Integrated System to Monitor Dairy Calf Feeding Behavior for Pre-Clinical Detection of Disease

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Project Title: Integrated System to Monitor Dairy Calf Feeding Behavior Monitoring System for Pre-Clinical Detection of Disease

Abstract

An automated milk bottle monitoring system was designed and evaluated to address pre-clinical detection of disease and other health issues in dairy calves. Veterinary and animal behavior scientists increasingly recognize changes in feeding behavior as an early identifier of potential health issues, so identifying such behavioral change may reduce mortality and enhance overall animal wellbeing. A bottle monitoring system was designed to measure different feeding behavior characteristics of young dairy calves. Specific indicators identified by experts and monitored by this system were milk consumption rate, period between peak flowrates, total time to consume a bottle, and various bottle dynamic measurements as indicators of the aggressiveness of an animal's feeding pattern. Overall design constraints included the following: no modifications to the bottle, no external power source, and wireless data collection from a large number of bottle holders. A low-power system equipped with accelerometers and force sensors was designed to measure and record feeding characteristics. Each unit wirelessly transmits data to a central storage location using low-power RF radios. Software was developed in MATLAB to synchronize recorded data with corresponding video to allow experts to validate performance. Testing of the bottle monitoring system was conducted at the University of Tennessee's Dairy Research & Education Center, and the results show that the milk bottle monitoring system can capture the desired dynamic feeding attributes necessary for early detection of diseases commonly found in infant dairy calves, such as aspiration, pneumonia, diarrhea, and septicemia.

Acknowledgements

We would like to thank our advisor, Dr. John Wilkerson, for giving us the support needed to engineer a successful design. Dr. Maria Prado of the UT Vet. Med. Center provided animal behavioral expertise through the duration of our project. Charlie Young of the UT Little River Animal and Environmental Unit for allowing access to the UT Dairy for testing. Mr. David Smith of BESS ordered electrical components and designed the circuit boards contained by each data collection unit. Mr. Scott Tucker of BESS helped us machine the inner aluminum sleeve that was used by the data collection units. Thanks also to BESS for the financial support of this project.

Table of Contents

Need and Purpose

A current substantial financial and animal well-being issue in the dairy industry is disease and early death of un-weaned calves during this most susceptible and critical phase in the life of a dairy calf. During this period calves are highly vulnerable to various disease-causing pathogens commonly found in their environment. According to Dr. Maria Prado, a large animal veterinarian in the UT Animal Science Department, the three most important disease problems affecting young calves are pneumonia, diarrhea, and septicemia. Despite improved management practices, morbidity and mortality in dairy calves during this period are still significant. Ability to identify disease and other health issues in the early stages of development would allow producers to intervene promptly, increasing the chances of success for the treatment and decreasing the negative impact of these conditions on subsequent productivity. Death of un-weaned heifer calves is especially detrimental to the dairy industry because these calves grow to be milk-producing cows.

There is currently no commercial monitoring system that can predict when a given calf is becoming sick. Dairy farmers instead rely on visual inspections of calves made by the workers during feeding. These visual diagnoses are usually based on calves either showing little interest in feeding or not coming to feed at all, and this behavior is generally not easy to spot in early stages of illness. As a result, the un-weaned heifer calf mortality rate is around 8 percent of calves born, causing an appreciable loss to dairy farmers, in addition to the cost of veterinary care for calves that are treated for disease and recover (USDA, 2010). Therefore, an inexpensive early detection system for sickness could be of significant financial benefit to dairy farmers around the country.

The overall goal for this project is to identify disease and other health issues in dairy calves before a farmer can by developing a cost-effective system that monitors their feeding behavior, which according to animal experts is often an early indicator of illness or other health issues. The proposed design can be implemented with minimal adjustments made to standard calf feeding systems and with almost no impact on the calves or operators. It will also consolidate all data into one system such that software can later be developed to notify operators directly if any abnormalities in calf behavior are detected, allowing immediate reaction to potential health issues.

Approach

In order to develop a feeding behavior monitoring system, the team had to observe and understand the feeding process utilized by dairy operations. This design project will be based on the feeding process used by the University of Tennessee's Little River dairy farm, which uses individualized hutch bottle feeding as opposed to an automated group feeding system. Based on the UT dairy's system, the dairy calf is immediately separated from its mother after birth and is placed in an individual hutch. Each hutch contains a small pen area enclosed by metal panel fencing. A plastic bottle holder is zip-tied to the panel fencing, and a two-liter or three-liter milk bottle (depending upon the calf's age) is placed into the holder twice a day for the calf to feed from. Farm caretakers remove the bottles once the calves are finished feeding and wash each bottle for sterilization. Calves stay in the hutches until they are about six weeks old, at which point they are moved to a larger pen and managed using a group feeding system. For this project, the design will be created such that it accommodates the hutch feeding process.

Having established a basis for the method in which dairy calves are fed, the design can be divided into two sub-categories that address the overall goal:

1. Establishment of the feeding attributes indicative of dairy calf health concerns;
2. Design of a system that can collect and transmit feeding data.

The first part of this project to be addressed is to determine how normal dairy calf feeding behavior can be quantified, and what deviations from normal are symptomatic of impending disease. Having consulted with Dr. Maria Prado, a University of Tennessee large animal veterinary specialist, it was determined that the following feeding attributes should be obtained by the system:

1. *The time it takes for the calf to begin feeding after the bottle has been placed in the bottle holder.* This attribute directly relates to the eagerness of the calf to feed. Healthy calves begin feeding almost immediately following the insertion of the milk bottle into the holder, while unhealthy calves will sometimes show little to no interest in the bottle, resulting in the farm caretakers having to get inside its hutch and lead the calf to its bottle.
2. *The time it takes for the calf to empty the bottle.* This attribute is related to overall calf appetite. Healthy calves will be able to finish the bottle significantly faster than sick calves will be able to finish. Furthermore, healthy calves will drink all of the milk within the bottle, whereas calves with health issues may not drink all of the milk.
3. *The number of starts and stops in each feeding event.* Healthy calves typically will not release the bottle until all of the milk is consumed. Conversely, a sick calf—especially those with respiratory infections—may take a number of breaks while it feeds in order to obtain the oxygen it needs.
4. *The overall aggressiveness of the calf feeding.* In natural feeding, calves will aggressively butt their mother's utter. This causes hormones within the cow to signal the brain to release milk from the utter to the feeding calf. In hutch bottle feeding, this aggressive behavior can be seen at the end of feeding events. Once a calf has consumed all of the milk within its bottle, it will tug on the empty milk bottle to try to obtain more milk.
5. *The fluid flow patterns generated as the calf drinks*. As calves feed, movement of neck muscles used for swallowing generate a drinking frequency. Typically, this frequency will be around 2 Hz and may change as the calf becomes ill.

The measured value for each of these five attributes will vary with age as well as varying slightly from calf to calf, so analysis of collected information should consider calf age as well as previous feeding habits to establish whether or not deviation indicates health concerns.

The second part of this project involves construction of a physical device to collect data required to measure these five attributes. The three primary components of the device are:

1. Power supply;

2. Data system, consisting of sensors transforming physical responses into digital data, and storage of resulting information;
3. Data transmission system.

Design Criteria

In overall system design, the team had to take into account a variety of mentor and client requirements. For example, the data collection method that is chosen must be able to indicate all five attributes of calf drinking listed earlier with a reasonable degree of resolution., An observer with minimal training must be able to accurately read the data produced. In addition, to be flexible enough to work on a range of facilities, the data transmission system must be able to link individual monitors with a central data collection system up to 200 ft. from calf hutches. A central collection system will collect and process feeding data to detect potential illness. Finally, the power supply for each unit must be able to run the system for at least one year.

For the feeding behavior monitoring system to be considered successful, it must be able to meet a number of design criteria and limitations. First and foremost, the device monitoring calf feeding behavior must not modify the actual bottle from which a calf is being fed. Bottles are machine and/or hand washed regularly, so any bottle modification would result in a major impact on normal practices. The design must therefore solely modify the bottle holder and only interact with outer surfaces of the bottle, ensuring that the bottle can be removed and washed with ease. Furthermore, implementation of those holder modifications should be such that they have minimal impact on day-to-day activities of calf caretakers and the calf feeding process.

