Neonatal Intensive Care Unit Pressure Ulcer Prevention Alert System

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Ally Wang
Jadyn Taylor
Youzi Bi
Tiya Madhavan

Abstract and Index terms
Infants in neonatal intensive care units (NICU) require constant monitoring. When left immobile in these units, constant pressure applied to an infant's skin can cause damage to surrounding tissues, enabling "pressure ulcers." Therefore, a system was developed to alert clinical workers to reposition infants. Using a load cell sensor and Arduino Leonardo, prolonged immobility of weight could be monitored, providing staff with a repositioning alert system for their infants. A temperature and humidity sensor was integrated to report NICU environmental conditions. Our system was able to detect a 1.1 kg weight simulating a laying infant, coupled with a repositioning timer that triggers an LED alert. Therefore, using a load cell sensor and temperature/humidity sensor is an effective way to detect and alert for conditions conducive to pressure ulcer formation. The proposed system is worth developing as it has the potential to reduce the risk of pressure ulcers in NICU infants.

Index terms: pressure ulcers, NICU, NICU monitoring system

Introduction
Neonatal intensive care units (NICUs) care for premature and fragile infants who often require prolonged bed rest, continuous monitoring, and the use of medical devices. Although these interventions are necessary, they can also place sustained pressure on an infant's delicate skin and underlying tissue, increasing the risk of pressure ulcers [1]. Pressure ulcers are localized injuries caused by prolonged pressure, and are especially concerning in newborns due to their underdeveloped epidermal barrier and limited tissue protection compared to older children and adults [2]. Our project specifically aims to improve early monitoring and timely intervention for prolonged pressure exposure in NICU infants. Rather than waiting until visible skin damage occurs, we propose a low-cost alert system that detects when an infant has remained in one position for too long and notifies caregivers that repositioning is needed. In addition to pressure-related load sensing, the device also monitors environmental factors associated with skin integrity, namely humidity and temperature. Recommended NICU humidity is approximately 70–80% for vulnerable neonates, while a typical thermoneutral temperature range is 72–76 °F (22–26 °C) [3,4]. Repositioning is also an important preventative strategy, with a 2-hour interval serving as a practical target within the broader 2-to-4-hour range reported for pressure-injury prevention [5]. By integrating load sensing with temperature and humidity monitoring, the system is designed to identify and alert for conditions that may contribute to skin injury before ulcer formation begins. This biomedical application is significant because it supports preventative care in a vulnerable patient population, and offers a simple and financially accessible tool for continuous monitoring.

Experimental Setup
Hardware:
The base of the load-detecting part of the device consists of a 5 kg strain-gauge load cell [6], which is mounted between rigid plastic 3D-printed base and top plates [7]. 3D-printed M4x0.70 screws [8] and duct tape were used to secure the base and top plates to the load cell. The load cell's differential output is conditioned and digitized by a HX711/ADC Module load cell amplifier, which feeds into the Arduino Leonardo microcontroller. The red wire from the load cell sensor fed into E+ on the HX711, the black wire to E-, the green wire to A+, and the white wire to A-. The HX711 is connected to the Leonardo via a two-wire digital interface (DAT and SCK on HX711 to pins 7 and 8 on Arduino), along with VCC/VDD and GND on the HX711 connected to 5 V and GND power on the Arduino, respectively. Connections to the HX711 were done with male to male jumper wires soldered on the HX711 for stability. Ambient temperature (℃) and relative humidity (%RH) are captured by the Grove Temperature and Humidity TH02 sensor, which connects to the Leonardo via the I²C bus (SDA/SCL) and for 5 V and GND power via jumper wires. The Leonardo handles sensor acquisition, signal processing, taring and calibration, and output control. Particularly, the built-in orange LED on the Leonardo (shown in Figure 1b) is used as a visual alert for time since the last reposition that exceeds the threshold. The Leonardo plugs into a laptop, and the 5 V power supply on the Leonardo is used to power the HX711 and TH02 sensor through

distribution organized by an intermediary breadboard. The sensing components of the device are enclosed in a clear unit, similar to standard NICU units, for temperature and humidity control.

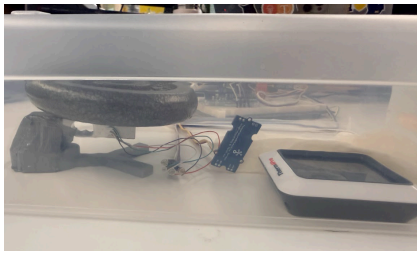
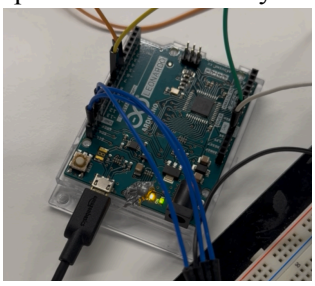
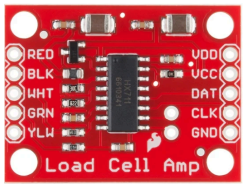
(a)  (b)  (c) 

Figure 1: (a) Load cell and temperature/humidity sensor setup under clear bin. (b) Arduino Leonardo with LED. (c) HX711 load cell amplifier/ADC module [9].

