final report

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Photogrammetric Feed Trough Assessment System

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Abstract

Feed bunk management is a primary function in cattle production for feedlots in Australia and the United States. Feed bunk management is the process of delivering the optimal amount of feed to the cattle to maximize the amount of growth while minimizing food waste. Determining the amount of feed that is currently available in each length of feed bunk is estimated by a bunk caller. The bunk caller makes multiple visual observations at a scheduled interval to estimate the rate of consumption and amount of feed available in the bunk. These observations are subjective in nature as they rely heavily on the bunk caller's ability to accurately quantify their visual observations. Digital Photogrammetry is the science of calculating three-dimensional information from stereoscopic two-dimensional digital images. This technology works in a similar fashion to the human eye and can be used to quantify three-dimensional geometric outputs such as volume. This report will outline a system design and present preliminary results of a digital photogrammetric camera system to measure varying amounts of feed in a standard feed bunk. The following discussion will highlight some of the inconsistencies found in the preliminary results and will make recommendations on future studies that attempt to use this technology.

Executive summary

Monitoring and measuring feed levels in a feedlot feed bunk is a vital operation performed by bunk callers. This subjective method is a product of a bunk caller's depth of experience and total number of visual observations made continually throughout a given day.

Structure from motion (SfM) is a photogrammetric technique in which three-dimensional structures are generated from a two-dimensional image sequence. This technology is currently being utilized in several professional fields such as archaeology and the geosciences. This technology is particularly useful in estimating position, elevation, and volumetric changes. Utilizing a high-resolution digital camera and computer vision algorithms to generate a three-dimensionally accurate computer model, measuring feed can be conducted in a more objective manor.

This report will outline;

1. Prototype design of the photogrammetric camera system
2. Volumetric measurement methodology
3. Prototype assessment methodology
4. Preliminary results of volumetric measurements
5. Discussion on data inconsistencies and sources of error
6. Recommendations for future improvements
7. Other uses for this technology in the cattle industry

This report will outline the design, construction, and preliminary results of the photogrammetric feed trough assessment system. Since this study is under current review by the MLA donor company, additional information will be added to this report to outline the breadth of work that has been conducted under this contract.

Link to a movie of an experimental run of the constructed photogrammetric measurement system and setup: https://youtu.be/OROm96HYu34

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1 Background

Measuring the amount of feed in a feed bunk is a subjective process that depends on the depth of knowledge and number of observations made by the bunk caller. Photogrammetric technologies can be utilized to mimic the human eye by generating a three-dimensional model from a series of overlapping images. These overlapping images are known as stereoscopic image pairs. Commercially available digital cameras and computer software can measure distance and infer depth by using computer vision algorithms known as structure from motion (SfM).

Structure from motion (SfM) software analyses a series images to corelate a single pixel in one image to the next. The movement of these pixels is measured based on the spatial orientation of the camera and the distance of the camera from the object. These movements are recorded by the software and are then used to calculate a three-dimensional position to the corresponding pixel. The software repeats this process thousands of times for an entire image sequence to generate a 3-D point cloud. From this 3-D point cloud, a 3-D model can be generated.

Figure 1: Visualized 3-D Models of a feed trough filled with corn and superimposed camera positions

While several professions currently utilize structure from motion (SfM) technologies to monitor and measure geophysical processes, the feed lot industry could benefit from this technology to implement an objective/automated system for monitoring and measuring cattle feed.

2 Project objectives

As outlined in the research agreement, the project objectives are:

1. Understanding if photogrammetric measurements can be accurately made of the feed trough.
2. Determining if these measurements can be reproduced multiple times in a day.
3. Assess if this new process can be a viable option to replace the current manual process.
4. Assess other trends related to volume of feed in the trough using the camera system.
5. Identify components to the system that should be automated and can be made cheaper for commercialization purposes.

3 Methodology

3.1 System Design

3-D reconstruction of a cattle feed trough from a series of 2-D images will utilize two overlapping fields of study. Photogrammetry, which is defined as the science of measuring distance between objects in an image and structure from motion (SfM) which utilizes a set of computer vison algorithms to track and measure corresponding pixels from a series of images (Recker, 2014).

Over the last five years major advancements in these studies have produced commercialized workflows that are now being utilized by the public to produce 3-D models. While these 3-D models are seemingly easy to produce they are generally inaccurate metrologically (Recker, 2014). However, incorporating some key components into the system design, which will be outlined in the following sections, can produce a metrologically accurate 3-D reconstruction.

3.1.1 Motorized Trolley & Camera assembly and design

An important aspect to understand if this technology is a viable option for the feed lot industry is proposing a mechanical system design that will not impede feed lot operations. For this analysis CompassData designed and built a motorized rail system to propel a camera over the top of the feed bunk while timing the camera trigger release with a built in intervalometer.

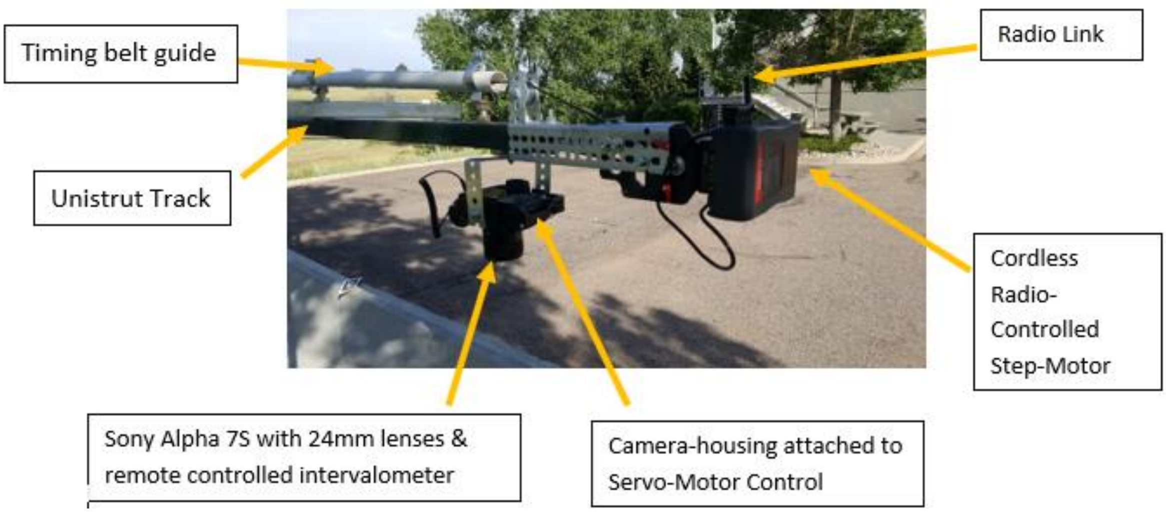


Figure 2: Image of the experimental motorized trolley with camera

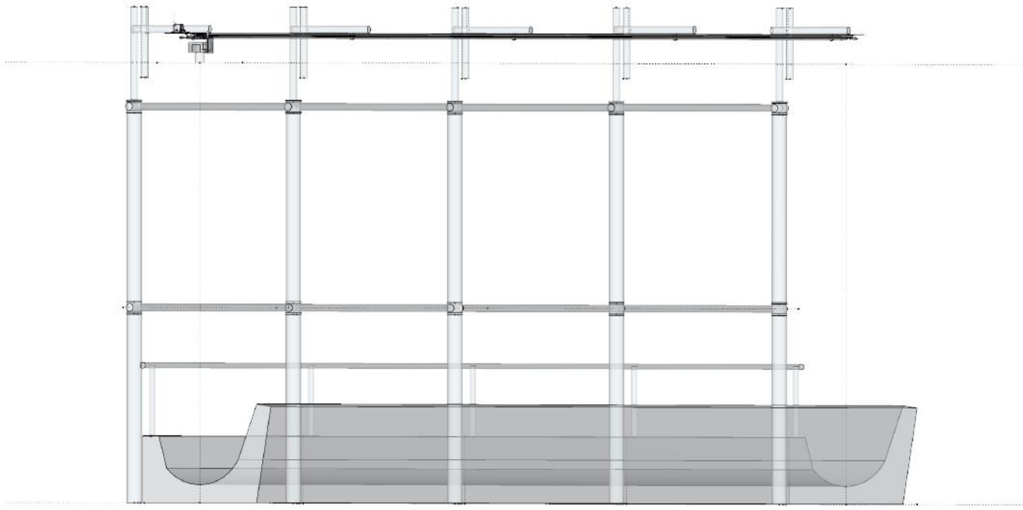


Figure 3: Design of the trough, trolley track with construction and camera

Figure 4: Realization of the design

The motor purchased for the camera rail system was based off a belt drive design. The iFottage S1A1 electric motor is a wireless step motor with programable functionality. The 32-watt motor is light weight relative to its power output (1.3kg weight to 8 kg max load).