With those constraints in mind, design of the system should be such that it can measure feeding attributes discussed above to a reasonable level of accuracy. Also, it should incorporate wireless, low-power technology. As previously mentioned, the system should be able to wirelessly transmit collected feeding data to a central storage location. From there, farm operators should be able to easily access collected data via an internet server.

Another important aspect of the design is to keep overall production cost below $100 per unit for a run of 1000 units. In order for this detection system to appeal to farmers, they must be confident that the initial price they are paying for the system will be worth the money recovered by the number of calf lives that are saved as well as the reduction in veterinary costs. Therefore, it is essential that the system is cost-effective.

Engineering Design

The most important feature of the design is the data collection system. Although the information transmission, storage, and interface are important, they simply exist as a framework through which a user can access the data captured by the data collection system, so collecting worthwhile data is paramount. Several methods were considered and analyzed based on ability to acquire data related to the five desired feeding attributes. Some of the initial designs considered include:

1. Modeling the bottle and milk as a capacitor by attempting to measure its capacitance to detect changes in the milk level.
2. Using infrared beams to detect the height level of the milk.
3. Sending ultrasonic vibrations through the bottle and measuring the resonance.

However, after establishing cost estimates for designing each of the above systems as well as keeping in mind overall design criteria, it was decided to explore other options for data collection.

- **Inner Sleeve and Sensor Design**

After a number of discussions with the project mentor, the team decided on an approach using a thin independent sleeve suspended within the bottle holder using a slender rod connected to a load cell (see Figure 2). Dynamics of the bottle are transferred to the sleeve and measured using both the aforementioned load cell and an accelerometer. A microcontroller manages the data collection process. Data storage and transmission are handled by an SD card, clock, and RF radio (see Figure 1).

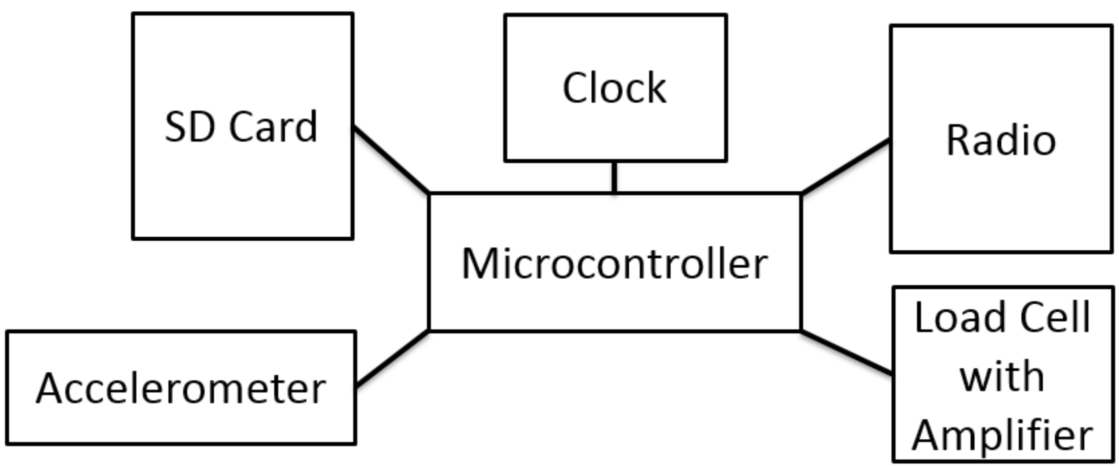


Figure 1: Basic layout for electronic components in data collection system. Each component is managed by a microcontroller.

This inner sleeve is necessary because it allows the load cell to measure downward forces exerted on the milk bottle by the calf as well as gravitational forces exerted as a result of milk within the bottle. Suspending the sleeve within the holder using a load cell via a slender rod captures these forces. Please see Appendices A and B for the sleeve strength design, and for analysis using a finite-element approach. Taking into account dimensions of the bottle holder, the sleeve is designed such that plastic inserts are attached exterior to the sleeve, allowing the sleeve to fit snugly within the plastic bottle holder. Also, because plastic inserts have a low coefficient of friction when interfacing with aluminum, inserts allow for movement within the bottle holder.

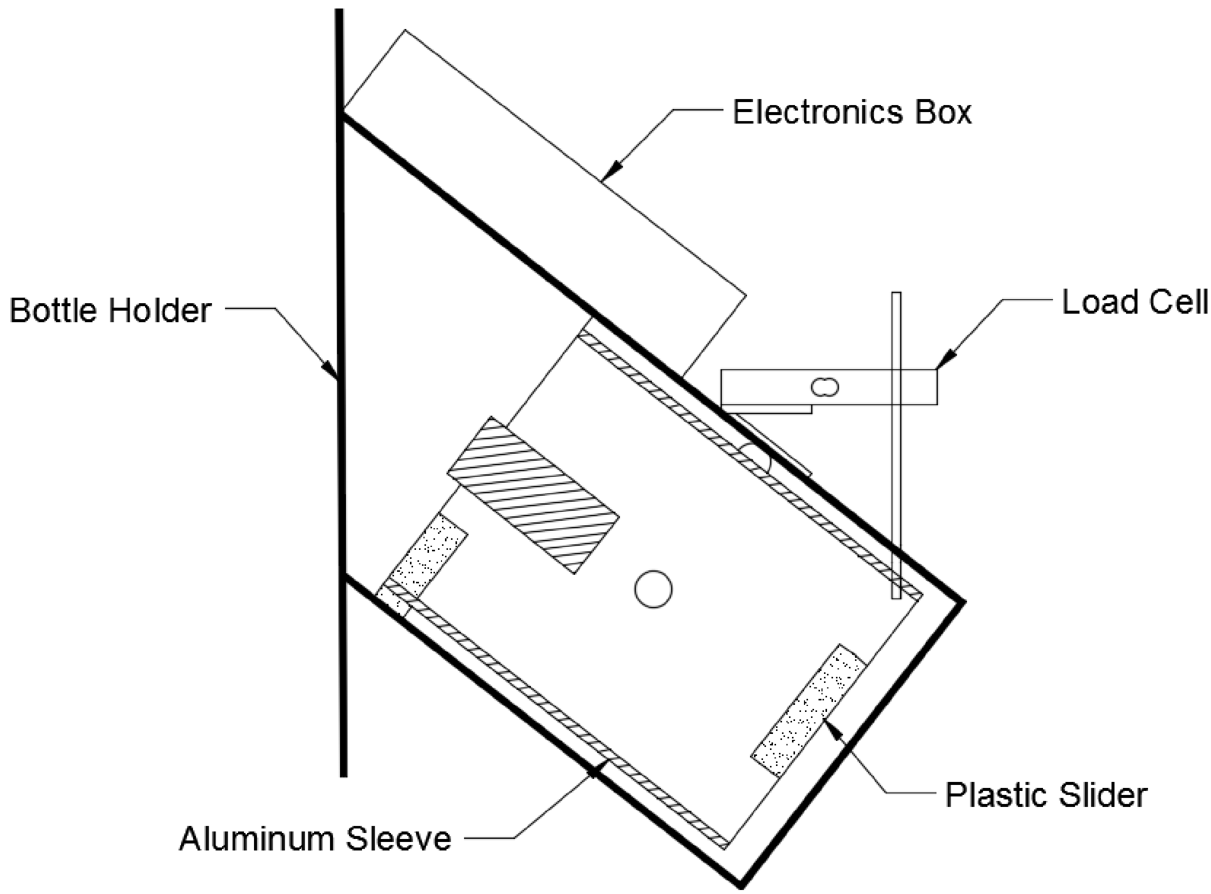


Figure 2: Cross-section of sleeve inside of a bottle holder, with a load cell attached at top-center of the sleeve via a slender rod. Also depicted are plastic sliders mounted to the sleeve, as well as an electronics enclosure and load cell mounted to the top of the bottle holder.

A TAL220 beam type load cell with maximum load capacity of 22 lbs and output rating of 1.0 ± 0.15 mV/V was selected. In addition to a load cell, the design uses a MMA8451 low-cost accelerometer mounted on the inside of the sleeve. This accelerometer provides a way to capture the dynamics of the bottle during feeding and generates data that assists in addressing all five of the established feeding attributes that the data collection system is measuring. Additionally, its ability to send an interrupt signal when movement is detected provides a method of alerting an Arduino Pro Mini microcontroller to the presence of a bottle. This capability allows the system to enter a low power mode when no bottle is present, thereby conserving energy.

