

ABSTRACT

ABNER, VICTORIA ANN. Accurate and Rapid Weight Assessment of Finishing Pigs. (Under the direction of Dr. Jonathan Holt).

Accurate pig body weight assessment is an important factor in managing swine herds and imperative when determining acceptable market weights. Pigs marketed outside the desired weight range established by the packer can lead to severe economic loss to the producer. A producer can gain a premium if the carcass weight falls within the ideal range but may lose up to \$99,000 on a 2,400 head barn in a worst-case scenario. A multitude of methods have historically been tried and evaluated in terms of accuracy and practicality. These include but are not limited to body measurements, individual or pen scales, human observation, and cameras. Ultimately, producers need a simple method that requires minimal human input, minimizes stress on the pig, and is accurate enough to reduce sort loss. This study's objective was to validate new weight measurement technologies and determine their usefulness on swine farms. Accuracy of three methods were evaluated: human observation, a walk-across platform scale (CIMA; Correggio, Italy), and PigVision mounted cameras (Asimetrix Inc; Durham, NC). Weights were validated with a calibrated livestock scale in all three studies. In the first study, a trained individual selected pigs estimated to be market weight at two sites. Site one had 468 pigs and an accuracy of 84.4%, site two had 522 pigs and an 82.5% accuracy. Accuracy was measured by whether the pig was marked correctly in the market weight range. A 16-week study was then conducted to determine PigVision camera accuracy over time from placement to market. Cameras were mounted above 12 pens. Weights were validated every two weeks. The accuracy for pigs that weighed 32.7 kg (87.7%) was lower ($P < 0.05$) than the accuracy for pigs that weighed 117.5 kg (97.6%) or 125.7 kg (96.6%). The overall accuracy from placement to market was 94.1%. A final study at market compared human observation, the walk-across scale, and PigVision. A total

of 91 pigs were weighed with each method. The accuracy for the walk-across scale was 98.2%. The walk-across scale did not register a weight for six pigs. Final accuracies were 88.2% for human observation, and 96.6% for PigVision. PigVision and the walk-across scale accuracy were measured by the distance from the individual pig weight recorded. Human observation is the chosen method in many operations today yet offers the lowest accuracy. The walk-across scale is easy to operate but requires tactical animal movement. PigVision is the least arduous option, provides constant data, but does require maintenance. This work was funded by the National Pork Board.

© Copyright 2021 by Victoria Abner

All Rights Reserved

Accurate and Rapid Weight Assessment of Finishing Pigs.

by
Victoria Ann Abner

A thesis submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the
requirements for the degree of
Master of Science

Animal Science

Raleigh, North Carolina
2021

APPROVED BY:

Dr. Jonathan Holt
Committee Chair

Dr. Mark Knauer

Dr. Sierra Young

BIOGRAPHY

Victoria “Tori” Ann Abner was born on December 2, 1996, in Morris, Minnesota to Mark and Dee Ann Abner. She has one younger sister, Mati Abner. Tori began showing pigs at the age of 8 and quickly developed a passion for the swine industry.

In 2015, Tori graduated from Howe High School and began attending Texas A&M University to pursue a Bachelor of Science degree in Animal Science. She spent a summer interning with Iowa Select Farms and the Texas Pork Producers Association; in 2019 she graduated from Texas A&M. Tori moved to Raleigh, NC to pursue a Master of Science in Animal Science with a focus on swine production and technology under the advisement of Dr. Jonathan Holt at North Carolina State University. While at NC State, Tori also worked with the U.S. Pork Center of Excellence as a student editor for the Pork Information Gateway, an online resource for producers. In June of 2021, Tori married her husband, Riley and began her career as a Technical Communications Specialist for PIC.

ACKNOWLEDGMENTS

First and foremost, I'd like to thank Dr. Jonathan Holt for taking a chance on a Texan and welcoming me into the SWaT lab. Thank you for always encouraging me and believing in me; your passion for the industry is contagious and I hope to carry it with me into my career. I would also like to thank my committee members Dr. Mark Knauer and Dr. Sierra Young for all of their support and encouragement throughout my graduate career. Dr. Knauer, you have always been very industry focused and it is great to pursue research with someone in that mindset. Dr. Young, you are an inspiration to all women in your field and I am grateful to have been able to work with and learn from you.

I'd like to thank Lauren Anderson for her constant guidance and help in navigating graduate school. I'd also like to thank Alyx Fisk and Brooke Anderson for their support as fellow graduate students and Bailee Arnold for her incredible help with the Pork Information Gateway. Of course the undergraduates help keep our lab running, and I'm thankful for all of the incredible undergraduates I was able to meet and work alongside. I feel incredibly blessed to have been part of such an incredible lab.

Lastly, I'd like to thank my friends and family for always supporting my dreams. Thank you to my parents, sister, and grandparents for the unwavering support you have given me every step of the way. Mom and Dad, thank you for letting Mati and I get started in show pigs, and supporting us through all of it. A special thank you to Riley, my husband, for always believing in me and pushing me to be the best version of myself.