The speed of the motor as per manufactures specifications is set at 160mm/sec. However, with our design the velocity increased due to an increased gear ratio of 1.5. Our actual velocity for the camera system is 234.5 mm/sec.

The camera selected for this study was the Sony Alpha 7s. The following table outlines some of the specification of this camera and why it was beneficial to use for this study.

Camera Feature	Specification	Utility Gained
Full Frame Exmor™ CMOS sensor	35 mm frame with 12.2 mega pixels	High resolution image quality allows for processing software to generate a dense 3-D point cloud. GSD at 8’ = .03”
Expanded ISO range	50 - 409,600	Allows for wide range of lighting conditions.
Shutter Speed	1/8000 second	The camera rate of travel at 20 mph would still only produce one-pixel width (.08 cm) of pixel blur.
Wireless capabilities	Wi-Fi enabled connection	Transfer images to remote desktop or laptop for image processing.

Table 1: Camera specifications

3.1.2 Structure from Motion Software

While there are many SfM software packages commercially available today (Shervias, 2015) there were two utilized for this study. Photoscan which is produced by Agisoft, a Russian based company and Pix4D and company based out of Switzerland.

Photoscan and Pix4D are commercially available software packages and are similar in cost. Both software packages use the opensource scale-invariant feature transform (SIFT) algorithm along with other SfM algorithms to generate a 3-D model from overlapping 2-D digital images.

3.2 Measurement & Assessment Methodology

To accurately measure and predict the amount in weight (lbs) of feed in the test trough we must know;

1. The total volume of feed currently in the trough (ft3)
2. The bulk density of the medium contained in the trough (lbs/ft3)

3.2.1 Calculating Volume

In this study we calculated the volume of feed in the test trough by generating two separate 3-D models using our motorized camera rail and photogrammetric computer software (Photoscan & Pix4D). One 3-D model without feed (Fig. 6) and one with feed. The total volume of these two models are then subtracted from each other to get the total volume of the feed.

Figure 5: Empty and full troughs modelled based on multiple images taken by the constructed system

Top Views:

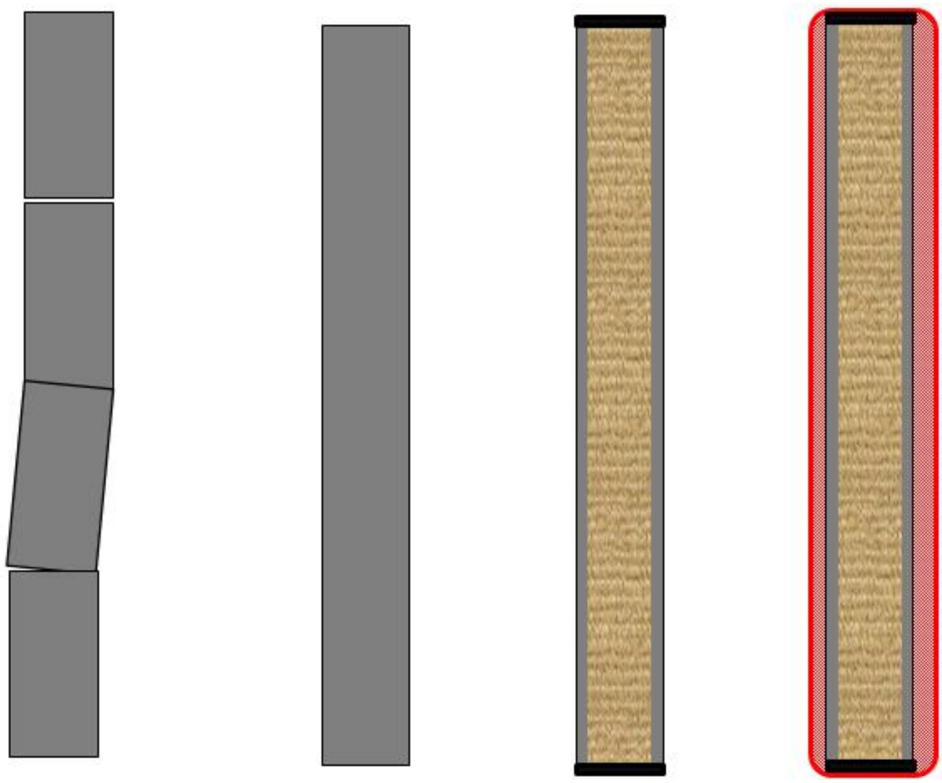


Figure 6: From left to right: Four concrete elements, each approximately 8 feet long and 3 feet wide. These elements are accurately produced forms with insignificant geometric variances. All four elements are generally in line, but small gaps, angles and elevation changes exist. Simulated empty trough with a total length of 32 feet.

While these models are geometrically accurate within an individual dataset (dataset = series of overlapping images or single pass of the camera) the system still required a series of reference points or control points to ensure the two models where in the same spatial context. Visual targets or photo identifiable control points where placed on the feed trough and measured using a high precision Global Positioning System (GPS). The coordinates generated from the GPS where associated with the visual markers (Fig. 8) and used to calibrate the 3-D trough models.

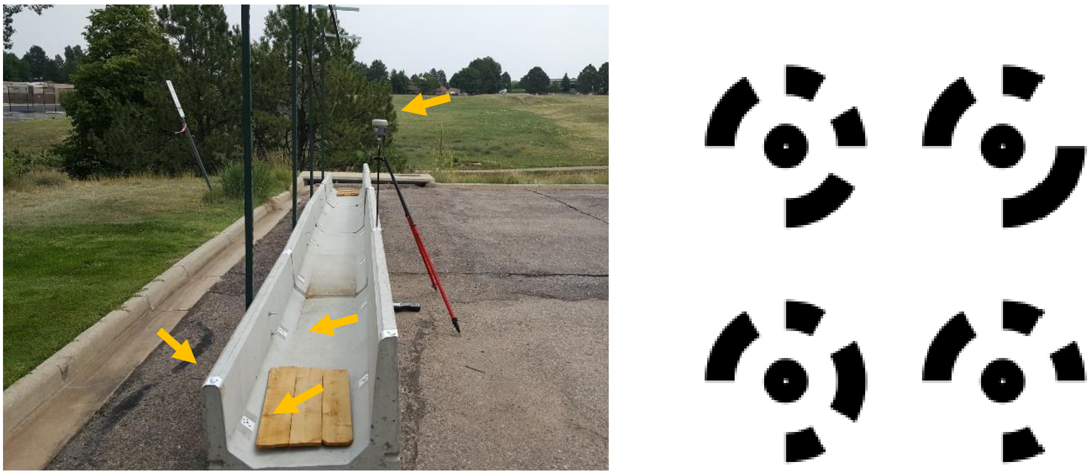


Figure 7: Empty trough, GPS equipment and reference points attached to trough. Right: Bar-coded reference point detail.

Testing of different materials, shapes, and surfaces.

The functionality of the system shows great modelling results on other objects besides feed. Tested features included an orange basketball, grey plastic containers, traffic cones, cardboard boxes and a bicycle. The purpose of this test was to analyse different objects and show the functionality of the system. This test also show the challenges of photogrammetric modelling.

Figure 8: A basketball photogrammetrically modelled. You can see artefacts of the computer modelling.

The basketball in the foreground is nicely modelled on the top, while its lower part 'melted' in a cone-shape into the trough floor. Fortunately, corn and silage are heaping in stockpiles and such artefacts are not complicating this experiment.

Grey plastic grates with the geometric defined grids have modelled extremely well due to the structured plastic and shade contrasts. Also, the colour similarity with the concrete did not have any negative impact.

Small artefacts of a few square inches increase and decrease parts of the volume model, however at a balance.