Software:

The device software was written in C++ using the Arduino IDE and implemented on an Arduino Leonardo to control sensor acquisition, taring and calibration commands, reposition detection, timer tracking, and LED alert output. The program uses the Wire.h library for I2C communication with the temperature/humidity sensor and HX711.h to interface with the load cell amplifier, averaging 10 weight readings per cycle to improve stability. The load cell is initialized with a calibration factor and tared at startup, and serial-monitor commands were included for taring, calibration with a known mass, calibration-factor adjustment, sensor-offset entry, and manual timer reset during testing. Reposition detection is based on a three-state logic system (UNOCCUPIED, OCCUPIED_STABLE, and LIFT_IN_PROGRESS). When the measured load exceeds 0.20 kg, the system records a baseline weight and enters the occupied state; a lift is detected when weight falls below 20% of baseline for at least 1500 ms, and a repositioning event is confirmed when weight returns above 60% of baseline for at least 1500 ms. To avoid false detections, the code also applies an empty threshold of 0.05 kg with a 500 ms debounce period. The software continuously tracks the elapsed time since the last confirmed repositioning event and activates a repeating LED warning pattern when the preset maximum interval is exceeded; in the current proof-of-concept code this interval was set to 30 seconds for testing, although the intended clinical interval is 2 hours. Our program supports real-time environmental monitoring by repeatedly sampling temperature and humidity data from the digital sensor through the I2C interface during each execution of the loop. The measured raw values are converted into calibrated temperature and relative humidity readings, which are then made available for live serial output and future alert logic. This continuous sensing approach allows the system to track changes in the patient's local environment as they occur (tempC: temperature in Celcius, rh: relative humidity, alertCode: indicator of whether the baby should be repositioned). The "alertCode" has 6 states: 0 = AC_NORMAL, 1 = AC_T_BELOW_22, 2 = AC_T_ABOVE_26, 3 = AC_RH_BELOW_70, 4 = AC_RH_ABOVE_80, 5 = AC_TIME_OVER_2H. If alertCode = 5, it means the patient has not been repositioned for longer than the maximum allowed interval (**Figure 2**). Overall, the software provides the control logic necessary for real-time monitoring, event detection, and caregiver alert generation in the simulated NICU pressure-ulcer prevention system.

```
ms=496743,kg=0.856,state=1,secSinceReposition=373.6,tempC=24.14,rh=35.7,alertCode=5
ms=497617,kg=0.856,state=1,secSinceReposition=374.5,tempC=24.13,rh=35.7,alertCode=5
ms=498493,kg=0.856,state=1,secSinceReposition=375.3,tempC=24.15,rh=35.7,alertCode=5
ms=499367,kg=0.856,state=1,secSinceReposition=376.2,tempC=24.14,rh=35.7,alertCode=5
ms=500243,kg=0.856,state=1,secSinceReposition=377.1,tempC=24.14,rh=35.8,alertCode=5
ms=501117,kg=0.857,state=1,secSinceReposition=378.0,tempC=24.13,rh=35.7,alertCode=5
ms=501992,kg=0.857,state=1,secSinceReposition=378.8,tempC=24.14,rh=35.7,alertCode=5
ms=502867,kg=0.857,state=1,secSinceReposition=379.7,tempC=24.13,rh=35.7,alertCode=5
ms=503742,kg=0.857,state=1,secSinceReposition=380.6,tempC=24.15,rh=35.7,alertCode=5
ms=504617,kg=0.857,state=1,secSinceReposition=381.5,tempC=24.14,rh=35.7,alertCode=5
```

Figure 2: Sample Arduino IDE Serial Monitor Output

Experiment protocol

Several sets of tests were conducted to validate the load detection, overtime since last repositioning alert, and temperature/humidity detecting capabilities of the system. To test load detection, we tared and calibrated the load cell setup with a 1.1 kg weight, and ensured that the serial monitor displayed near 0 kg

when the weight was removed, and displayed near 1.1 kg after putting the weight back. The 1.1 kg weight was placed on the platform for controlled periods of time over three trials to simulate a laying infant for validation, and to ensure the LED blinking alert begins once the preset time threshold is exceeded. The threshold was modified from 2 hours to 30 seconds for ease of testing. The system was further tested after each trial by lifting the weights briefly to ensure the system detects lift events and resets the LED alert and time since last reposition timer to display as “NA”. Environmental testing was conducted to ensure the system can identify temperature and humidity changes accurately. Heated wet paper towels were placed in the plastic bin to simulate a humid NICU environment over a range of humidities, across which we recorded values from the Arduino IDE serial monitor output and a commercial reference temperature/humidity sensor. Temperature and humidity thresholds were temporarily edited in the code to test for correct alert code display on the serial monitor, as it was difficult to simulate temperatures outside of the 70-80 °F range.

