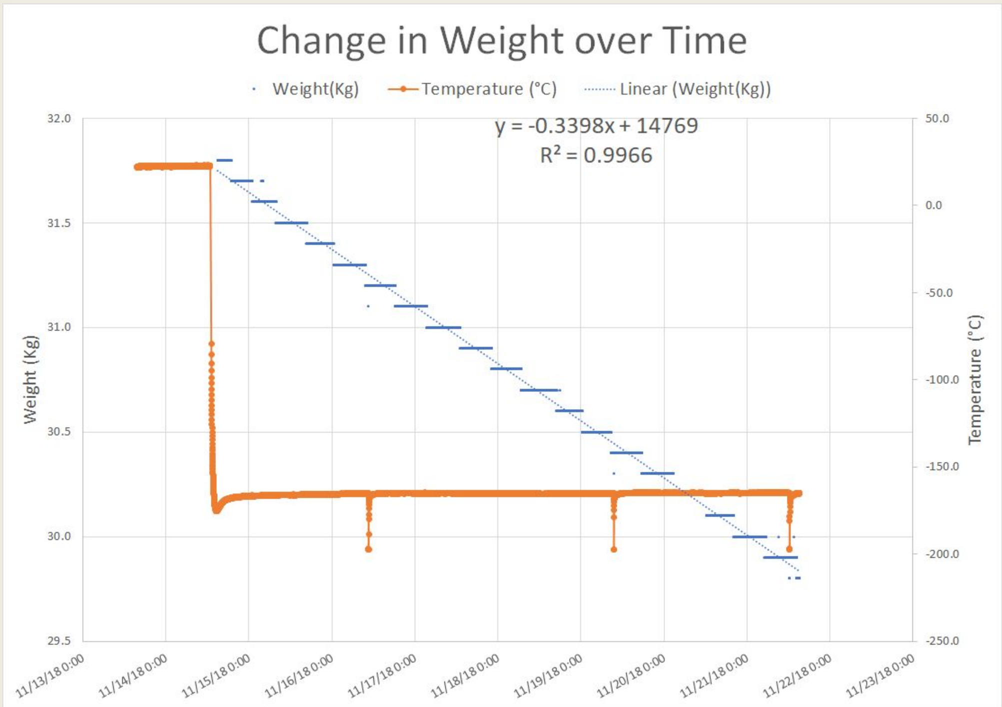

Figure 4: Graphing Weight and Temperature of our client's VHC35 LN2 tank from November 14th to November 21st

Data collected by:
Dr. Jeffrey Jones

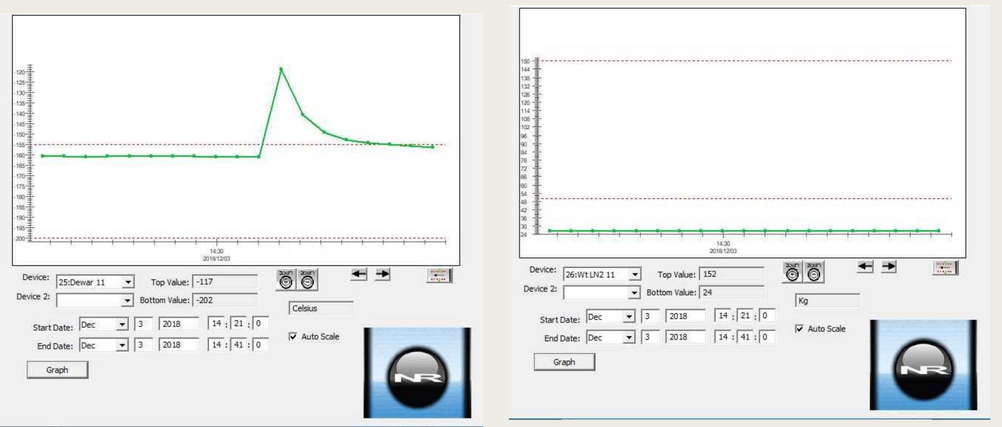

Figure 5: Graphs produced by NR's Tempurity Monitor upon addition of a single 0.02kg (20gm) specimen

Data collected by:
Dr. Jeffrey Jones

- 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

Predictive Monitoring

- "Smart" system - detect external events (sample removal, LN2 refilling, etc.)
  - Train the software from previous data; correlate specific values with events
  - Allows for more accurate monitoring
- Predict when the tank runs out of LN2
- Detect impending failure of the tank
  - Compare intrinsic leak rate to real-time leak rate

Future Work

- Improve aesthetic and create a box to house circuitry
  - Thin, metal plates with welded bolts to improve contact with load cells
  - Create a more compact circuit with a printed circuit & housing unit
- Program data logging and interfacing functionalities
  - Alarms at critical thresholds
  - ΔW/ΔT calculation every minute
- Develop predictive algorithm
  - Collect data from simulations to train algorithm
    - Record weight in 0.01 or 0.001 Kg increments
- Test device during extended use
  - Accuracy
  - Simulated failure scenarios
- Make system more user friendly
  - Eg. touchscreen or physical buttons
- Third-party collaboration
  - Networked Robotics
  - Lab/Fertility Clinics