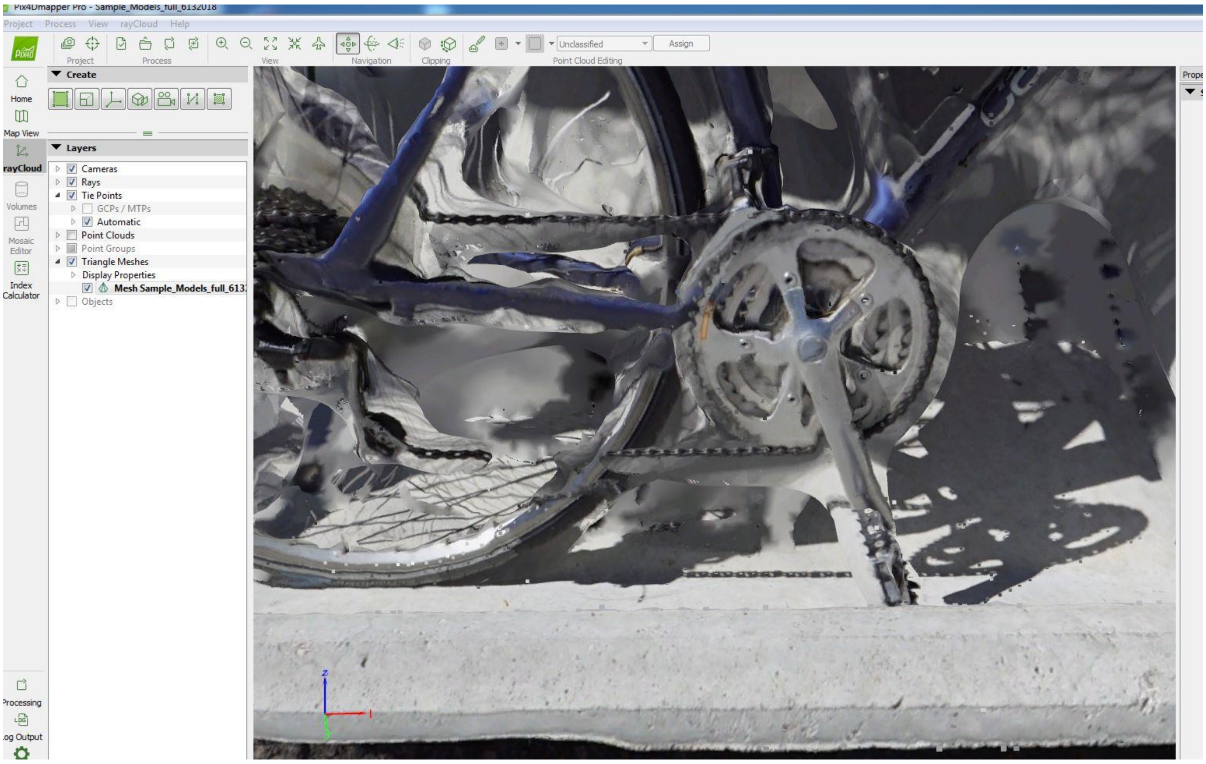


Figure 9: Superimposed photo on 3-D Model

The detail of a bike in the 3-D modelling software Pix4D shows on one hand blurriness in the image modelling as the extremely thin and detailed bicycle parts from the photo images did not match exactly the 3-D model and on the other hand the high-resolution capability of this system.

3.2.2 Calculating Bulk Density

For this study CompassData and MLA selected whole dry corn as the cattle feed medium to assess the photogrammetric camera system. Whole dry corn was selected for this study as it has a consistent bulk density of approximately 45 lbs/ft3.

To determine the exact bulk density of the whole dry corn used in this study, CompassData utilized a 5-gallon bucket and a calibrated digital scale (precision value +/- .10 lbs). The 5-gallon bucket was first weighed using the calibrated digital scale (bucket weight = 1.7 lbs). The bucket was then filled with distilled water. Distilled water has a known density of 62.4 lbs/ft3 and can be considered a constant medium for this study.

The bucket was weighed with the distilled water (bucket weight with distilled water = 49.6lbs). To get the weight of the water you subtract the weight of the bucket (1.7lbs) from the total weight (49.6lbs) equalling a total water weight of 47.9 lbs. To get the true volume of the bucket you divide the weight of the water (47.9lbs) by the density of the distilled water (62.4 lbs/ft3). This resulted in a true bucket volume of 0.8 ft3.

Figure 10: Confirming the specific weight of the used corn with a comparison to distilled water

With the true volume of the bucket known, the bucket was filled with the corn medium and weighed. The total weight of the corn came to 37.0 lbs. To get the bulk density of the corn medium you divide the weight of the corn (37.0 lbs) by the volume of the bucket (0.8 ft3). to gives us a **bulk corn density of 46.2 lbs/ft3**.

3.2.3 Assessment Methodology

To assess the operability and feasibility of the photogrammetric camera system, MLA and CompassData decided to break this assessment into two phases. Phase 1 would assess

a. The ability of the system to map the profile of the empty bunk
b. The rate of travel of the sensor along the test bunk
c. Computation time for measurements of volume
d. The ability to measure volume in both day and night

Phase 1 of the assessment measured three volumes empty, half full, and full to assess these parameters. Five passes of the camera where conducted for each of the three volumes.

In this experiment half full and full values relate to the total length of test bunk at 32 feet in length. The recommended length of feed bunk per cattle is approximately 9 inches per head of cattle. This equates to 42 head of cattle for this test bunk. Whole dry corn is generally fed to cattle at the finishing stages of beef production. Whole dry corn rations are around 20 lbs per head per day. Thus, we determined a “full” trough for 32 feet of length to equate to 848 lbs of whole dry corn. The definition for “half-full” equates to (full/2) or 424 lbs of whole dry corn and “empty” equates to 0 lbs of whole dry corn.

Figure 11: CompassData Scientists pouring corn in the experimental trough.

Figure 12: Cross-sections and weight of corn for the three different fillings

Phase 2 of the assessment was to determine the “feasibility” of the photogrammetric camera systems ability to determine volumetric quantities of feed vs. the “gold standard.” In this phase of testing the amount of feed measured would be segregated into smaller increments to look for a mean and linear bias existed in the observed (gold standard) vs. the predicted (camera measurements) values. However, due to inconsistencies in the data from Phase 1, CompassData felt it not feasible to conduct Phase 2 until these inconsistences were sorted out.

One known source of error was due to the camera angle in relation to the feed bunk walls. Areas that are not visible to the field of view of the camera end up generating distortions or artefacts in the computer model. This becomes problematic when trying to calculate a volume from the photogrammetrically derived 3-D model. Where there is null data the computer must interpolate to fill in the gaps. When the computer does this, volumetric values become random and inconsistent. However, there are editing capabilities in the software to reduce the areas of null or inconsistent data (Figure 13 & Figure 14). We called this process "calibrating" the model.

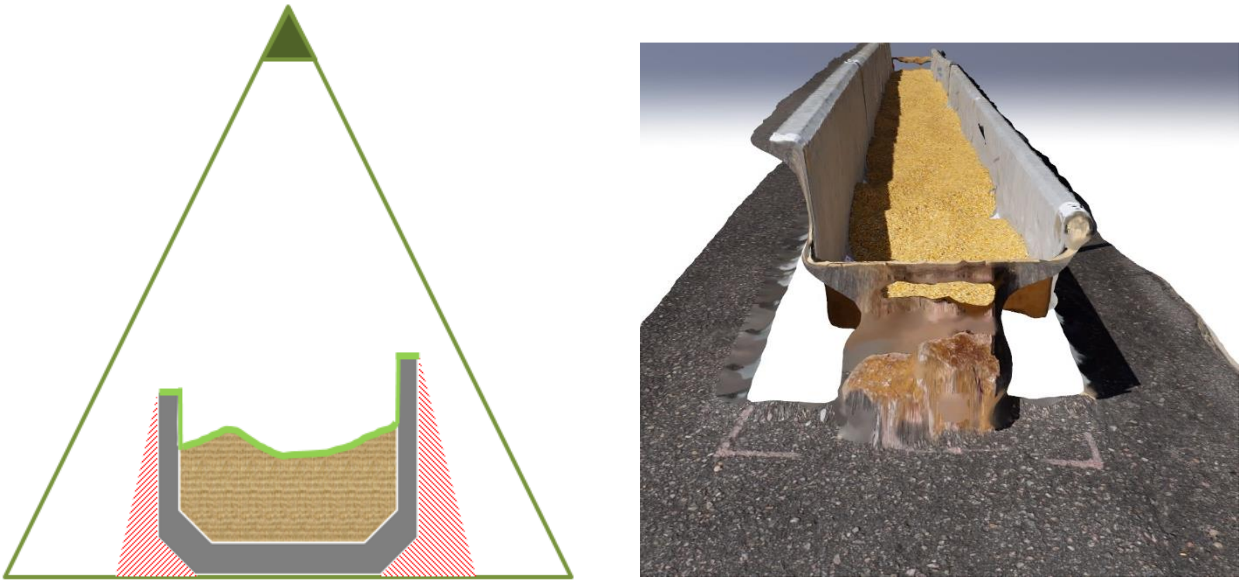


Figure 13: Cross-sections and blind spot. Right model.