Low energy usage is important because the entire system will be run from three disposable D-cell alkaline batteries wired in series. These batteries will provide 4.5V, which will need to be regulated down to the 3.3V required by the electronic components.

- **Data Logging and Communication System**

The accelerometer is always on, as it draws an extremely low current of 0.4 mA and is capable of waking the microcontroller. Upon waking, the microcontroller begins sampling from both the accelerometer and force sensor and writing the collected data to an SD card (see Appendix D). The microcontroller will also periodically wake up and check the real-time clock (DS1307) in order to check if it is time to transmit data to the central collection unit. When it is time to transmit, the microcontroller wakes the radio and transmits data from the SD card via a 2.4 GHz XBee radio to the collection system, which will store feeding data (see Appendix D). Each hutch will be scheduled to transmit at a different time, so there will be no interference between multiple hutches. A schematic of the printed circuit board used to connect the various electronics can be seen in Appendix C.

Selection of a transmission device is also important to power usage, as there are vast differences in consumption level for various devices. Although the team considered using WiFi modules due to their low cost, XBee radios were chosen instead based on their significantly lower energy requirement.

- **Electronics Enclosure**

Finally, it is important that all devices and components fit neatly into a self-contained package, allowing them to be weather resistant and prevent damage due to everyday activities like washing out the calf hutches. Also, the combination of all components should be designed such that if any part of the system malfunctions the entire box can be exchanged for a new one with minimal operator effort. We selected the "See-Through Washdown Enclosure" from McMaster-Carr to house our electronics.

Design Testing

- **Data Collection Unit**

In order to verify that the load cell and accelerometer can capture feeding data, the team developed a prototype system using a sleeve made from 1/8 inch x 1 inch pieces of stock aluminum. Members were cut to size and assembled such that the sleeve would fit snugly around the milk bottle. As seen in Figure 3, the sleeve was constructed to allow little side-to-side movement between sidewalls of the bottle holder. An accelerometer was inserted on the upper inside corner of the sleeve and wires were fed through the back of the bottle holder to a microcontroller, thus keeping all wires protected from the calf.

Figure 3: Prototype sleeve alone (left) and within the bottle holder (right).

To protect the load cell from the calf during testing, a piece of rectangular tubing was mounted to a tripod stand, allowing the load cell to be cantilevered over the panel fence and mounted directly above the bottle holder. Aluminum wire was used to suspend the sleeve from the load cell. Output wires from the load cell were inserted into pins on a load cell amplifier before being fed into a microcontroller. For this preliminary testing, a laptop was used to power the load cell, the accelerometer, and retrieve data from the microcontroller. Collected data was then saved as a text file. Additionally, to aid in the analysis of data, video of the feeding process was captured. Figure 4 shows the entire prototype setup in operation at the UT dairy.

Figure 4: Prototype system in use during field testing at the Little River dairy.

- **Data Analysis**

Collected load cell and accelerometer data were read from the saved text file and opened in Excel. Prior to comparing feeding data to video, the team attempted to determine the five feeding attributes directly from the data. Knowing that the insertion of the bottle into the bottle holder would result in an increase in force on the load cell as well as acceleration, the first major event corresponds to the bottle being placed into the holder. The next identifiable event is the calf latching-on to the bottle. Time to approach would be the difference in time between the bottle entering the holder and the calf latching-on.

The number of starts and stops that the calf takes can be seen by analyzing the decreasing trend in the force data, understanding that during this period any abrupt decrease in force/acceleration followed by a sudden increase in force/acceleration corresponds to the calf slipping off the nipple and then latching back on. Next, overall aggression corresponds to the amplitude of the force/acceleration data while the calf is playing with the bottle. Also, fluid flow pattern corresponds to the rate at which the calf is swallowing milk. This frequency is expected to be approximately 2 Hz based on previous observation of feeding. Data is captured at a rate of 10 Hz, allowing the capture of 5 events per cycle, well above the Nyquist Sampling Rate.

Finally, it must be identified when the bottle is empty. This "empty" point can be located via two major occurrences. Knowing that as the calf drinks, overall volume in the bottle will decrease, this point of emptiness would lie where the force data begins to plateau. Also, based on observation, once the calf has finished feeding, it begins aggressively pulling on the bottle in a sporadic manner. Therefore, the calf playing with the bottle indicates "bottle empty" has occurred.

The team then used video to verify timestamps of key feeding events. It was determined that predicted timestamps match actual values within 1.2 seconds (see Table 1), and therefore the load cell / accelerometer combination provide a viable method to obtain the desired feeding attributes.

Furthermore, during preliminary testing, the team was able to collect data from a calf that had been diagnosed as sick. This data set allowed the team to compare typical feeding attribute numbers measured for healthy dairy calves to those of sick calves. Appendix E shows the data set obtained for the sick calf in parallel with a healthy calf of similar age.

- **Freshman Apprentice Data Analysis**

Six students in assigned to the team by the Biosystems Engineering 104 class helped with preliminary data analysis. One of the desired outcomes of this system is that an operator with limited instruction / knowledge about the data collection system be able to analyze collected feeding data and identify desired feeding attributes. With no advance training, each apprentice was given a data set and instructed to identify the timestamps for when the bottle was inserted into the bottle holder, each time the calf latched-on to the bottle, and when the bottle became empty. However, apprentices had difficulty identifying those events within given data sets.

The BsE 104 students were then given a ten-minute instructional lecture on how to interpret the data sets and key events they should be looking for. Each apprentice was then given a new data set and asked to evaluate it based on knowledge they received from the lecture. Comparing these new timestamp results to timestamps recorded by the team, each apprentice's timestamp was within one to two seconds of the actual event time as acquired from the video. These results prove that even an operator with no prior knowledge of how to analyze feeding data can perform adequate analysis after receiving a brief lecture on the process.

Final Product Construction

After using the prototype design to prove that the components within the bottle holder system can obtain the desired data, the team constructed the final data collection unit. This was done by mounting the electronics box (containing the batteries and circuit board) and load cell to the top of the bottle holder, with the accelerometer mounted to the inside of the aluminum sleeve contained within the holder. Figure 5 shows three images of the implemented data collection unit at the Little River dairy.

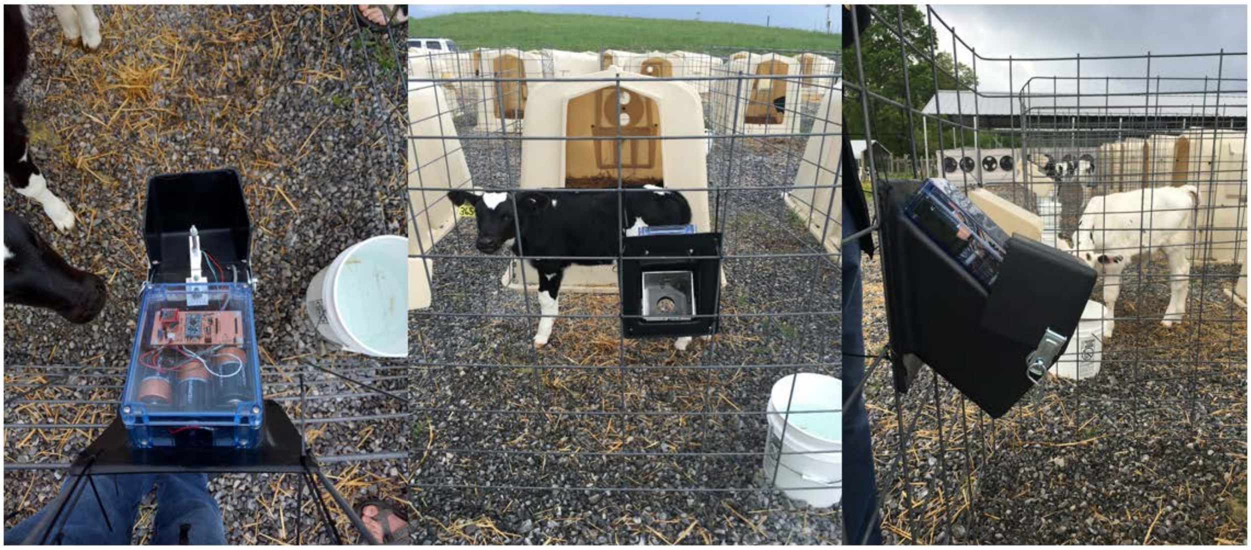


Figure 5: Three images of the installed final design data collection unit.