TABLE OF CONTENTS

LIST OF TABLES	8
LIST OF FIGURES	9
Chapter 1: Literature Review	1
Introduction to Sort Loss	1
Weighing using Individual Scales or Pen Scales	4
Market Weight as Determined by Human Observation.....	5
Weighing using Body Measurements	6
Camera Work in Various Livestock Species	8
Utilization of Cameras as a Weighing Device in Swine.....	10
Conclusion	18
Literature Cited	20
Chapter 2: Accurate and Rapid Weight Assessment of Finishing Pigs	24
Abstract	25
Introduction.....	27
Materials and Methods.....	29
Human Observation	29
PigVision by Asimetrix Mounted Cameras over Time.....	30
Comparison of Multiple Weight Assessment Methods	31
Statistical Analysis.....	32
Camera Data Collection	32
Results	33
Discussion	35
Implications.....	37
Literature Cited	38

LIST OF TABLES

Table 1.1 Tyson Marketing grid from 2012.....	3
Table 2.1 Human Observation marking accuracy.....	33
Table 2.2 Accuracy of comparing multiple weight methods	34

LIST OF FIGURES

Figure 1.1 Length Measurements of a finishing pig	6
Figure 1.2 Width measurements of a finishing pig	7
Figure 1.3 Girth measurement of a finishing pig	7
Figure 1.4 Setup of image capture area in Schofield et al. 1999	12
Figure 2.1 PigVision Accuracy by weight over time	34

CHAPTER 1: LITERATURE REVIEW

Introduction to Sort Loss

Assessment of pig body weight is an important factor in the management of a swine herd but may be most important when trying to determine acceptable market weights. Countless authors including Brandl and Jorgensen (1996), Pope and Moore (2002), Wu et al. (2004), and Wang et al. (2008) have all cited the benefits of weighing pigs from a management viewpoint. One of the main reasons to know the weight of the pig is for marketing purposes. While the final live weight is important, the producer is often paid based on a grid system once the pigs are marketed, though the method of payment will vary between the contracts held amongst producers and the processing facility. Countless grids have been utilized and reported throughout the industry (Boland et al., 1999; Niemi et al. 2010). Some grids award the producer a premium if a carcass falls within the most desired weight range and is leaner than average carcasses (IPC, 2015). Within this grid system, pigs must have a carcass weight or live weight within a set threshold in order to receive a premium for the animal.

Packing plants strive for consistency to ensure the retail cuts displayed in a grocery store are visually similar to consumers. In order to achieve this, a team or experienced individual is tasked with “marking” the targeted number to fulfill the load of pigs to be shipped (McBride and Key, 2003). The ultimate goal is to ensure the pigs selected to market fall within the desired range the packing plant has set for the producer. If the weight falls outside of the desired range, the producer receives a predetermined discounted market price. If the live weight of an animal is substantially lower than the threshold, the animal may be turned away outright and not allowed to enter the packing plant. This discount is commonly referred to as “sort loss” in today’s commercial farms (Cheng et al., 2018; Keeler et al., 1994).

Although pigs are managed in large pens and large group settings, due to extenuating factors such as genetics, sex, and environment the animals will not fall within the desired weight range simultaneously (Schinckel and De Lange, 1996). Sort loss occurs when the market-sized pigs are not shipped and instead are skipped over. This can happen if there are pigs that are well above the desired weight range in the pen, making market-ready pigs look smaller in comparison (Cabezón et al., 2016). Comparison also poses a threat to animals that are too small but look big compared to extraordinarily small pen mates. Lastly, errors can occur when an animal is simply skipped over or not evaluated (Cabezón et al., 2016). However, the accuracy of manual sorting was not evaluated and reported until approximately 2017 (Boys et al., 2007; Khamjan et al., 2013; Que et al., 2017). In 2016, Que et al. performed a case study on sorting accuracy and later evaluated the financial effects of sort loss. The study found that the second cut of pigs often had much higher sort loss if the first load was inaccurately sorted to begin clearing the barn out. Although, no single value was selected for sort loss as it varied based on carcass weights due to the payment grid (Que et al., 2016).

Producers often schedule multiple truckloads to be shipped out over a period of time that varies in length depending upon the capacity of the barn. Since there are multiple opportunities for a pig to be shipped, it is essential that they are shipped at the correct time in order to maximize the chance that the animal falls within the premium price based on their weight. Barring the cost of transportation and labor, it would be more profitable for producers to add more market cuts to hit the target weight for all pigs (Zhou and Bohrer, 2019). A study by Cheng completed in 2018 showed that the ideal carcass weight for their particular processing facility ranged from 172 to 218 pounds, placing the live weight range at approximately 230 to 290 pounds based on National Pork Board's most recent estimate of dressing percentages. A carcass

weight that falls above the desired threshold may lose up to \$15.28/cwt according to a 2012 Tyson marketing grid. If the animal is not marketed on the optimal day. If the carcass fell below 139 pounds, it was discounted \$18.71/cwt (Cheng, 2018). Most barns can hold around 4,000 animals, so the numbers quickly begin to add up after the entire barn has been marketed. Ideally, all carcasses would fall within 177-218 pounds and no discounts would be received. Based on current published discounts, a carcass of 219 pounds would be discounted a total of \$2.91. Additionally, a carcass weighing 272 pounds, which would be approximately a 370-pound live animal, would be discounted a total of \$41.56. When these numbers are viewed as a worst-case scenario, a producer with a 2,400 head finishing barn could lose from \$7,000 - \$99,000 when one barn is marketed.