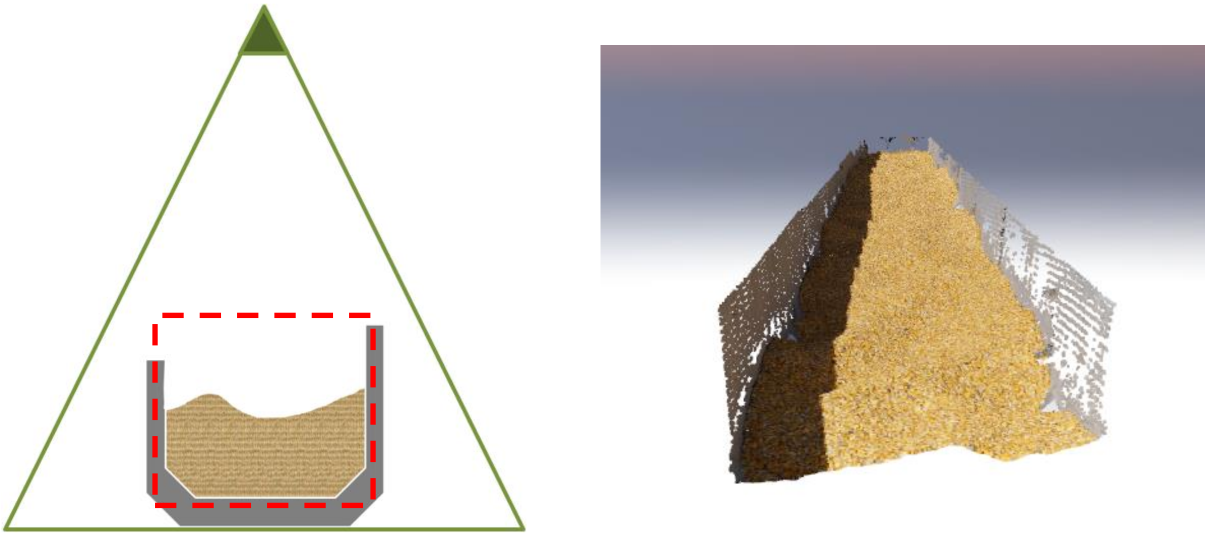
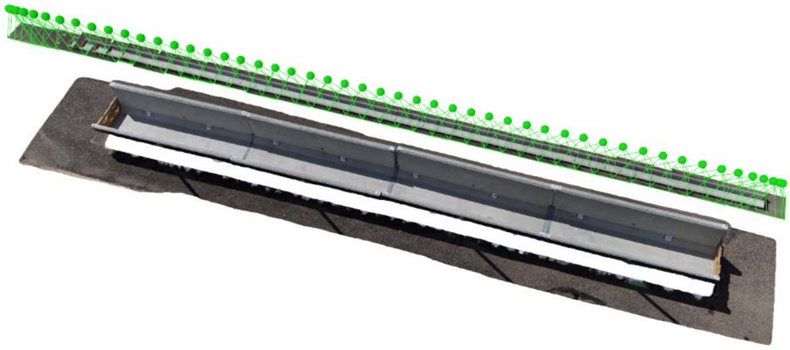


Figure 14: Cross-sections showing the calibration by horizontal planes eliminating the blind spots and majority of the wall artefacts

4 Results

To calculate the total volume of whole dry corn feed at full and half full observed volumes the camera system must first show that it can successfully map the empty feed bunk. Five passes where conducted with the photogrammetric camera system. Consistent 3-D models were generated of the five data sets and volumes were calculated (Fig. 15).



Empty Trough = 0lbs	
Pass #	Volume (ft3)
1	152.8
2	152.6
3	153.0
4	153.1
5	152.8
Avg.	152.9

Figure 15: The empty trough model has a consistent theoretical ‘base volume’

The rate of travel was then calculated for each pass to determine the speed of acquisition time. The total time for the camera to travel the length of the 32-foot trough was 1 minute 15 seconds. Thus, the rate of travel for the camera system is approximately 0.43 feet/per second. Photo acquisition time is relatively short compared to the computation time to generate a final volume calculation.

Most of the time lag for the final computation is due to manual processes in transferring the data from camera to computer processing software. Other factors that impact computation time include processing speeds of the computer. A machine with higher RAM and processing clock speeds can process the images much faster. Pix4D and Photoscan have capabilities of leveraging all a machines computing power. A sample report produced by Pix4D is displayed in Appendix A that outlines processing time and the processing capabilities of the Computer Processing Unit (CPU) used in this study.

While the goal of this study was to understand the feasibility of utilizing this technology in the feed lot industry, a heavier amount of time was spent trying to reproduce reliable results instead of minimizing computational time. However, for the purposes of this report an approximate time from acquisition to final volume calculation was around 1 hour per calculation.

4.1 Volumetric Calculations

Table 2: Final Observations on the Day Time Measurements on Empty, Half-Full, and Full Troughs

Volumetric Measurements of Dry Corn Feed Using Photogrammetric Methods: **Day Time Assessment**

Empty Trough = 0lbs		Half Full Trough Observed = 424lbs		Full Trough Observed = 848lbs	
Pass #	Volume (ft3)	Pass #	Volume (ft3)	Pass #	Volume (ft3)
1	68.56	1.00	77.99	1.00	86.89
2	68.35	2.00	77.88	2.00	86.63
3	68.82	3.00	77.83	3.00	86.87
4	68.64	4.00	77.78	4.00	86.77
5	68.57	5.00	77.77	5.00	86.55
Avg.	68.59	Avg.	77.85	Avg.	86.74

All Passes at Day Time / Normalized to Averages

Pass	Volume		Delta	Delta2
1.00	68.56		-0.03	0.00
2.00	68.35		-0.24	0.06
3.00	68.82		0.23	0.05
4.00	68.64		0.05	0.00
5.00	68.57		-0.02	0.00
1.00	77.99		0.14	0.02
2.00	77.88		0.03	0.00
3.00	77.83		-0.02	0.00
4.00	77.78		-0.07	0.00
5.00	77.77		-0.08	0.01
1.00	86.89		0.15	0.02
2.00	86.63		-0.11	0.01
3.00	86.87		0.13	0.02
4.00	86.77		0.03	0.00
5.00	86.55		-0.19	0.04
		Max	**0.23**	
		Min	**-0.24**	
		RMSE	**0.13**	

Note:

The normalized averages of the calibrated volume measurements for empty, half-full, and full troughs show very consistent volume differences within each sample set.

Table 3: Final Observations on the Night Time Measurements on Empty, Half-Full, and Full Troughs

Volumetric Measurements of Dry Corn Feed Using Photogrammetric Methods: **Night Time Assessment**

Empty Trough = 0lbs		Half Full Trough Observed = 424lbs		Full Trough Observed = 848lbs	
Pass #	Volume (ft3)	Pass #	Volume (ft3)	Pass #	Volume (ft3)
1	66.16	1.00	78.94	1.00	88.56
2	67.31	2.00	78.70	2.00	86.70
3	67.78	3.00	79.11	3.00	86.11
4	67.84	4.00	78.41	4.00	86.43
5	68.07	5.00	78.62	5.00	86.27
Avg.	67.43	Avg.	78.76	Avg.	86.81

All Passes at Day Time / Normalized to Averages

Pass	Volume		Delta	Delta2
1.00	66.16		-1.27	1.62
2.00	67.31		-0.12	0.01
3.00	67.78		0.35	0.12
4.00	67.84		0.41	0.17
5.00	68.07		0.64	0.41
1.00	78.94		0.18	0.03
2.00	78.70		-0.06	0.00
3.00	79.11		0.35	0.13
4.00	78.41		-0.35	0.12
5.00	78.62		-0.14	0.02
1.00	88.56		1.75	3.05
2.00	86.11		-0.70	0.50
3.00	86.11		-0.70	0.50
4.00	86.43		-0.38	0.15
5.00	86.27		-0.54	0.30
		Max	1.75	
		Min	-1.27	
		RMSE	0.69	

Note:

A comparison of Day and Night Time measurements revealed that the empty troughs and also the half-full troughs show volume differences exceeding expectations (red), while measurements for the full throughs are acceptable.

Averages Day-Night		Day	Night	Delta
Empty Trough		68.59	67.43	1.16
Half Full Trough		77.85	78.76	-0.91
Full Trough		86.74	86.81	-0.07

Table 4: Volumetric Differences and Weight Calculation between empty and half-full troughs measured during the day.