Results and Analysis

In order to verify that the bottle holder system could repeatedly collect valuable feeding data, the team selected eight data sets for analysis. Video taken for each feeding event was used to obtain the “truth-value” for the timestamps associated with the bottle entering the holder, the calf latching onto the bottle, and the bottle being empty.

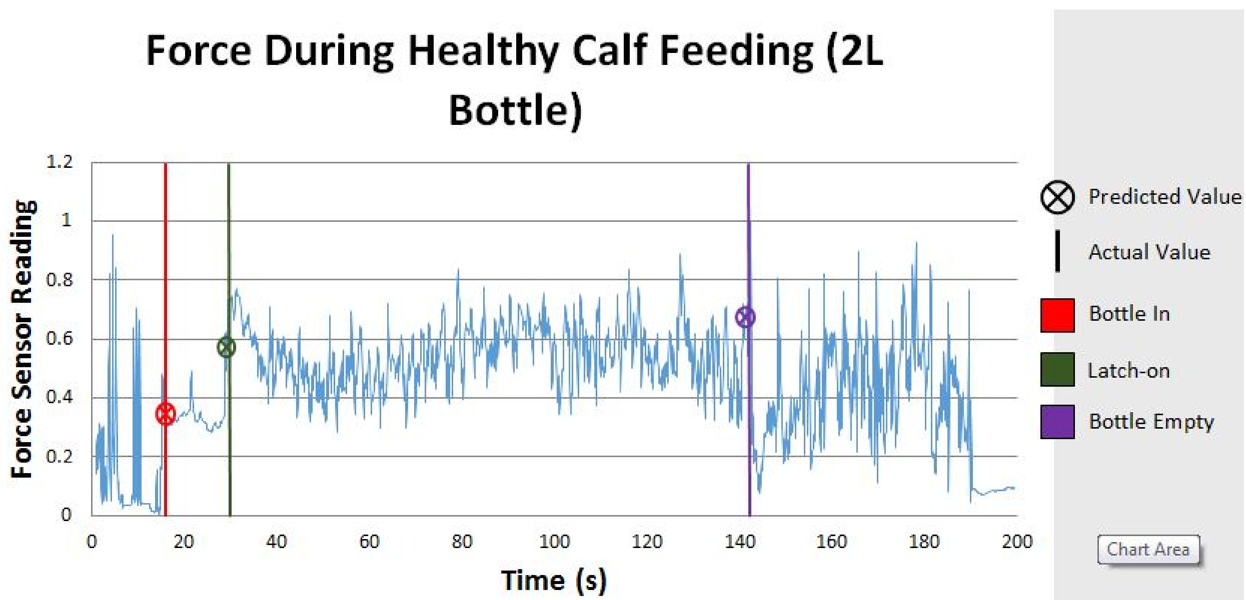


Figure 6: Data set of a healthy calf feeding from a 2-liter milk bottle.

The team attempted to predict feeding attributes by observing data produced by the system. Figure 6 shows the predicted times for the bottle entering the holder, the calf latching onto the bottle, and the bottle being empty for one of the datasets used. Also shown are the actual values for these attributes, as determined by analyzing video of this feeding event.

Table 1: Associated average margin of error for the predicted and actual time values of the various signature events analyzed within the eight data sets. The median time of consumption for these feeding events was 146.5 seconds, with a minimum time of 97 seconds and a maximum time of 633 seconds.

Data Collected	**Variance(seconds)**
Bottle In	0.6
Time of Latch-Ons	1.2
Bottle Empty	7.2

Table 1 shows the variance between predicted and actual values for the time at which the bottle enters the holder, the time at which latch-ons occur, and the time at which the bottle is empty. For bottle in and time of latch-ons, the team was able to get within $\pm$ 1.2 seconds of actual times, which shows that signature events of data sets can be identified within a reasonable margin of error. Although variance is significantly larger for detecting bottle empty, this result is not alarming. There was significant variance within the "actual" time of bottle empty due to difficulty in visually confirming via video that the bottle was empty. Therefore a large variance between predicted and actual is to be expected.

Conclusions and Recommendations

After analyzing data collected by the monitoring system, it can be seen that the design can successfully capture dairy calf feeding data by using a load cell in conjunction with an accelerometer. Also, signature events within captured data demonstrate that the design can be used to identify key feeding attributes significant for pre-clinical disease detection. Furthermore, the design was constructed in a cost-effective manner that kept overall production cost below $100 per unit for a run of 1000 units, a breakdown of which can be seen in Appendix G.

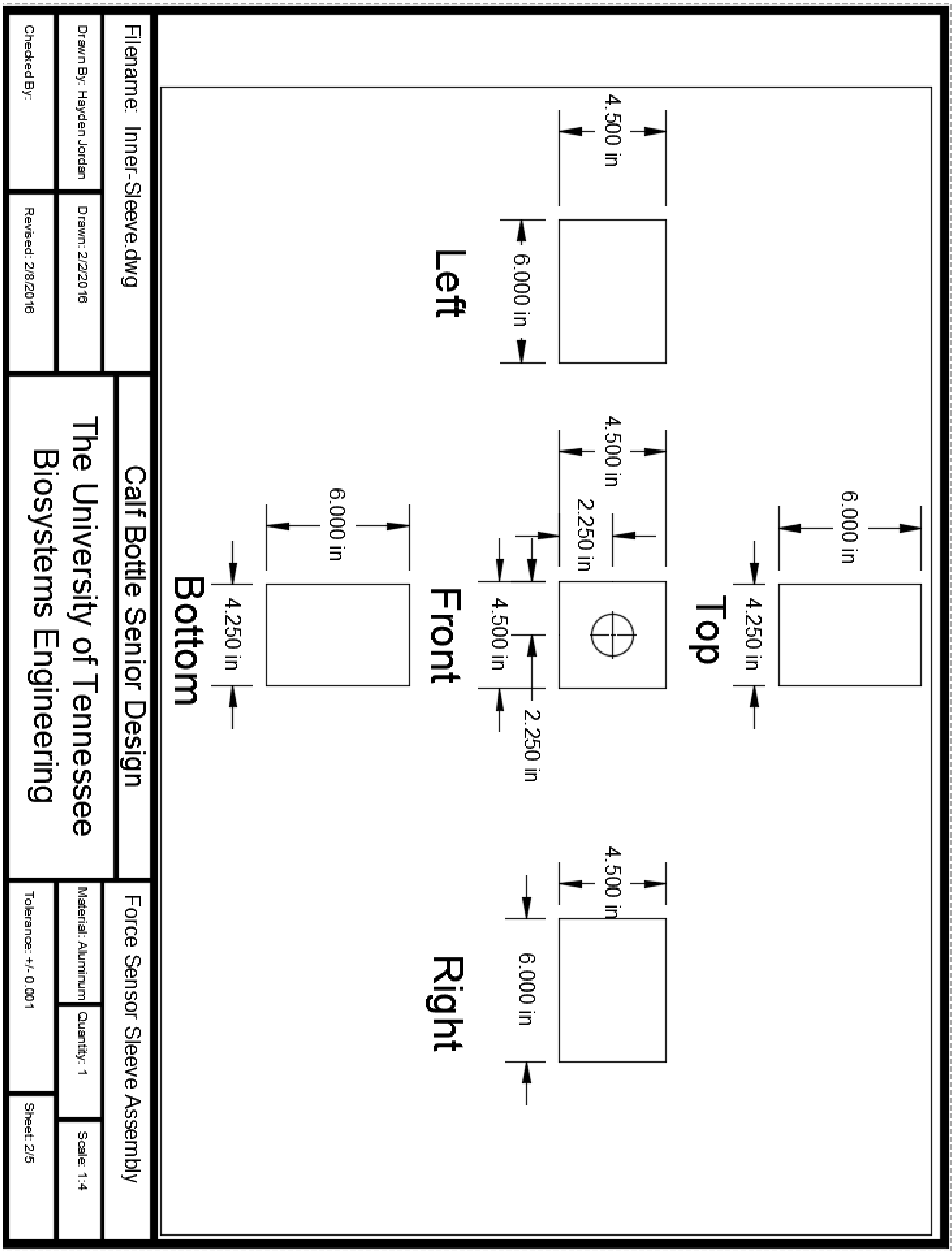
It is recommended by the design team that future product development continue by collecting feeding data from a large number of dairy calves, ranging in both age and size and uploading this collected data to a central storage location or server. Using this data, software can then be created such that it can analyze real-time feeding data and recognize signature changes in an individual dairy calf's feeding pattern, correlating to poor calf health. Additionally, a system that would alert farm operators of potential calf health issues should be constructed and integrated into the overall design.