Table 1.1: Tyson marketing grid from 2012. (Cheng et al., 2018)

Carcass weight, lb	Discount, \$/CWT
< 139	18.71
140-146	14.62
147-155	11.82
156-163	8.08
164-171	3.37
172-218	0
219-225	1.33
226-233	2.67
234-240	4.67
241-248	7.00
249-255	9.00
256-263	10.67
264-271	12.67
> 272	15.28

While producers continue to aim for marketing their largest animals first, packers continue to offer little to no incentive for groups with less variation (Schinckel et al., 2020). It is

in the producers' best interest to market pigs that should yield the highest carcass weight which is directly correlated to body weight. This will also allow them to qualify for lean percent premiums (IPC, 2015). However, with sorting accuracies in today's farms around 48, 52, and 56% (Schinckel et al., 2020), additional methods may need to be implemented to ensure pigs are sold correctly and at the optimal time.

Weighing using Individual Scales or Pen Scales

One of the most accurate ways to decrease sort loss and increase profits would be to individually weigh each animal on or near the date these animals are to be marketed and indicate which animals are to be shipped. Weighing animals has long been used by producers to monitor the herd's output (Brandl and Jorgensen, 1996). Individually weighing animals is a great way to manage the progress, feed efficiency, and growth rate of each animal (Halachmi and Guarino, 2016). Weighing animals has also been used as a method of management for detecting disease within the barn (Brandl and Jorgensen, 1996). While direct weighing of the animal using a scale is undoubtedly the most accurate method, it is a difficult and time-consuming option that is often not feasible in a commercial operation. Many operations do not have an individual scale or any type of pen scale on farm due to the cost or lack of use. If the pigs are weighed often, the additional cost of labor and time would increase substantially. According to Brandl and Jorgensen (1996), weighing each pig individually requires two people and can take up to five minutes per animal, depending on their size. If the only weighing occurs toward the end of closing the barn out, the animals will not be acclimated to moving to the scale or the environment surrounding the scale. Thus, the weighing has great potential to induce unnecessary stress on the animal prior to shipping as well as the animal caretakers (Pezzuolo et al., 2018;

Schofield, 1990). The stress placed on the animal from this process can cause weight loss, health problems, and in the most extreme scenarios, death (Schofield, 1990; Wang et al., 2006).

Another on-farm scale option is a scale placed in each pen, in front of a common location such as the feeder or water source. However, these too are problematic as the animal must be fully and individually on the scale in order to read accurately. The pen environment plays a large role in the accuracy of these scales as well. If a scale is not completely cleaned off, feces can alter the reported number. Lastly, the mechanics of the scale must remain clean, working, and intact which can be difficult to maintain in a pen that is constantly full of animals (White et al., 2004).

Utilizing a scale is undoubtedly the most accurate method to determine if a pig has reached market weight. However, it is widely known that this method is not economically or ergonomically feasible for most producers. Even if a barn has the financial or physical capabilities to incorporate individual weighing into their management strategy, the stress placed on both the animal and handler to accomplish this task will far outweigh the benefits.

Market Weight as Determined by Human Observation

The most common method in today's farms to choose pigs with an ideal weight is by a subjective visual evaluation of all animals. The individual tasked with this responsibility is often highly experienced and familiar with the genetics, nutrition, and management methods in that barn. Unfortunately, even the most trained individuals can be inaccurate at times. Cabezon et al (2018) cites two different types of sort loss incurred by human evaluation for sorting market loads: 1) error in estimating the live weight of an animal and 2) pigs that are not evaluated at all possibly due to reaching a target number of pigs marketed prior to reaching all pens. In a

simulation performed by Cabezon (2018), there were three cuts, two at 25% of the barn and the final cut would include the remainder of the barn or 50%. Barn A marketed with 59.3% accuracy, Barn B at 53.3% accuracy, and Barn C had 57.7% of pigs sold correctly. Though this is the method of choice for many producers, there is a lack of literature studying the accuracy of visual market weight observation. Ultimately, more research is needed to determine whether producers are accurate in an on-farm setting.

Weighing using Body Measurements

Another valid option to determine market readiness would be to measure the size of animals via length, width, and heart girth measurements. In 1955, it was stated linear measurements of the animal could be just as useful as mass measurements (Hammond, 1955). Although, this method fell out of practice as it was difficult and replaced with the use of scales (Whittemore and Schofield, 2000).

The length of a pig can be measured in two different ways. The first includes the head from the tip of the snout to the base of the tail (solid line). The second includes the anterior scapula and ends at the base of the tail (dashed line) (McGlone et al., 2004).