Volumetric Calculation & Predicted Dry Corn Weight: Observed during the DAY @ Half Full (424lbs)

Final Corn Volume (ft3) = half full trough Volume (ft3) - empty trough volume (ft3)

Final Feed Weight (lbs) = volume (ft3)*bulk density(lbs/ft3)

Empty Trough Ref. # 1

Pass #	Corn Volume (ft3)	Corn Weight (lbs)	Residual Observed - Predicted	Abs. Residual	% Diff of Residual/Observed
1	9.4	435.9	11.9	11.9	2.8%
2	9.3	430.8	6.8	6.8	1.6%
3	9.3	428.5	4.5	4.5	1.1%
4	9.2	426.1	2.1	2.1	0.5%
5	9.2	425.7	1.7	1.7	0.4%
Avg.	9.3	429.4	5.4	5.4	1.3%

Empty Trough Ref. # 2

Pass #	Corn Volume (ft3)	Corn Weight (lbs)	Residual Observed - Predicted	Abs. Residual	% Diff of Residual/Observed
1	9.6	445.6	21.6	21.6	5.1%
2	9.5	440.5	16.5	16.5	3.9%
3	9.5	438.2	14.2	14.2	3.3%
4	9.4	435.9	11.9	11.9	2.8%
5	9.4	435.4	11.4	11.4	2.7%
Avg.	9.5	439.1	15.1	15.1	3.6%

Empty Trough Ref. # 3

Pass #	Corn Volume (ft3)	Corn Weight (lbs)	Residual Observed - Predicted	Abs. Residual	% Diff of Residual/Observed
1	9.2	423.8	-0.2	0.2	0.0%
2	9.1	418.8	-5.2	5.2	1.2%
3	9.0	416.4	-7.6	7.6	1.8%
4	9.0	414.1	-9.9	9.9	2.3%
5	9.0	413.7	-10.3	10.3	2.4%
Avg.	9.0	417.4	-6.6	6.6	1.6%

Empty Trough Ref. # 4

Pass #	Corn Volume (ft3)	Corn Weight (lbs)	Residual Observed - Predicted	Abs. Residual	% Diff of Residual/Observed
1	9.3	432.2	8.2	8.2	1.9%
2	9.2	427.1	3.1	3.1	0.7%
3	9.2	424.8	0.8	0.8	0.2%
4	9.1	422.5	-1.5	1.5	0.4%
5	9.1	422.0	-2.0	2.0	0.5%
Avg.	9.2	425.7	1.7	3.1	0.7%

Empty Trough Ref. # 5

Pass #	Corn Volume (ft3)	Corn Weight (lbs)	Residual Observed - Predicted	Abs. Residual	% Diff of Residual/Observed
1	9.4	435.4	11.4	11.4	2.7%
2	9.3	430.3	6.3	6.3	1.5%
3	9.3	428.0	4.0	4.0	0.9%
4	9.2	425.7	1.7	1.7	0.4%
5	9.2	425.2	1.2	1.2	0.3%
Avg.	9.3	428.9	4.9	4.9	1.2%

Table 5: Volumetric Differences and Weight Calculation between empty and half-full troughs measured during the night.

Volumetric Calculation & Predicted Dry Corn Weight: Observed during the NIGHT @ Half Full (424lbs)

Final Corn Volume (ft3) = half full trough Volume (ft3) - empty trough volume (ft3)

Final Feed Weight (lbs) = volume (ft3)*bulk density(lbs/ft3)

Empty Trough Ref. # 1

Pass #	Corn Volume (ft3)	Corn Weight (lbs)	Residual Observed - Predicted	Abs. Residual	% Diff of Residual/Observed
1	12.8	590.7	166.7	166.7	39.3%
2	12.5	579.6	155.6	155.6	36.7%
3	13.0	598.5	174.5	174.5	41.2%
4	12.3	566.2	142.2	142.2	33.5%
5	12.5	575.9	151.9	151.9	35.8%
Avg.	12.6	582.2	158.2	158.2	37.3%

Empty Trough Ref. # 2

Pass #	Corn Volume (ft3)	Corn Weight (lbs)	Residual Observed - Predicted	Abs. Residual	% Diff of Residual/Observed
1	11.6	537.5	113.5	113.5	26.8%
2	11.4	526.4	102.4	102.4	24.2%
3	11.8	545.4	121.4	121.4	28.6%
4	11.1	513.0	89.0	89.0	21.0%
5	11.3	522.7	98.7	98.7	23.3%
Avg.	11.4	529.0	105.0	105.0	24.8%

Empty Trough Ref. # 3

Pass #	Corn Volume (ft3)	Corn Weight (lbs)	Residual Observed - Predicted	Abs. Residual	% Diff of Residual/Observed
1	11.2	515.8	91.8	91.8	21.7%
2	10.9	504.7	80.7	80.7	19.0%
3	11.3	523.7	99.7	99.7	23.5%
4	10.6	491.3	67.3	67.3	15.9%
5	10.8	501.0	77.0	77.0	18.2%
Avg.	11.0	507.3	83.3	83.3	19.6%

Empty Trough Ref. # 4

Pass #	Corn Volume (ft3)	Corn Weight (lbs)	Residual Observed - Predicted	Abs. Residual	% Diff of Residual/Observed
1	11.1	513.0	89.0	89.0	21.0%
2	10.9	501.9	77.9	77.9	18.4%
3	11.3	520.9	96.9	96.9	22.9%
4	10.6	488.5	64.5	64.5	15.2%
5	10.8	498.3	74.3	74.3	17.5%
Avg.	10.9	504.5	80.5	80.5	19.0%

Empty Trough Ref. # 5

Pass #	Corn Volume (ft3)	Corn Weight (lbs)	Residual Observed - Predicted	Abs. Residual	% Diff of Residual/Observed
1	10.9	502.4	78.4	78.4	18.5%
2	10.6	491.3	67.3	67.3	15.9%
3	11.0	510.3	86.3	86.3	20.3%
4	10.3	477.9	53.9	53.9	12.7%
5	10.6	487.6	63.6	63.6	15.0%
Avg.	10.7	493.9	69.9	69.9	16.5%

Table 6: Volumetric Differences and Weight Calculation between empty and full troughs taken during the day.

Volumetric Calculation & Predicted Dry Corn Weight: Observed during the DAY @ Full (848lbs)

Final Corn Volume (ft3) = full trough Volume (ft3) - empty trough volume (ft3)

Final Feed Weight (lbs) = volume (ft3)*bulk density(lbs/ft3)

Empty Trough Ref. # 1

Pass #	Corn Volume (ft3)	Corn Weight (lbs)	Residual Observed - Predicted	Abs. Residual	% Diff of Residual/Observed
1	18.3	847.2	-0.8	0.8	0.1%
2	18.1	835.2	-12.8	12.8	1.5%
3	18.3	846.3	-1.7	1.7	0.2%
4	18.2	841.7	-6.3	6.3	0.7%
5	18.0	831.5	-16.5	16.5	1.9%
Avg.	18.2	840.4	-7.6	7.6	0.9%

Empty Trough Ref. # 2

Pass #	Corn Volume (ft3)	Corn Weight (lbs)	Residual Observed - Predicted	Abs. Residual	% Diff of Residual/Observed
1	18.3	844.9	-3.1	3.1	0.4%
2	18.3	844.9	-3.1	3.1	0.4%
3	18.5	856.0	8.0	8.0	0.9%
4	18.4	851.4	3.4	3.4	0.4%
5	18.2	841.2	-6.8	6.8	0.8%
Avg.	18.3	847.7	-0.3	4.9	0.6%

Empty Trough Ref. # 3

Pass #	Corn Volume (ft3)	Corn Weight (lbs)	Residual Observed - Predicted	Abs. Residual	% Diff of Residual/Observed
1	18.1	835.2	-12.8	12.8	1.5%
2	17.8	823.2	-24.8	24.8	2.9%
3	18.1	834.3	-13.7	13.7	1.6%
4	18.0	829.6	-18.4	18.4	2.2%
5	17.7	819.5	-28.5	28.5	3.4%
Avg.	17.9	828.4	-19.6	19.6	2.3%

Empty Trough Ref. # 4

Pass #	Corn Volume (ft3)	Corn Weight (lbs)	Residual Observed - Predicted	Abs. Residual	% Diff of Residual/Observed
1	18.3	843.5	-4.5	4.5	0.5%
2	18.0	831.5	-16.5	16.5	1.9%
3	18.2	842.6	-5.4	5.4	0.6%
4	18.1	838.0	-10.0	10.0	1.2%
5	18.0	831.0	-17.0	17.0	2.0%
Avg.	18.1	837.3	-10.7	10.7	1.3%

Empty Trough Ref. # 5

Pass #	Corn Volume (ft3)	Corn Weight (lbs)	Residual Observed - Predicted	Abs. Residual	% Diff of Residual/Observed
1	18.3	846.8	-1.2	1.2	0.1%
2	18.1	834.7	-13.3	13.3	1.6%
3	18.3	845.8	-2.2	2.2	0.3%
4	18.2	841.2	-6.8	6.8	0.8%
5	18.0	831.0	-17.0	17.0	2.0%
Avg.	18.2	839.9	-8.1	8.1	1.0%

Table 7: Volumetric Differences and Weight Calculation between empty and full troughs taken during the night.