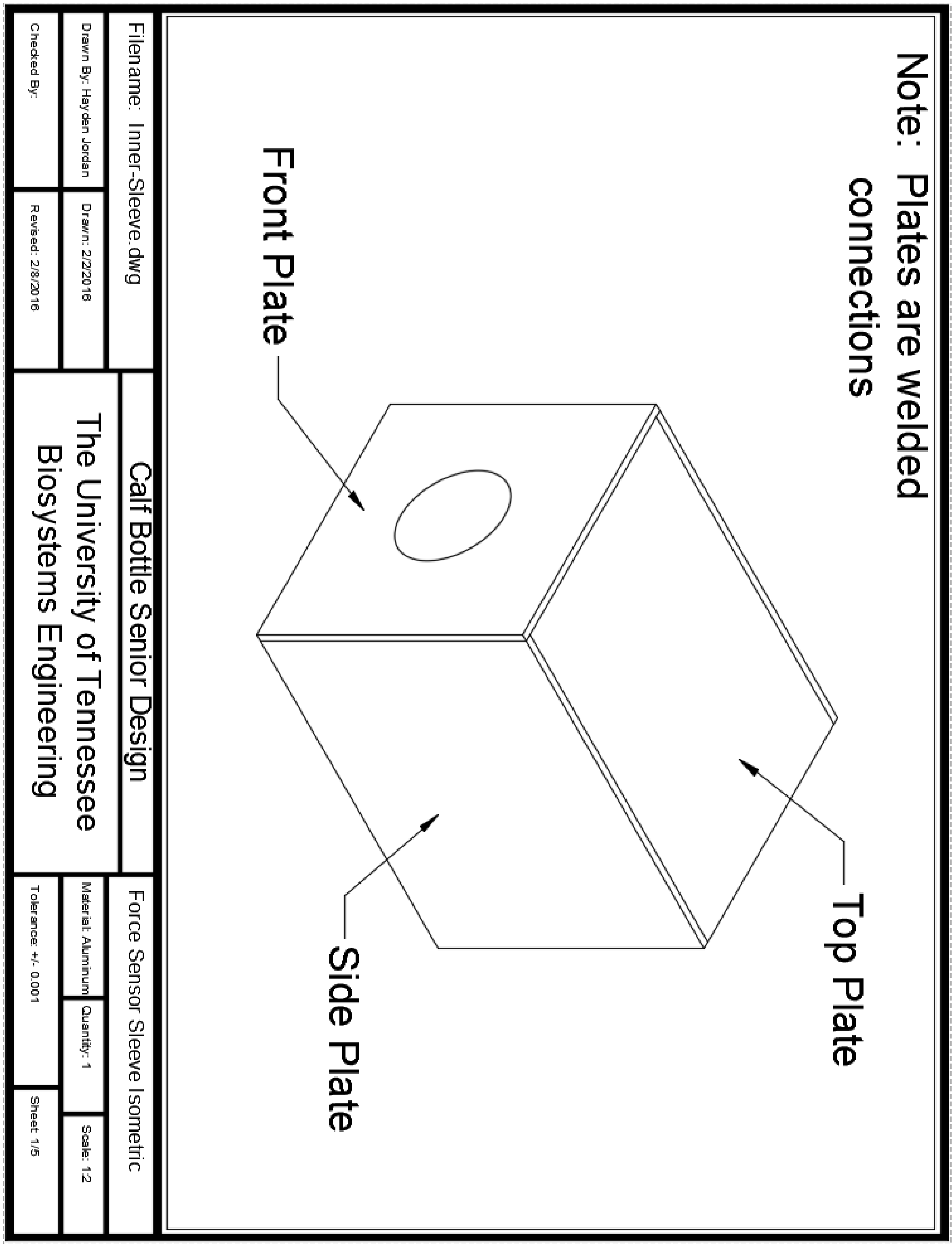
References

USDA. 2010. Heifer Calf Health and Management Practices on U.S. Dairy Operations, 2007.

United States Department of Agriculture. Fort Collins, CO.

Appendix A: AutoCAD Inner Sleeve Drawings



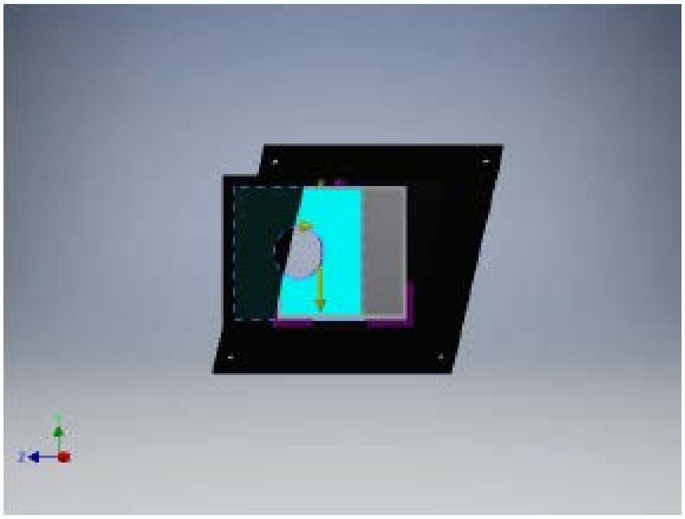


AutoCAD drawings used in constructing the aluminum sleeve component of the data collection system. The first drawing is an orthographic drawing of the sleeve while the second drawing is isometric.

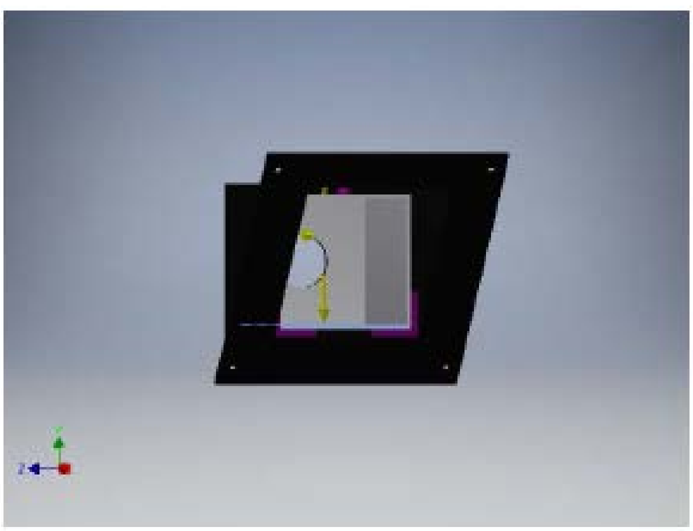
Appendix B: Inventor Professional 3D Force Simulation

Force:1

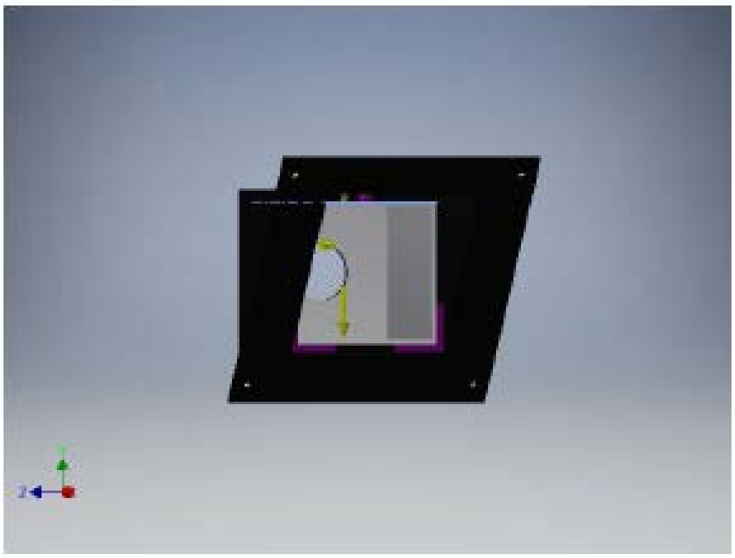
Load Type Force
Magnitude 10.000 lbforce
Vector X -10.000 lbforce
Vector Y 0.000 lbforce
Vector Z 0.000 lbforce