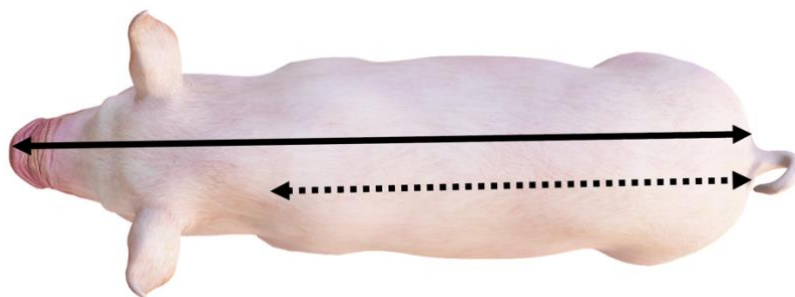


Figure 1.1: Length measurements of a finishing pig.

The width of a pig can be measured in multiple places. O' Connell et al. measured sow width at the widest point of the shoulder (solid line), the last rib (small dotted line) and the widest part of the ham (large dashed line) (O' Connell et al., 2007).

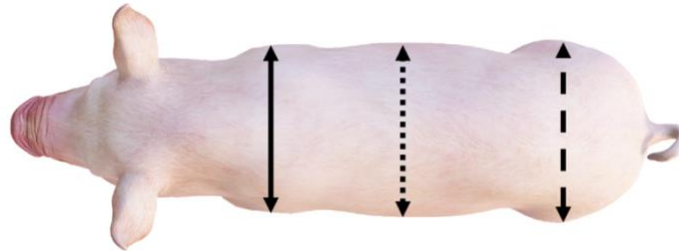


Figure 1.2: Width measurements of a finishing pig.

In 1977, Yeo and Smith set the standards for measuring girth as a weight predictor in sows. Girth of a pig is measured right behind the forearm and reaches all the way around the animal, it is read at the top of the shoulders (depicted by the solid arrow in the figure below) (Groesbeck et al., 2002). It is important to measure girth when the animal's head is down or level with its body. Once the animal's head is raised above the shoulders, the girth increases and can be inaccurate (Groesbeck et al., 2002).

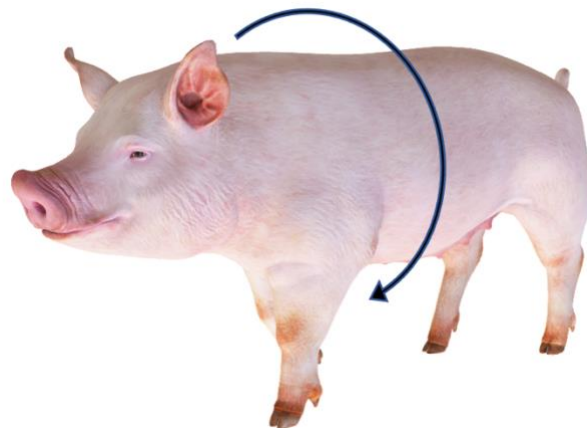


Figure 1.3: Girth measurement of a finishing pig.

In 2002, Groesbeck et al. (2002) evaluated the accuracy of heart girth in finishing pigs. Two different test groups were utilized: commercial pigs from the Kansas State University farm and show pigs from the Swine Classic Youth Exposition. A correlation between the commercial pigs' girth and weight was found ($R^2=0.98$). The show pigs had a greater variation most likely due to transportation shrink and stress causing weight loss and affecting gut fill. It is essential that the girth is measured correctly, specifically in the scenario using the regression equation derived from Groesbeck et al. Being two or three centimeters off can result in a 4.5-kilogram inaccuracy. It is also recommended to keep the animals on full feed and water to decrease the chance of inaccuracies (Groesbeck et al., 2002).

However, to manually take these measurements in person requires the pig to be immobilized. This is often difficult to obtain when an animal is in a large group pen as is often the case in a commercial farm (Brandl and Jørgensen, 1996). Also, physically obtaining these measurements requires increased human interaction with each individual animal. If these animals are not accustomed to this, it will cause unnecessary stress and can result in inaccurate measurements (Pope and Moore, 2002). This method has long been considered as an option, but ultimately is decided to be too time consuming and inaccurate to take the place of manually weighing each pig. Although, body measurements have served as the basis for introducing camera technologies as a weighing device in a study completed by Schofield et al in 1999.

Camera Work in Various Livestock Species

While the world continues to develop technological advancements each and every day, the livestock production sector seems to be following the same path. Cameras have been utilized in dairy cattle weights and milking abilities, broiler chicken weights, sheep production and

slaughter, behavior, and even structural soundness in horses (Pallottina et al., 2015; Kuzuhara et al., 2014; Menesatti et al., 2014; Pezzuolo et al., 2018; Nir et al., 2018; Mortensen et al., 2016)). Cameras allow for an infinite number of observations and details to be obtained without interfering with the animal. By moving simple tasks like weighing and carcass measurements to camera technologies, the need for excess labor to fulfill this role is limited.