Volumetric Calculation & Predicted Dry Corn Weight: Observed during the NIGHT @ Full (848lbs)

Final Corn Volume (ft3) = full trough volume (ft3) - empty trough volume (ft3)

Final Feed Weight (lbs) = volume (ft3)*bulk density(lbs/ft3)

Empty Trough Ref. # 1

Pass #	Corn Volume (ft3)	Corn Weight (lbs)	Residual Observed - Predicted	Abs. Residual	% Diff of Residual/Observed
1	22.4	1035.3	187.3	187.3	22.1%
2	29.0	1340.4	492.4	492.4	58.1%
3	20.0	922.1	74.1	74.1	8.7%
4	20.3	936.9	88.9	88.9	10.5%
5	20.1	929.5	81.5	81.5	9.6%
Avg.	22.3	1032.8	184.8	184.8	21.8%

Empty Trough Ref. # 2

Pass #	Corn Volume (ft3)	Corn Weight (lbs)	Residual Observed - Predicted	Abs. Residual	% Diff of Residual/Observed
1	27.9	1287.2	439.2	439.2	51.8%
2	27.9	1287.2	439.2	439.2	51.8%
3	18.8	868.9	20.9	20.9	2.5%
4	19.1	883.7	35.7	35.7	4.2%
5	19.0	876.3	28.3	28.3	3.3%
Avg.	22.5	1040.7	192.7	192.7	22.7%

Empty Trough Ref. # 3

Pass #	Corn Volume (ft3)	Corn Weight (lbs)	Residual Observed - Predicted	Abs. Residual	% Diff of Residual/Observed
1	20.8	960.5	112.5	112.5	13.3%
2	27.4	1265.5	417.5	417.5	49.2%
3	18.3	847.2	-0.8	0.8	0.1%
4	18.7	862.0	14.0	14.0	1.7%
5	18.5	854.6	6.6	6.6	0.8%
Avg.	20.7	958.0	110.0	110.3	13.0%

Empty Trough Ref. # 4

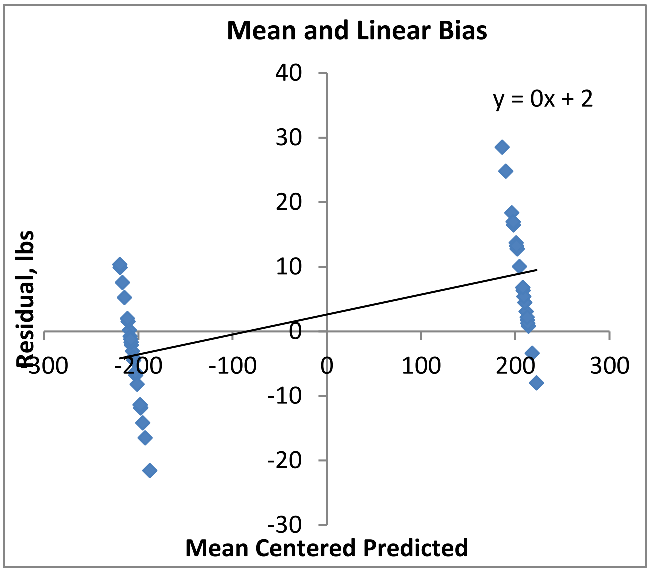
Pass #	Corn Volume (ft3)	Corn Weight (lbs)	Residual Observed - Predicted	Abs. Residual	% Diff of Residual/Observed
1	20.7	957.7	109.7	109.7	12.9%
2	27.3	1262.7	414.7	414.7	48.9%
3	18.3	844.4	-3.6	3.6	0.4%
4	18.6	859.2	11.2	11.2	1.3%
5	18.2	841.2	-6.8	6.8	0.8%
Avg.	20.6	953.1	105.1	109.2	12.9%

Empty Trough Ref. # 5

Pass #	Corn Volume (ft3)	Corn Weight (lbs)	Residual Observed - Predicted	Abs. Residual	% Diff of Residual/Observed
1	20.5	947.0	99.0	99.0	11.7%
2	27.1	1252.1	404.1	404.1	47.7%
3	18.0	833.8	-14.2	14.2	1.7%
4	18.4	848.6	0.6	0.6	0.1%
5	18.2	841.2	-6.8	6.8	0.8%
Avg.	20.4	944.6	96.6	104.9	12.4%

4.2 Mean and Linear Bias Regression

While the data in the daytime measurements appears to have an adequate % error in relation from predicted to observed volumes there does appear to be a significant mean and linear bias in predicting the half full to full quantities.



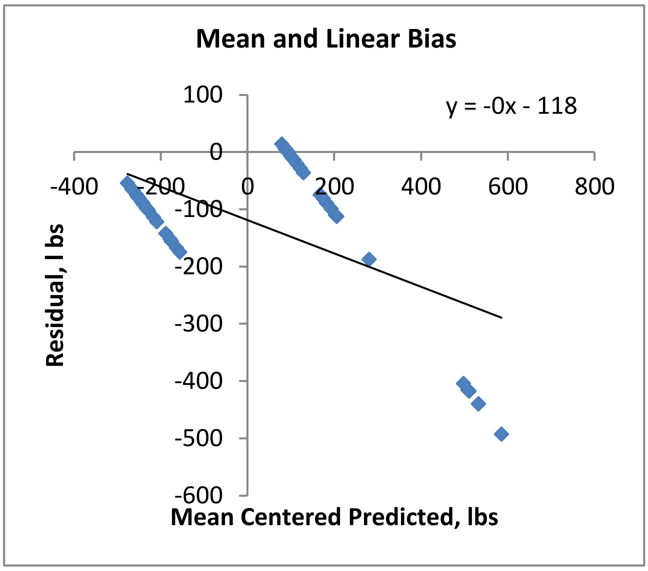


Figure 16: Linear regression models of the mean. Left is for the daytime half full and full. On the right is for the night time measurements half full and full.

Regression Statistics	
Multiple R	0.599078095
R Square	0.358894564
Adjusted R Square	0.345538201
Standard Error	8.658127994
Observations	50

Figure 17: Daytime measurement regression statistics.

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	2014.311639	2014.312	26.8706801	4.30043E-06
Residual	48	3598.232657	74.96318		
Total	49	5612.544296			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	2.591876	1.224444203	2.116778	0.03948864	0.129965926	5.053786074	0.129966	5.053786
X Variable 1	0.03088889	0.005958857	5.183694	4.30043E-06	0.018907805	0.042869975	0.018908	0.04287

**Significant Mean and Linear bias

Regression Statistics	
Multiple R	*0.604050283*
R Square	*0.364876745*
Adjusted R Square	*0.35164501*
Standard Error	*103.0373881*
Observations	*50*

Figure 18: Night time measurement regression statistics.

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	*1*	*292764.9554*	*292765*	*27.57588167*	*3.40839E-06*
Residual	*48*	*509601.761*	*10616.7*		
Total	*49*	*802366.7164*			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	*-118.606208*	*14.57168717*	*-8.1395*	*1.35648E-10*	*-147.9045487*	*-89.30786729*	*-147.905*	*-89.3079*
X Variable 1	*-0.291018104*	*0.055418568*	*-5.25127*	*3.40839E-06*	*-0.402444604*	*-0.179591604*	*-0.40244*	*-0.17959*

**Significant Mean and Linear bias

5 Discussion and Recommendations

System functionality was accomplished. However, feasibility of this technology to adequately predict feed still requires more research. Based on the working mechanical construction and the photogrammetric models further research should focus on exact determination of various feed types.

For the first assessment the concrete trough was filled with dried corn. Resulting volume calculations showed differences in the magnitude of approximately 5% after elimination of the outliers. Expectations on the photogrammetric methods are higher.

With any photogrammetrically derived model there is always an inherent amount of noise produced in the model. Noise can be defined as the amount of variation from reality (observed) that the photogrammetric modelling calculates (predicted). While this study aimed to reduce and quantify these factors the results proved to be unreliable and result in bias in their predictive capabilities.

Other feed types might provide a better ‘photogrammetric structure’ than corn. Aggregated corn has a very uniform appearance, potentially an unfortunate structure for computer vision algorithms used in the software. While a mix of silage and haylage could provide better results due to a different visual appearance.

Figure 19. Close-up photo of the used corn

Further it is not clear yet what causes the remaining volume differences. Also unknown is the cause of outliers in the 3-D models or at a minimum how to set parameters to filter outliers. Below are graphs showing estimated, but unconfirmed, error sources.