Force:2
Load Type Force
Magnitude 15.000 lbforce
Vector X 0.000 lbforce
Vector Y -15.000 lbforce
Vector Z -0.000 lbforce



Force:3
Load Type Force
Magnitude 5.001 lbforce
Vector X 3.080 lbforce
Vector Y 3.940 lbforce
Vector Z 0.000 lbforce

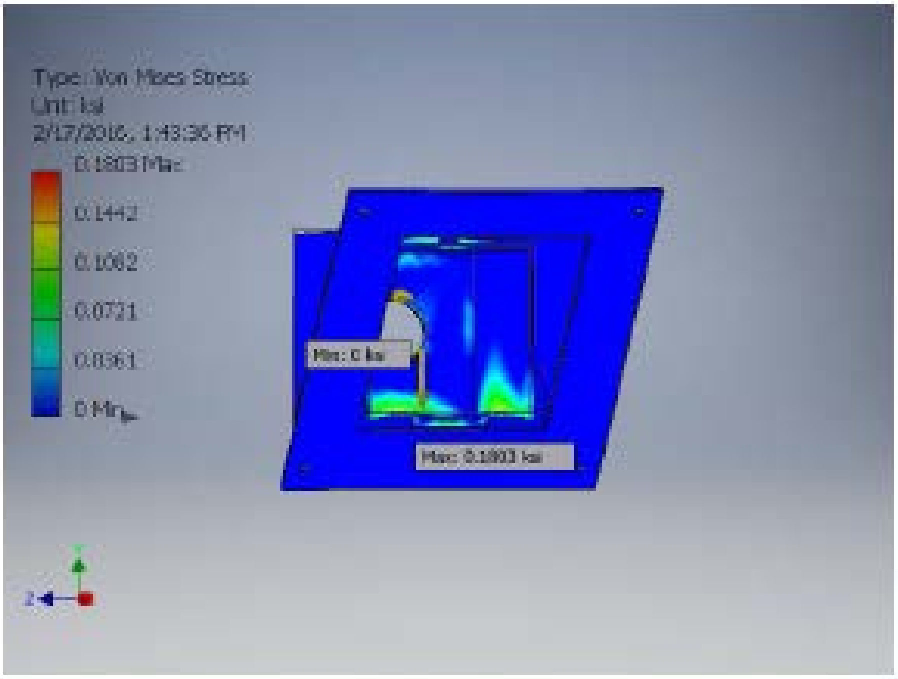


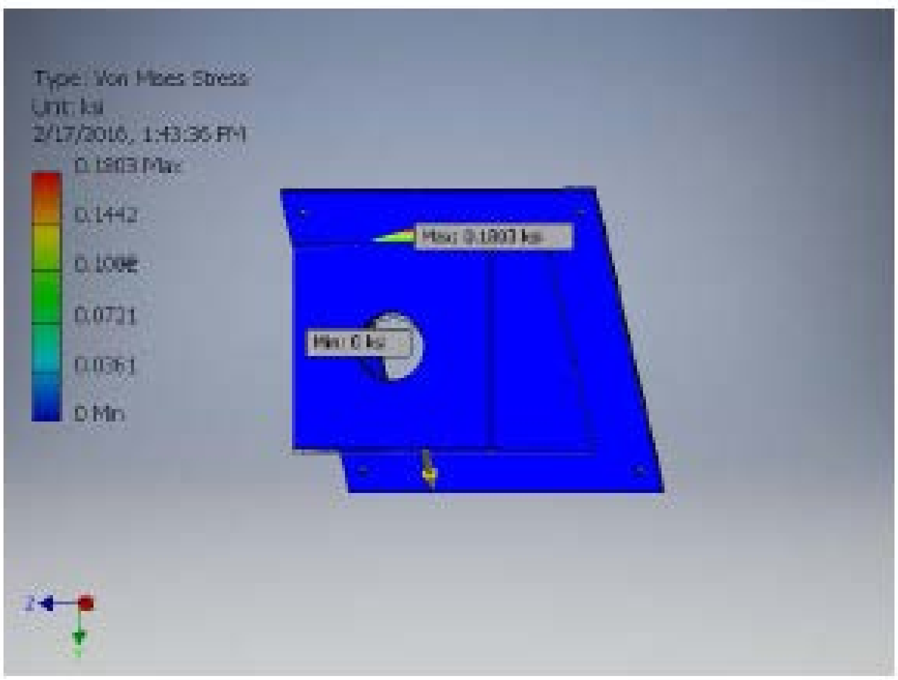
Simulation of feeding events in Inventor Professional 3D software. Forces correspond to three major forces acting on bottle holder. Force 1 corresponds to maximum force that dairy calf will exert on the system. Force 2 represents maximum downward force that calf and bottle weight apply to the holder. Finally, Force 3 depicts force that the load cell is exerting upwards on bottle holder.

Result Summary

Name	Minimum	Maximum
Volume	48.2191 in^3	
Mass	2.68099 lbmass	
Von Mises Stress	0.00000294581 ksi	0.180282 ksi
1st Principal Stress	-0.0294483 ksi	0.200433 ksi
3rd Principal Stress	-0.194949 ksi	0.0679884 ksi
Displacement	0 in	0.000423326 in
Safety Factor	15 ul	15 ul
Stress XX	-0.153372 ksi	0.149861 ksi
Stress XY	-0.0486163 ksi	0.056139 ksi
Stress XZ	-0.0777917 ksi	0.0784999 ksi
Stress YY	-0.158863 ksi	0.170873 ksi
Stress YZ	-0.0552582 ksi	0.0549074 ksi
Stress ZZ	-0.194949 ksi	0.200432 ksi
X Displacement	-0.000102332 in	0.0000331167 in
Y Displacement	-0.000423311 in	0.0000772277 in
Z Displacement	-0.00011569 in	0.000115688 in
Equivalent Strain	0.0000000207504 ul	0.000475119 ul
1st Principal Strain	-0.00000285426 ul	0.000372787 ul
3rd Principal Strain	-0.000473446 ul	0.000000720193 ul
Strain XX	-0.000223595 ul	0.000221567 ul
Strain XY	-0.000314175 ul	0.00027201 ul
Strain XZ	-0.000188543 ul	0.000166545 ul
Strain YY	-0.000397944 ul	0.000361607 ul
Strain YZ	-0.000193323 ul	0.000210577 ul
Strain ZZ	-0.000144316 ul	0.000233518 ul
Contact Pressure	0 ksi	0.827537 ksi
Contact Pressure X	-0.232457 ksi	0.817845 ksi
Contact Pressure Y	-0.152039 ksi	0.082753 ksi
Contact Pressure Z	-0.279759 ksi	0.307433 ksi