Dairy cattle are often still manually measured to determine body dimensions. In 2018, Nir et al. developed a quantile regression to extract human estimated weight, hip height, and withers height. They implemented it into a Microsoft Kinect V2 Time-of-Flight sensor that is very similar to a camera. The trial included 107 Holstein heifers, some of which were a training set and the remainder served as a test set for the algorithm. The cameras were installed to obtain a top-down image at a height of 2.8 meters in a high traffic area. An ellipse was fitted to the image of the heifer to obtain body mass. For hip height, an R^2 value of 95.2% was obtained withers height resulted in an R^2 value of 98.5% and body mass an R^2 value of 94.6%. The manager also had less interaction with the heifers potentially reducing the stress on animals. The study set the framework for other dairy farms to implement this technology and more research to be done on a larger scale (Nir et al., 2018).

Broiler chickens are often weighed in house using a platform that is voluntarily visited. Since it is voluntary, it is likely that the weight of the barn can easily be misrepresented as large birds tend to avoid stepping up to the platform. In 2016, Mortensen et al. utilized a Kinect camera to obtain weights from a one meter² area. The camera was placed above the platform to validate weights captured. Approximately 13,000 images were captured of 83 broiler chickens. As this was one of the first steps to implement camera weighing in poultry, weights fluctuated from 20-250 grams. It was noted that wing flapping caused drastic changes along with head

movements; removing these frames from the algorithm narrowed the weight fluctuation range. An average relative mean size error of 7.8% between camera weights and platform weights was reported. Using this technology, farmers would also be able to implement other monitoring techniques that could benefit managerial decisions (Mortensen et al., 2016).

Menesatti et al. (2014) utilized two high-resolution web cameras to capture three-dimensional images of Alpagota sheep. The cameras were placed at the same height a short distance from each other. Only 27 sheep were tested on this system as a calibration method. When the sheep were within 10 meters of the setup, the mean size error was always below 2%. Although this seems fairly accurate, the sample size would need to be increased to relate to commercial type operations. The benefits of this device are how inexpensive the equipment is and the ease of setup; this proves promising for future use in production and research (Menesatti et al., 2014).

Utilization of Cameras as a Weighing Device in Swine

Use of cameras is one alternative to the aforementioned laborious or inaccurate methods to determine the weight of the pig. Various imaging systems claim to have the capability to rapidly predict the weights of an animal based on an image. These images are processed through a specialized software and algorithm to provide a weight estimate. Some cameras utilize only a top-down image, either extrapolating body measurements and dimensions to conclude a weight (Brandl and Jørgensen, 1996; Wang et al., 2008; Lu et al., 2018) or utilizing a preexisting algorithm to provide immediate data (Kashiha et al., 2014). Some utilize multiple two-dimensional cameras to recreate a three-dimensional model to assist in predicting body weight (Wu et al., 2004; Pezzuolo et al., 2018). The use of three-dimensional cameras is also very

common, as the algorithm is able to determine the volume of the pig and thus correlate a weight to that determined number (Konsgro, 2014).

Schofield et al. (1999) is cited in several papers as one of the original innovators in the field of camera weighing in swine barns. They captured a top-down image as well as a simultaneous side image, utilizing only one camera. By taking the images simultaneously, they eliminated the opportunity for the pig to move or shift in any way and alter the surface area seen by the camera. In order to do this, they placed a mirror above the animal at a 45-degree angle and captured the image from a distance. A video camera was assembled on a tripod 7.4 meters from the pen front (Figure 1.4). The 15 pigs were photographed weekly until they reached a final weight of 80 kilograms. Immediately after image capture, each pig was weighed to validate the image predicted weight. The pigs were also weighed two days prior to and after image capture to ensure a normal growth curve. This eliminated any oddity that would occur due to lack of eating or a full stomach. The pigs were weighed at the same time each week to maintain consistency. They utilized three different areas for weight prediction: whole top view, top view without head and ears, and top view without head and neck. Ultimately, they found that they were able to predict the weight of a 75-kilogram pig (without the head and neck) within 6.2%. This decreased to 8.5% for a 52-kilogram pig and even further to 15.4% for a 30-kilogram pig. The best prediction occurred on images where the pig was stationary, and no legs were visible from the top view. This group struggled to find ideal lighting and image quality in barns at the time (Schofield et al., 1999). However, they certainly set the groundwork for the technological improvements that would follow their experiment.