Results

We successfully ensured that after taring and calibration, the serial monitor consistently displayed 0 ± 0.005 kg when the weight was removed, and 1.1 ± 0.005 kg when the 1.1 kg weight was placed on the platform for all subsequent testing. For the LED alert system, we tested with a time threshold of 30 seconds to achieve the following results:

Table 1: Test for LED Alert System

Trial Number	Weight displayed (kg)	Reposition Time (s)	LED blink?	LED reset and secSinceRepositio n = N/A after weight removed?
1	1.100	30	YES	YES
2	1.100	30	YES	YES
3	1.100	30	YES	YES

Humidity and temperature testing achieved the following results:

Table 2: Test for Humidity and Temperature

Trial Number	Reference Sensor Humidity (RH%)	Experimenta l Humidity (RH%)	Humidity error (%)	Reference Sensor Temperature (°F)	Experimenta l Temperature (°F)	Temperature error (%)
Baseline	56	53	5.660	73.4	73.292	0.147
1	65	67.2	3.385	72.5	71.96	0.745
2	69	73	5.797	72.5	72.032	0.646
3	74	81	9.459	72.1	71.744	0.494
4	77	92	19.481	73	73.778	1.066

Average error across all trials for humidity measurements was 8.756%, and average error for temperature measurements was 0.620%. Additionally, we were able to verify that alert codes displayed on the serial monitor matched the expected codes according to displayed temperature/humidity and the thresholds set in the code.

Discussion and Conclusion

Multiple infants in an NICU may need repositioning at different times, which can be challenging for healthcare workers to track. Neglecting to move an immobile infant may lead to the formation of pressure ulcers. Therefore, incorporating an alert system in NICUs can help healthcare workers significantly reduce the risk of pressure ulcer formation and provide a reliable monitoring system that does not rely on human memory. By notifying healthcare workers with a blinking LED when the time threshold is exceeded and displaying temperature and humidity values, our system can succeed in aiding healthcare systems to combat pressure ulcer formation in NICU infants. Several challenges were encountered during the development. One of the primary difficulties was ensuring the software operated reliably, particularly in calibrating the load cell and maintaining accurate weight readings over time. Additionally, synchronizing the LED with the timing logic took multiple iterations of Arduino code to ensure it consistently activated after exceeding the 30-second threshold. The humidity sensing portion of the system also posed challenges, as the experimental humidity readings diverged from those of the reference sensor as humidity levels increased during testing. This discrepancy is likely due to differences in sensor response time and enclosure conditions: the reference sensor was encased, causing it to respond more slowly to environmental changes, while our experimental sensor was exposed and therefore more sensitive and immediately responsive to fluctuations. As a result, simulating controlled humidity levels within the desired NICU range proved difficult and led to larger errors, limiting the precision for this component of our system. If given more time and resources, several improvements could be made to enhance the system's functionality, performance, and clinical applicability. Enclosing the experimental and reference sensors under identical conditions would allow for more standardized humidity reading testing by equalizing response time and measurement reliability of the reference sensor. Additionally, a multi-modal alert system, rather than merely an LED, could be implemented. This could include audible alarms or wireless notifications to a caretaker's device given a larger budget, improving usability and convenience in a busy NICU environment. Given more time, extending the testing duration to the intended clinical timeframe (2-hour intervals) and testing with varying weights to simulate different sized NICU infants would further validate our system. With these improvements, the device has strong potential to evolve from a proof-of-concept into a practical tool for enhancing neonatal patient care and reducing preventable pressure-related skin injuries.

Application

This device has the potential to be very impactful in NICUs. Incorporation in NICUs provides a dependable monitoring system. Real-time tracking of stationary laying and environmental conditions is provided and signaled to healthcare workers. Healthcare workers then know to reposition their patients promptly or take steps to adjust temperature and humidity, reducing the risk of pressure ulcer formation. Additionally, it not only has a biomedical impact but also has an economic impact as well. Taking preventative measures to reduce the risk of pressure ulcer formation has the added benefit of ensuring infants stay in these units for a limited time. Further injuries can leave infants in these units for longer periods and require additional treatment, which can increase the cost of care for parents. Therefore, these consistent monitoring systems have the potential to increase the safety of infants and reduce further treatment costs in NICUs, enabling a safer healthcare environment. As a future direction, further validation should include testing the device with real infants in an actual NICU setting, representing the final step before broader clinical implementation.

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