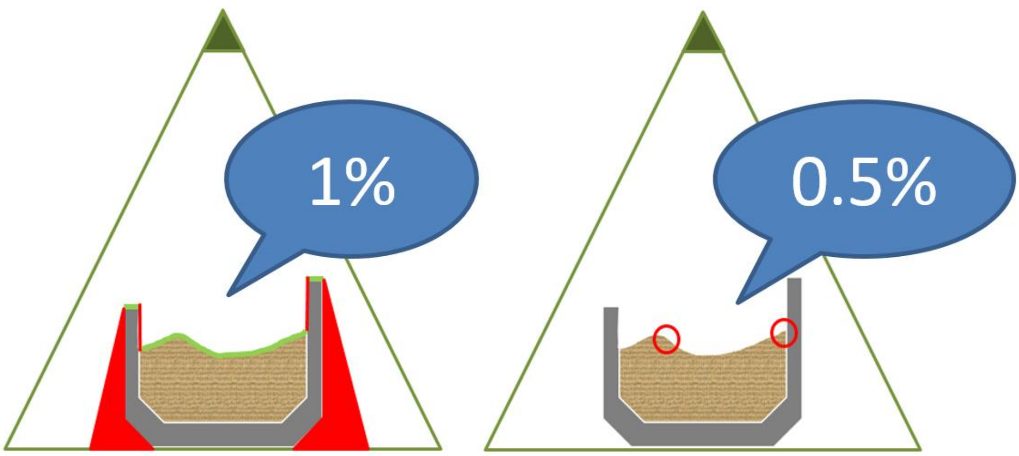


Figure 20. Estimated impacts on the volumes due to artefacts, lightning, and modelling.

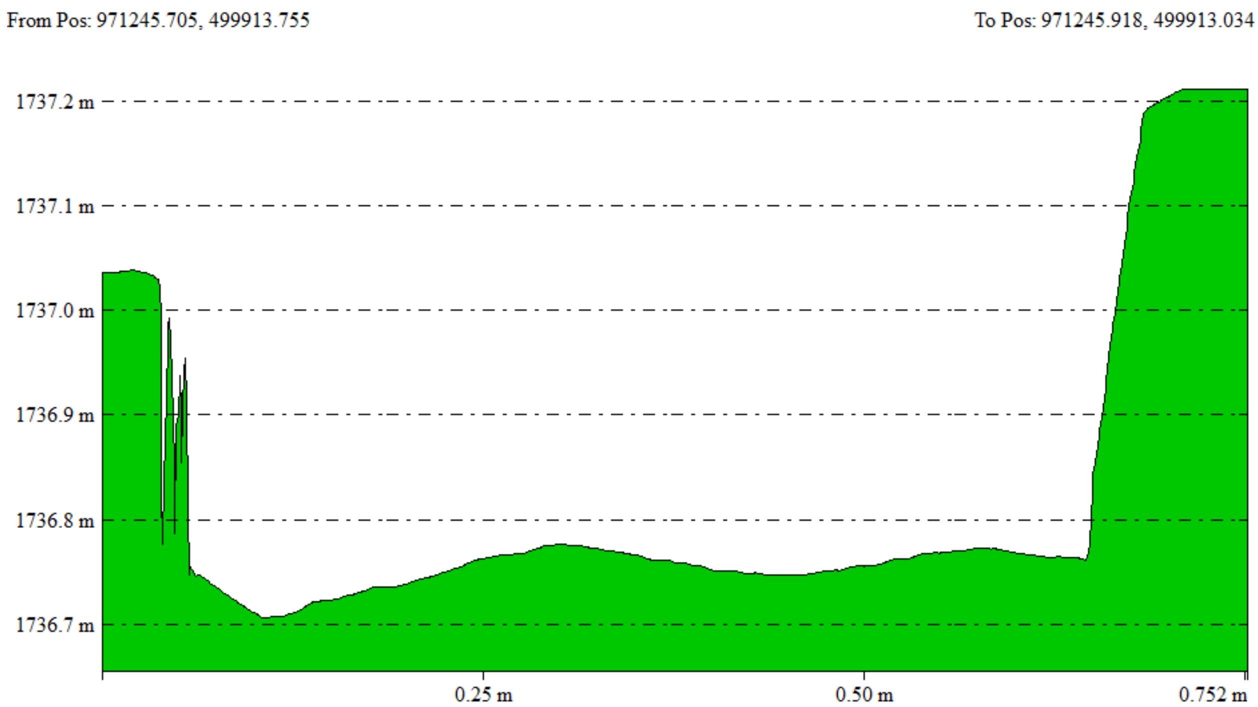


Figure 21. Gaps in the trough caused some difficult to filter artefacts in the 3-D model. The above cross section of the 3-D model demonstrates the “noise” in the data.

6 Additional uses for Photogrammetric and remote sensing technologies in the Cattle Production Industry.

While volumetric calculations related to the amount of feed in the actual feed bunk still requires more research other areas where this system could prove to be useful to the industry include;

1. Monitoring and measuring manure generation inside a feed lot pen.
2. Modelling biometrics of cattle for body weight and body dimension calculations.
3. Detection of feed contamination in feed bunks e.g. foreign objects or fecal matter.
4. Mounting the system to a UAV to visually observe open range cattle migrations.
5. Modelling surface water run-off to manage effluent contamination from large feed lot operations.

7 Bibliography

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Shervias K (2016) 'Structure from Motion Guide for Instructors and Investigators.' (UNAVCO Academic and Professional: unavco.org)

National Cattlemen's Beef Association NCBA (2017) 'Beef Industry Statistics' http://www.beefusa.org/beefindustrystatistics.aspx. 4/4/2018

Recker S, Shashkov M, Hess-Flores M, Gribble C, Baltrusch R, Butkiewicz, Joy K (2014) *Structure-From-Motion Systems for Scene Measurement.* Quality Digest. www.qualitydigest.com. November 13, 2014.

8 Appendix A

Quality Report

Generated with Pix4Dmapper version 4.3.27

Important: Click on the different icons for:

Help to analyze the results in the Quality Report

Additional information about the sections

Click here for additional tips to analyze the Quality Report

Summary

Project	Empty_01_SP
Processed	2018-09-19 10:43:12
Camera Model Name(s)	ILCE-7S_E24mmF1.8ZA_24.0_2768x1848 (RGB)
Average Ground Sampling Distance (GSD)	0.09 cm / 0.04 in
Time for Initial Processing (without report)	04m:02s

Quality Check

Images	median of 17215 keypoints per image	✓
Dataset	50 out of 50 images calibrated (100%), all images enabled	✓
Camera Optimization	1.62% relative difference between initial and optimized internal camera parameters	✓
Matching	median of 11483.6 matches per calibrated image	✓
Georeferencing	yes, 6 GCPs (6 3D), mean RMS error = 0.007 m	⚠

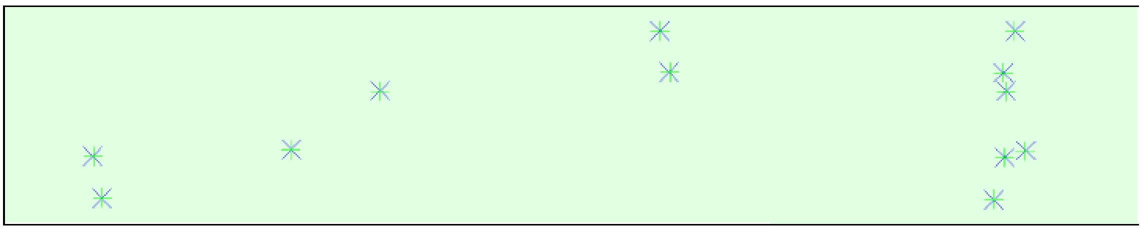
Calibration Details

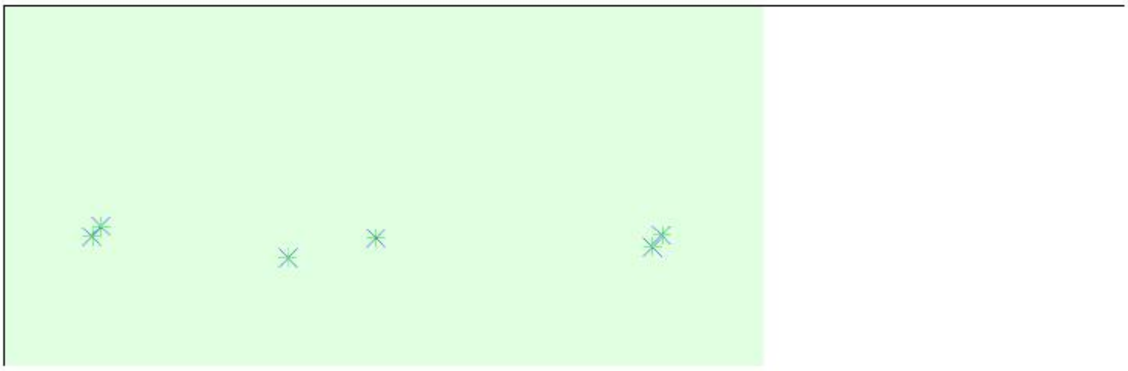
Number of Calibrated Images	50 out of 50
Number of Geolocated Images	0 out of 50

Initial Image Positions

The preview is not generated for images without geolocation.