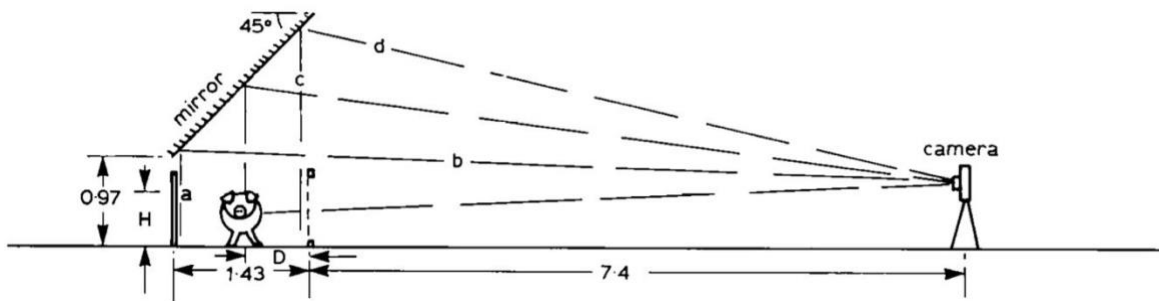


Figure 1.4: Setup of image capture area (Schofield et al., 1999)

In 1996, Brandl and Jørgensen evaluated camera weighing in blocks comparing pelleted and meal feed and ad libitum versus restricted diets. Each block contained four pigs: two barrows and two gilts. They replicated the trial three times for a total of 416 pigs, each weighed five or six times. Their focus was on pigs in the growing stage ranging from 25 to 100 kilograms. The camera was placed above the pen with a calibration scale on the floor to ensure extrapolated body measurements were correct. They found an almost linear relationship between the logarithm of the area of the animal from the top-down image and the logarithm of weight. Using this, they were able to estimate weights with a 5-6% deviation. They noted that while this is not precise, the exact precision is not of utmost importance in typical commercial settings due to the nature of (Brandl and Jørgensen, 1996). Compared to other studies, this sample size is very large and fairly accurate. This study set the stage for others in this field. It is highly referenced in papers written on this topic.

In 2008, Wang et al. combined a walk-through system and machine vision to weigh pigs. The study consisted of 61 Yorkshire and Landrace crosses, 39 for the training of the artificial neural network (ANN) and 22 to test the ANN. The weights ranged from 14 kilograms to 123 kilograms. Each weight was validated immediately after imaging with a mechanical scale calibrated to the kilogram. A color digital camera was connected to a computer and a lower resolution (640 x 480) was utilized in order to speed up data transfer. The camera was mounted

2.21 meters off the ground. The walkway was one meter wide and well-lit with two lamps. The images taken were from the top-down at a rate of 15 frames per second. A code was written to automatically select images; but as a control, manual selection was also employed. The only criteria for manual selection were that the entire pig be captured in the frame and there was no contact with the edges of the photo frame. The same were true for automatic selection, but additional parameters were also incorporated such as the head had to be up and visible to a certain extent and the pig had to be somewhat in the middle of the frame. To increase weight estimation accuracy, the head and ears were removed, and the remainder of the features were extracted from the image using MATLAB. Using the automatically selected images and scale-measured weight, the R^2 value was calculated to be 0.9925 indicating a high accuracy for weight prediction. The average relative error was 3% on a small sample size (Wang et al., 2008). Since this method requires very little unnatural handling of the pig, it is not likely to place stress on the animal. Although the setup is bulkier than a mounted camera or handheld device, many farms may have the ability to fit it in the alley between pens. The only requirement would be moving the animals through the machine to immediately capture weights, which could be done on the day of marketing potentially.

Following suit, Lu et al. utilized cameras to measure the dimensions of pigs to then predict weights. Only six pigs ranging from 80-90 days old were utilized to collect data. No specific weights were ever provided, only estimated age. A Kinect camera was mounted 2.28 meters above the slatted pen floor, and an RFID reader was installed in the feeder. The camera focused on the feeder so the RFID tag would correspond with the captured image. Each pig had a tag in one ear, the feeder was setup in a stall manner so only one animal could feed at a time. The system was set to capture an image after the tag reader was activated. Using a MATLAB

software, analysts would select body features of each pig in order to calculate dimensions. Unlike other studies extricating dimensions from images, Lu et al. focused on skeleton and backbone line extraction. This allowed the software to account for the animal's contour and different posture that often affects the surface area seen from a top-down image. Utilizing the six live animals, an algorithm was developed to test on 150 images of top-down pigs. 24 images were removed because of interference from other pigs resulting in a final test of 126 images. An accuracy of 97.71% was found using a four-step process called body shape dimensions parameters extraction algorithm (BSDPE) to predict pig weights (Lu et al., 2018). Though specific weights are not mentioned, it can be assumed that these are not finisher pigs and thus could not be applied to finishing pigs right away. With the RFID system incorporated, it is possible to see how the animal is growing and could be implemented in other ways. By consistent measuring, a growth curve could be developed and trips to the feeder can also be accessed to ensure health of the animal.