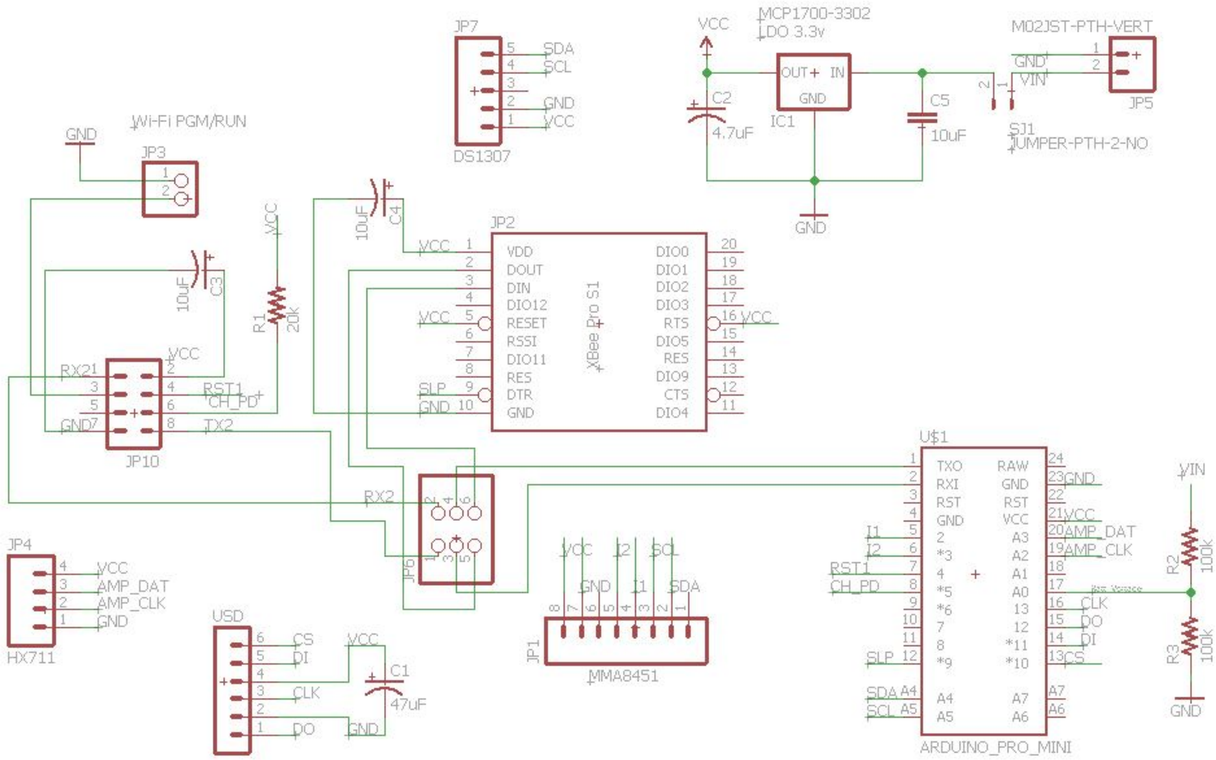
Summary of simulation conducted by Inventor for given design with aforementioned applied forces. In particular, the safety factor for design speaks volumes about overall safety of our system. Under given constraints, the system has an overall factor of safety of 15, which is acceptable and can be considered as over-designed.





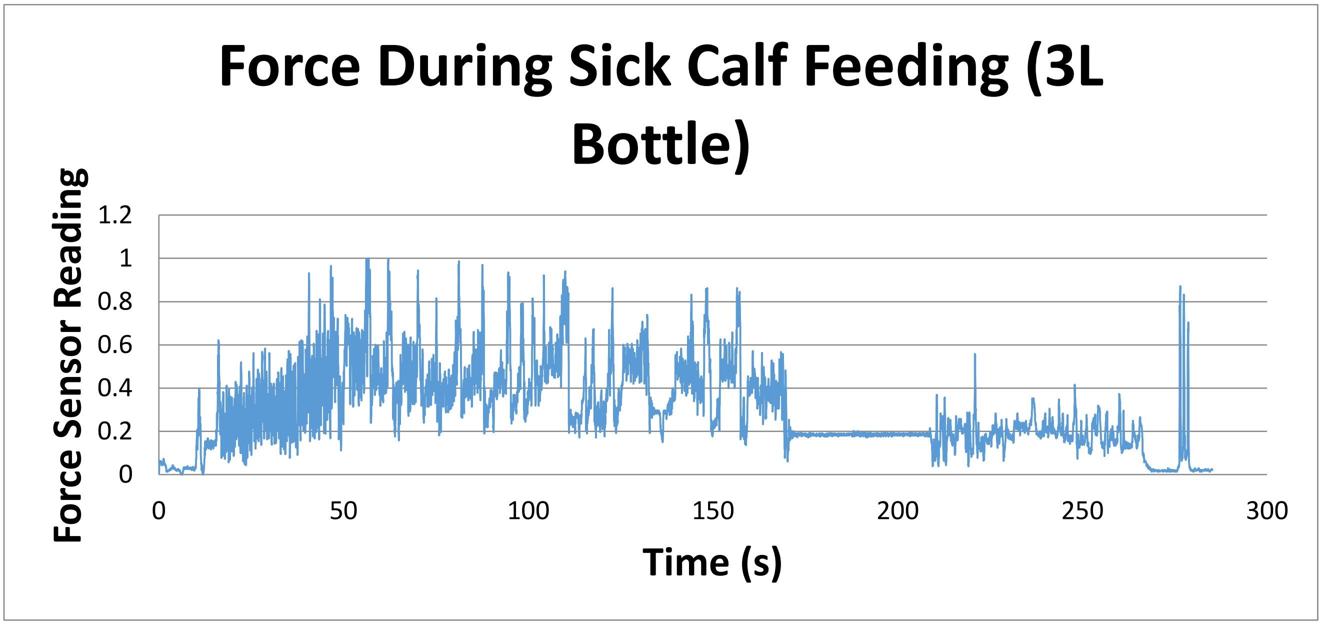
Images generated in Inventor and depict Von Mises stresses seen at various points on bottle holder system. Colors represent a given range of stress, and stresses increase in magnitude as color goes from blue to red. As it is a goal to keep the maximum value of Von Mises stress induced in material less than its strength, this analysis shows that the maximum Von Mises stress seen in the system is 180.3 psi. As this is well below the respective yield strengths of materials used in the design, the design is not likely to fail.

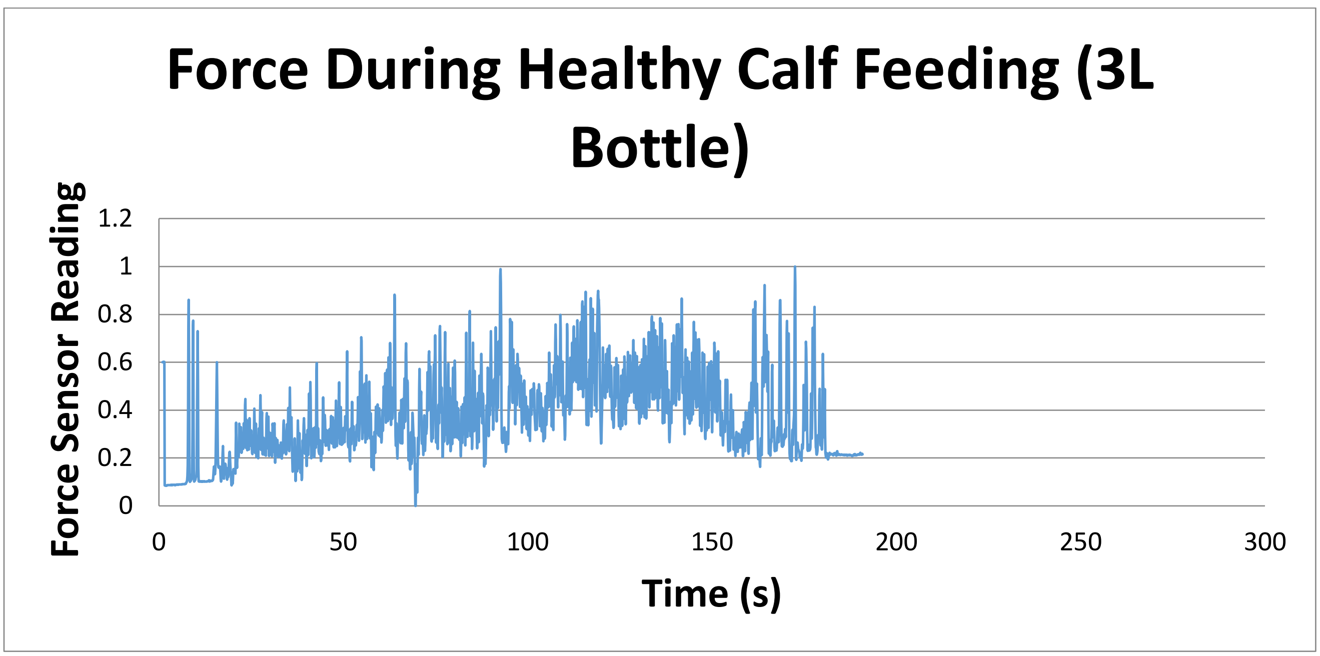
Appendix C: Data Collection System Electronics Schematic



Schematic for printed circuit board that will have electronics mounted to it. Board connects Arduino Pro Mini to XBee radio, accelerometer input, load cell amplifier, real time clock, and SD card as well as providing connections for power input through a 3.3V voltage regulator.