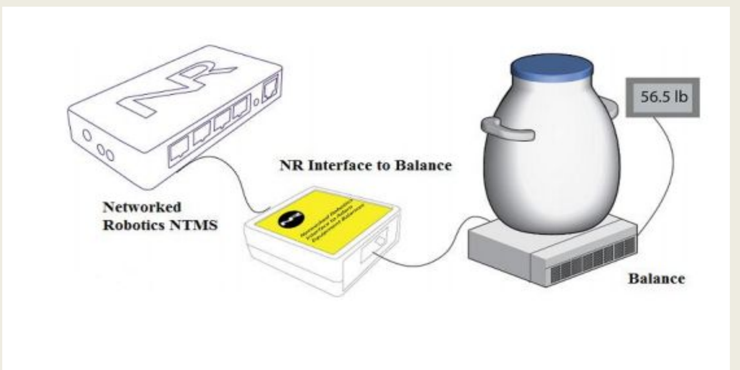

Figure 6: NR interface to custom scale

Image taken from:
Networked Robotics

Acknowledgements

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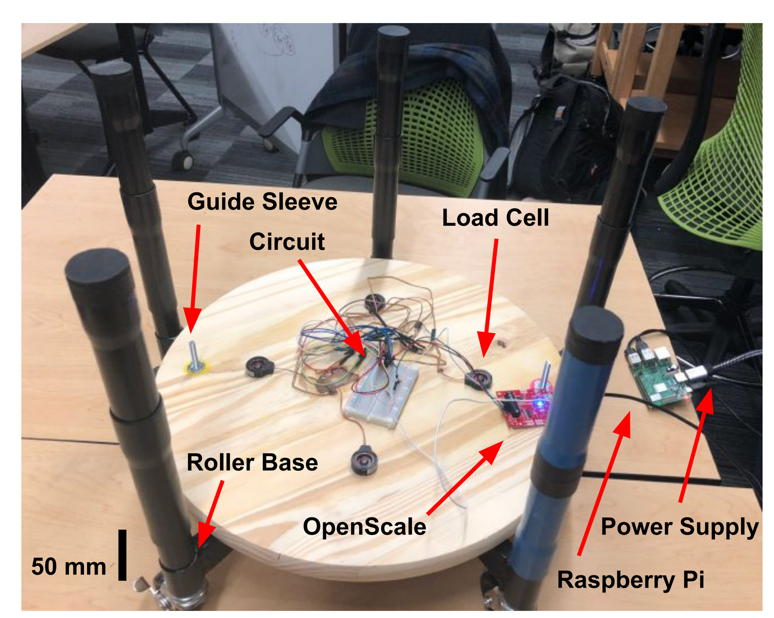
- Thank you to our advisor, Ms. Sarah Sandock, for guiding us through this project

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] ReportLinker (2016, September 14). Cryogenic Equipment Market by Product - Global Forecast to 2021 [Online].
[3] 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.



Prototype in Use

1. Hinge is inserted into neoprene sleeve
2. Align patellar cut-out in the sleeve with patella
3. Secure the sleeve
4. Align hinges with tibia and femur if necessary
5. Begin activities

Figure 7: Step 1

Figure 8: Steps 2-3

Figure 9: Step 4

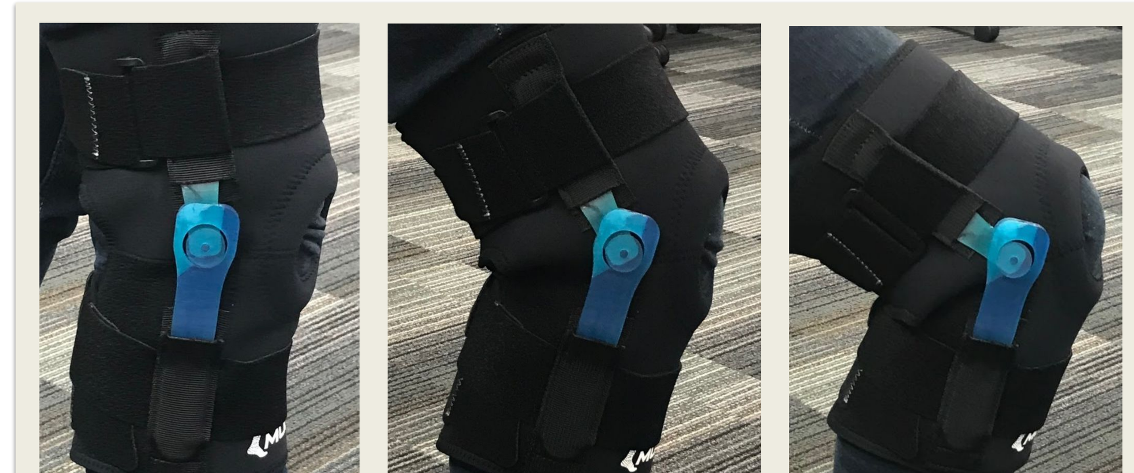


Figure 10: Step 5 - The hinge is in the sleeve, on the subject. The subject is performing activities leading to various degrees of knee flexion.