Taking a new approach, Kashiha et al. (2014) constantly monitored weight using a mounted camera above four pens of ten grower-size pigs for a total of 40 animals and was replicated once. Data from the first trial was utilized to create an algorithm for the latter trial. This trial used an average beginning weight of 23 kilograms through a final average weight of 45 kilograms. Lights were left on for a controlled 12 hours to ensure adequate images were captured. Panasonic cameras were mounted 2.2 meters above the floor. They captured images from videos at 25 frames per second for 13 days. The goal was to estimate both a pen average and individual weights, so each pig had a unique shape and/or placement on their back. A combination of lines, circles, and squares were placed either at the shoulders or hips. To validate weights, pigs were weighed twice weekly to the nearest kilogram. MATLAB extracted the

outline of each pig from the images captured to estimate weights. This particular algorithm identified the entire body in one ellipse, a head ellipse, and a corpus ellipse that comprised the body without the head. The three ellipses yield an area of the pig that is essentially used to calculate body weight. Utilizing pixels in the targeted surface area, the body area is entered into an equation that results in a body weight. The weights of individual pigs could be predicted with 96.2% accuracy and pen weights could be predicted with a 97.5% accuracy (Kashiha et al., 2014). While these accuracies are high and the equipment for group weight prediction requires no extra labor to incorporate, there are several issues to be addressed. Unlike other trials evaluating these technologies, this one focused solely on a smaller pig, thus it may have little to no effect on finishing pigs. At the finishing stage, weight plays a large role in marketing and sort loss economics; weights are very rarely taken on commercial farms, especially at the grower stage. Secondly, as mentioned previously, individual weights were also predicted but required unique identifiers on the top side of the animal. In a common pen of 30 or more pigs, it is likely that there would not be enough identifiers for each animal. This is also inconvenient and adds an unreasonable amount of labor for the farm. It is unlikely that the markings will stay clearly identifiable without being rubbed off by others or skewed by dirt or foreign matter. The formula utilized to extract body weights is a step in the right direction for weight prediction, but there are several issues to overcome before implementation can occur on a commercial level.

Similar to extracting body dimensions, Wu et al. (2004) utilized cameras to recreate a three-dimensional shape of the pig. Six Kodak digital cameras and three flash units were arranged into three groups to capture images. Two cameras and a flash were placed at the rear of the pig, on top, and to the side for a total of six images from three different vantage points. All cameras were connected to a computer and immediately transferred images after capturing them.

A slow shutter speed and fast flash speed were found to optimize image synchronization and minimize blurring of the pig. A group of 32 pigs were split in half and fed either a high or low lysine diet to ensure shape differences were present. For 14 weeks images were captured of the pigs; weights ranged from 30 to 80 kilograms throughout this period. In order to capture the image, the pig had to stand in a small area with a specific posture. Two images were captured for each pig in each imaging session. No pigs seemed stressed by the flashes but did seem to stress because of the increased handling and difficulty of positioning the pigs. No weights were predicted or collected, but depths and curvatures were reconstructed within tenths of a millimeter. Ultimately, five pigs from each group had ultrasounds taken and were slaughtered to collect carcass data including lean, fat, and bone percentages (Wu et al., 2004). Though this trial was not directly related to weight prediction, it could prove useful in future technologies to measure width, length, and even girth. Image processing and constructing the 3D model could take up to 90 minutes per animal; this number is likely much smaller now due to recent technological advancements. However, if it is to be relevant in production, either an identification method should be incorporated into the setup, or rapid reconstruction would have to occur.

In 2014, Kongsro utilized 71 (34 Landrace, 37 Duroc) boars ranging from 29 to 139 kilograms to estimate weights via a Microsoft Kinect prototype. Individual feeding stations allowed image capture and weighing to be done simultaneously. The camera was attached to a telescopic rod and held above the feeding station. Boars were herded directly into the station to collect data. 50 frames were taken for each boar. Image selection was manual and only one image per group was employed for weight extraction. The criteria used was that the entire pig be in the frame and eating with the head slightly lowered to obtain what was concluded as the most

uniform and stationary position. The head, tail, and ears were removed from all the selected images. The Kinect system generated a depth map to assist in predicting weights. Ultimately, an accuracy of 99% was found for each of the breeds and a combined prediction, even though muscle mass and shape often differ for these two breeds (Konsgro, 2014). Konsgro was one of the few if not the only to utilize boars in weight prediction by imaging studies. Image selection was the slowest part of the process and could be automated to allow for rapid weight assessment on the farm.

Pezzuolo et al. also tested a Kinect type camera, more specifically a v1 depth model. The two cameras were placed directly above the feeding area and lateral to the feeding area. Wean pigs were monitored for 55 days with an average weight range of 6 to 46.6 kilograms. Each day, three pigs were selected and sent to a separate feeding area to capture body measurements, weight, and images while feeding. Each pig had five to ten images captured while eating. The technology did not allow for simultaneous image capture; one camera was turned off while the other collected data. Using the three-dimensional reconstruction, length (from withers to rump), front height, back height, and heart girth were calculated. These dimensions were also collected manually. A 93.1% accuracy was found predicting heart girth measurements and only an 83.9% accuracy was found for predicting length, accuracy fell to 78% and 84% for back and front height, respectively. Weight estimation accuracy reached up to 99% for the Kinect depth camera (Pezzuolo et al., 2018). While body measurement extractions were relatively inaccurate, weight prediction seemed to be a very strong point for this study. Growth curves were also incorporated into the prediction of weight which could account for the high accuracies. Since many managers are familiar with the genetics and growth curves of the pigs in their barn, it is reasonable to believe that these could be incorporated into the technology if it were to be implemented.