Computed Image/GCPs/Manual Tie Points Positions





Uncertainty ellipses 50x magnified

Figure 3: Offset between initial (blue dots) and computed (green dots) image positions as well as the offset between the GCPs initial positions (blue crosses) and their computed positions (green crosses) in the top-view (XY plane), front-view (XZ plane), and side-view (YZ plane). Dark green ellipses indicate the absolute position uncertainty of the bundle block adjustment result.

Absolute camera position and orientation uncertainties

	X[m]	Y[m]	Z[m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.001	0.002	0.001	0.043	0.016	0.007
Sigma	0.000	0.000	0.000	0.000	0.002	0.002

Bundle Block Adjustment Details

Number of 2D Keypoint Observations for Bundle Block Adjustment	594746
Number of 3D Points for Bundle Block Adjustment	171704
Mean Reprojection Error [pixels]	0.147

Bundle Block Adjustment Details

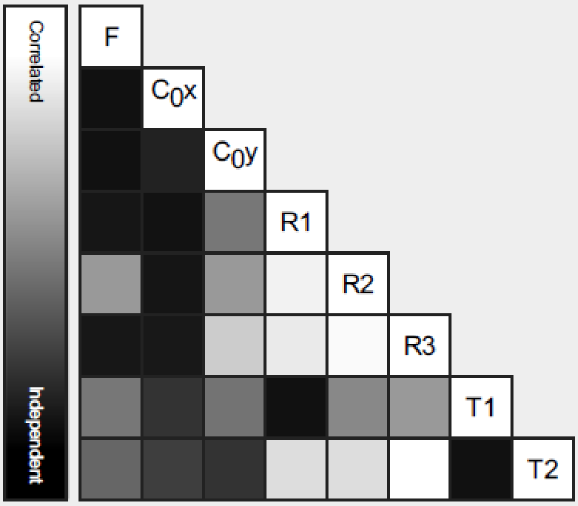
Number of 2D Keypoint Observations for Bundle Block Adjustment	594746
Number of 3D Points for Bundle Block Adjustment	171704
Mean Reprojection Error [pixels]	0.147

Internal Camera Parameters

ILCE-7S_E24mmF1.8ZA_24.0_2768x1848 (RGB). Sensor Dimensions: 23.333 [mm] x 15.578 [mm]

EXIF ID: ILCE-7S_E24mmF1.8ZA_24.0_2768x1848

	Focal Length	Principal Point x	Principal Point y	R1	R2	R3	T1	T2
Initial Values	2847.086 [pixel] 24.000 [mm]	1384.000 [pixel] 11.667 [mm]	924.000 [pixel] 7.789 [mm]	0.000	0.000	0.000	0.000	0.000
Optimized Values	2800.962 [pixel] 23.611 [mm]	1360.279 [pixel] 11.467 [mm]	935.429 [pixel] 7.885 [mm]	-0.002	0.080	0.101	0.000	0.001
Uncertainties (Sigma)	0.978 [pixel] 0.008 [mm]	0.345 [pixel] 0.003 [mm]	0.446 [pixel] 0.004 [mm]	0.000	0.002	0.004	0.000	0.000



The correlation between camera internal parameters determined by the bundle adjustment. White indicates a full correlation between the parameters, ie. any change in one can be fully compensated by the other. Black indicates that the parameter is completely independent, and is not affected by other parameters.

The number of Automatic Tie Points (ATPs) per pixel, averaged over all images of the camera model, is color coded between black and white. White indicates that, on average, more than 16 ATPs have been extracted at the pixel location. Black indicates that, on average, 0 ATPs have been extracted at the pixel location. Click on the image to the see the average direction and magnitude of the re-projection error for each pixel. Note that the vectors are scaled for better visualization. The scale bar indicates the magnitude of 1 pixel error.

2D Keypoints Table

	Number of 2D Keypoints per Image	Number of Matched 2D Keypoints per Image
Median	17215	11484
Min	14289	8328
Max	30414	19369
Mean	17766	11895

3D Points from 2D Keypoint Matches

	Number of 3D Points Observed
In 2 Images	83000
In 3 Images	31929
In 4 Images	18460
In 5 Images	12282
In 6 Images	8536
In 7 Images	6196
In 8 Images	4433
In 9 Images	3059
In 10 Images	2259
In 11 Images	1192
In 12 Images	257
In 13 Images	77
In 14 Images	21
In 15 Images	3

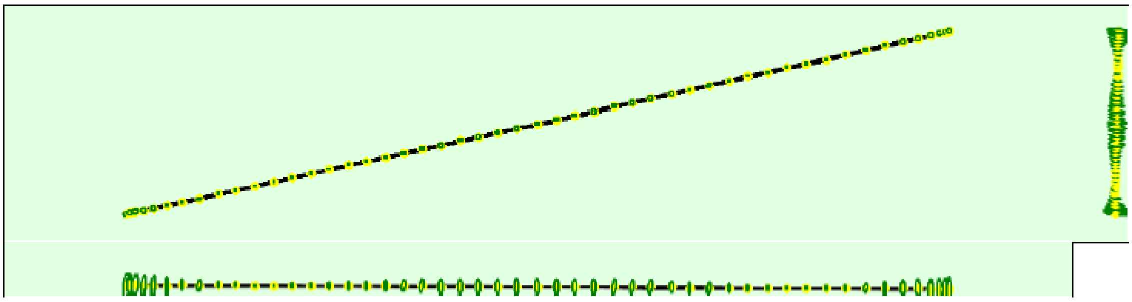


Figure 5: Computed image positions with links between matched images. The darkness of the links indicates the number of matched 2D keypoints between the images. Bright links indicate weak links and require manual tie points or more images. Dark green ellipses indicate the relative camera position uncertainty of the bundle block adjustment result.

Relative camera position and orientation uncertainties

	X [m]	Y [m]	Z [m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.000	0.000	0.001	0.007	0.030	0.006
Sigma	0.000	0.000	0.000	0.003	0.015	0.003

Geolocation Details

Ground Control Points

GCP Name	Accuracy XY/Z [m]	Error X [m]	Error Y [m]	Error Z [m]	Projection Error [pixel]	Verified/Marked
target 1 (3D)	0.020/ 0.020	-0.008	-0.009	0.000	0.390	8 / 8
target 2 (3D)	0.020/ 0.020	-0.005	-0.003	0.003	0.347	8 / 8
target 10 (3D)	0.020/ 0.020	0.009	0.014	0.003	0.261	8 / 8
target 15 (3D)	0.020/ 0.020	-0.003	-0.004	-0.009	0.527	9 / 9
target 16 (3D)	0.020/ 0.020	-0.007	-0.005	0.009	0.381	9 / 9
target 23 (3D)	0.020/ 0.020	0.014	0.007	-0.006	0.369	10 / 10
Mean [m]		0.000000	0.000001	-0.000026		
Sigma [m]		0.008304	0.008023	0.005986		
RMS Error [m]		0.008304	0.008023	0.005986		

Localisation accuracy per GCP and mean errors in the three coordinate directions. The last column counts the number of calibrated images where the GCP has been automatically verified vs. manually marked.

Initial Processing Details

System Information

Hardware	CPU: Intel(R) Core(TM) i7-4870HQ CPU @ 2.50GHz RAM: 16GB GPU: NVIDIA GeForce GTX 670 (Driver: 23.21.13.9135)
Operating System	Windows 10 Pro, 64-bit

Point Cloud Densification details

Processing Options

Image Scale	multiscale, 1/2 (Half image size, Default)
Point Density	Optimal
Minimum Number of Matches	4
3D Textured Mesh Generation	yes
3D Textured Mesh Settings:	Resolution: Medium Resolution (default) Color Balancing: no
LOD	Generated: no
Advanced: 3D Textured Mesh Settings	Sample Density Divider: 1
Advanced: Image Groups	group1
Advanced: Use Processing Area	yes
Advanced: Use Annotations	yes
Time for Point Cloud Densification	04m:37s
Time for Point Cloud Classification	NA
Time for 3D Textured Mesh Generation	02m:08s

Results

Number of Generated Tiles	1
Number of 3D Densified Points	1647978
Average Density (per m^3)	3.48864e+06