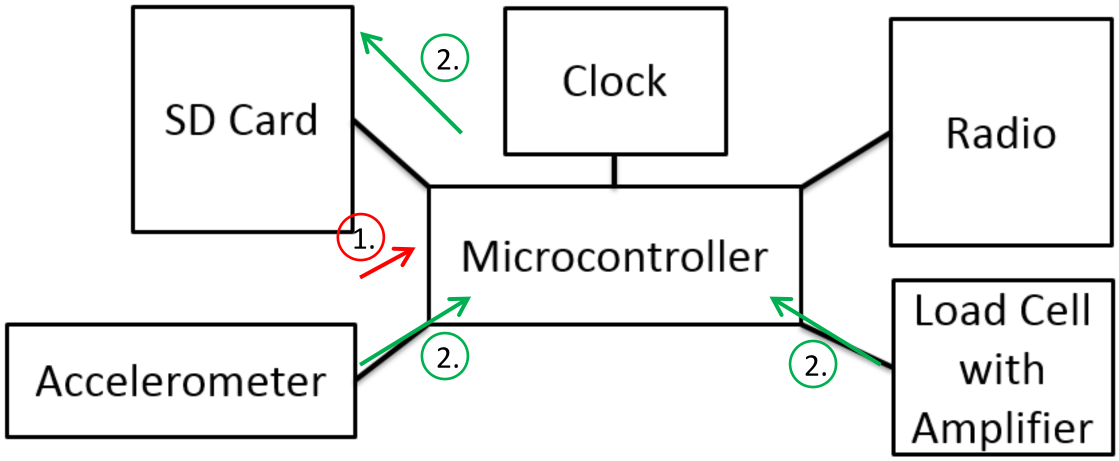
Appendix D: Sample Sick and Healthy Calf 3-Liter Data





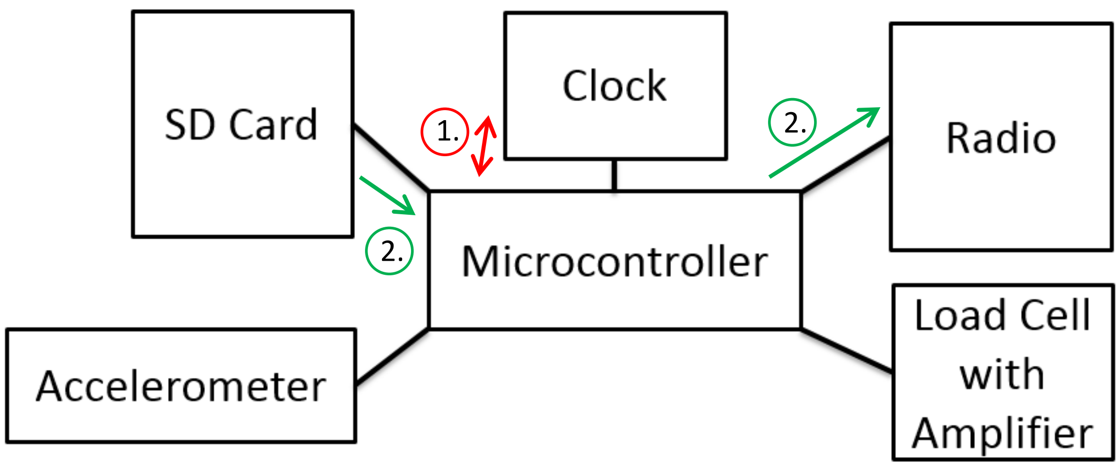
Two collected data sets for a healthy calf and a sick calf feeding from 3 liter bottles. Sick calf has a longer overall time of consumption as well as a large number of latch-ons during feeding process. These two graphs show that data collection system generates feeding data that can be used to distinguish between a healthy dairy calf and a sick dairy calf of similar ages.

Appendix E: Logic Flow Diagram



Representation of system as it collects feeding data.

1. Accelerometer detects movement due to a bottle entering holder and sends a signal to microcontroller.
2. Microcontroller collects data from accelerometer and load cell amplifier at a rate of 10Hz and saves this data to a SD card.



Representation of system as it transmits feeding data.

1. Microcontroller checks clock and compares given time to scheduled transmission time.
2. Current time is nearly equal to scheduled transmission time, so microcontroller reads data from SD card and transmits it to collection unit via radio.

Appendix F: Unit Cost Budget

System Component	Part	Retail Price	OEM Price	Number Required	Cost
Hutch Unit					
	Bottle Holder	$ 11.73	$ 8.00	1	$ 8.00
	Aluminum/Plastic Sleeve	$ 260.00	$ 8.00	1	$ 8.00
	Load Cell Amplifier	$ 9.95	$ 8.46	1	$ 8.46
	Load Cell	$ 6.95	$ 6.26	1	$ 6.26
	Mounting Bracket	$ 0.95	$ 0.75	1	$ 0.75
	Beads	$ 0.32	$ 0.20	2	$ 0.40
	Spring	$ 0.05	$ 0.04	1	$ 0.04
	Machine Screws	$ 0.42	$ 0.21	2	$ 0.42
	Bolt	$ 0.90	$ 0.50	1	$ 0.50
	Nut	$ 0.26	$ 0.10	2	$ 0.20
	Arduino Pro Mini	$ 9.95	$ 8.46	1	$ 8.46
	Xbee Radio	$ 24.95	$ 22.46	1	$ 22.46
	Accelerometer	$ 9.95	$ 8.46	1	$ 8.46
	Electronics Box	$ 22.19	$ 11.00	1	$ 11.00
	Battery Holder	$ 2.14	$ 1.71	1	$ 1.71
	D-cell Batteries	$ 1.62	$ 0.35	3	$ 1.05
	Bumpers	$ 0.25	$ 0.05	12	$ 0.60
	Slide Plates	$ 0.99	$ 0.50	4	$ 2.00
	Hooks/Tabs	$ 0.24	$ 0.10	2	$ 0.20
	Voltage Regulator	$ 0.40	$ 0.28	1	$ 0.28
	Circuit Board	$ 5.00	$ 0.50	1	$ 0.50
	SD Card	$ 4.99	$ 1.95	1	$ 1.95
	SD Card Adapter	$ 4.95	$ 4.21	1	$ 4.21
				Total	**$ 95.91**
Relay					
	Arduino Pro Mini	$ 9.95	$ 8.46	1	$ 8.46
	Xbee Pro Radio	$ 37.95	$ 34.16	1	$ 34.16
	Battery Holder	$ 2.14	$ 1.71	1	$ 1.71
	D-cell Batteries	$ 1.62	$ 0.35	3	$ 1.05
	Voltage Regulator	$ 0.40	$ 0.28	1	$ 0.28
	SD Card	$ 4.99	$ 1.95	1	$ 1.95
	SD Card Adapter	$ 4.95	$ 4.21	1	$ 4.21
	Electronics Box	$ 22.19	$ 11.00	1	$ 11.00
	Circuit Board	$ 5.00	$ 0.50	1	$ 0.50
				Total	**$ 63.32**

System Component	Part	Retail Price	OEM Price	Number Required	Cost
Central Unit					
	AC Power Converter	$ 5.95	$ 5.36	1	$ 5.36
	Xbee Pro Radio	$ 37.95	$ 34.16	1	$ 34.16
	Arduino Pro Mini	$ 9.95	$ 8.46	1	$ 8.46
	3G Chip	$ 20.00	$ 4.99	1	$ 4.99
	3G Chip Adapter	$ 39.95	$ 31.96	1	$ 31.96
	3G Antenna	$ 4.95	$ 3.96	1	$ 3.96
	Circuit Board	$ 5.00	$ 0.50	1	$ 0.50
	Electronics Box	$ 22.19	$ 11.00	1	$ 11.00
	SD Card	$ 4.99	$ 1.95	1	$ 1.95
	SD Card Adapter	$ 4.95	$ 4.21	1	$ 4.21
				Total	**$ 106.55**

Unit Cost Goal for 1000 Units	**< $100.00**
Unit Cost for 1000	**$ 99.18**

Budget for data collection unit, relay, and central unit. Unit cost for a run of 1000 units is below target of $100.