However, placing the camera on the ground in a pen of 30 or more pigs is highly unrealistic and alternative placement should be considered before it could be incorporated into an operation.

Conclusion

It is well-known that constant weighing or measuring of the pig gives a solid basis for growth and health of the animal. Several different manual methods have been tried and tested and ultimately decided to be too labor intensive or stress inducing for the animal. However, the economics of sort loss indicate that some measure of weight is needed to prevent crippling losses due to inaccurate human observations for weight. With the potential to lose anywhere from \$7,000 to \$99,000 in one turn of a barn, it is simple to understand why researchers have investigated cameras as a non-invasive method to capture pig weights.

Given the camera weighing papers reviewed, many have accurately predicted weights and body dimensions on small sample sets of pigs. However, many used wean pigs and grower size pigs for these trials, only on rare occasions were finisher pigs used. This could be utilized to predict weights throughout the entire grow-finish phase, and the algorithm is likely applicable to finishing size pigs. Nonetheless, the groundwork is there for these technologies to be improved upon and incorporated into large scale trials and operations.

A common theme across these studies would be the difficulty of individual identification or total lack thereof. In order to ensure pigs are marketed at the correct time, it would be essential to identify the exact weight of a single animal. While cameras above pens can accurately predict weights, they lack the ability to pair an animal with a weight without using some type of marker drawn on the animal, or an RFID tag and reader.

Ideally, cameras place no extra stress on the animal with excessive measuring or moving. There is more work to be done to include finishing size pigs and larger sample sets. Additionally, identification of the animal coupled with their respective weight needs to be taken into consideration to ensure the correct animal is selected when it comes time to market. Undoubtedly, a majority of these trials were successful and prove promising for future work in this area.

Literature Cited

- Boland, M. A., K. A. Foster, and P. V. Preckel. 1999. Nutrition and the economics of swine management. *Journal of Agricultural and Applied Economics*. 31(1): 83-96. doi: 10.1017/S008130520002879X
- Boys, K. A., N. Li, P. V. Preckel, A. P. Schinckel, and K. A. Foster. 2007. Economic replacement of a heterogeneous herd. *American Journal of Agricultural Economics*. 89(1): 24-35. doi: 10.1111/j.1467-8276.2007.00960
- Brandl, N., and E. Jørgensen. 1996. Determination of live weight of pigs from dimensions measured using image analysis. *Computers and Electronics in Agriculture*. 15(1):57-72. doi:10.1016/0168-1699(96)00003-8
- Cabazon, F., A. P. Schinckel, Y. Que, and N. M. Thompson. 2018. Evaluation of sorting accuracy for market pigs. Purdue Extension Animal Science publication.
- Cabazon, F., A. P. Schinckel, and Y. Que. 2016. Evaluation of statistics to be used to quantify the magnitude of errors in the sorting of pigs for market via simulation. *The Professional Animal Scientist*. 32(4): 495-506. doi: 10.15232/pas.2015-01499
- Cheng, J., J. Claudy, E. Allen, A. P. Schinckel, and N. Thompson. 2018. Pigs and the Tyson foods marketing grid impact of sorting errors on sort loss and optimal market weight for market pigs. Purdue Extension Animal Science publication.
- Cheng, J. 2018. Evaluation of economic improvement in united states and china pork industry through modeling and genetic tools. M.S. Defense. Purdue University, West Lafayette, IN.
- Groesbeck, C. N., R. D. Goodband, J. M. Derouchey, S. S. Tokach, Dritz, J. L. Nelssen, K. R. Lawrence, and M. G. Young. 2002. Using heart girth to determine weight in finishing pigs. *Proceedings of Kansas State University Swine Day*.
- Halachmi, I., and M. Guarino. 2016. Precision livestock farming: A 'per animal' approach using advanced monitoring technologies. *Animal (Cambridge, England)*. 10(9): 1482-1483. doi: 10.1017/S1751731116001142
- Hammond, J. 1955. In: *Progress in the Physiology of Farm Animals*, Butterworths Scientific Publications. London, pp. 395-542.
- IPC. 2013. Indiana Packers Corporation. Procurement Program. Indiana Packers Corp., Delphi, IN.
- Kashiha, M., C. Bahr, S. Ott, C. P. H. Moons, T. A. Niewold, F. O. Ödberg, and D. Berckmans. 2014. Automatic weight estimation of individual pigs using image analysis. *Computers and Electronics in Agriculture*. 107: 38-44. doi: 10.1016/j.compag.2014.06.003
- Keeler, G. L., M. D. Tokach, R. D. Goodband, J. L. Nelssen, and M. R. Langemeier. 1994. Assisting swine producers to maximize marketing returns. *Journal of Extension*. 32(1).

- Khamjan, S., K. Piewthongngam, and S. Pathumnakul. 2013. Pig procurement plan considering pig growth and size distribution. *Computers & Industrial Engineering*. 64(4): 886-894. doi: 10.1016/j.cie.2012.12.022
- Kongsro, J. 2014. Estimation of pig weight using a Microsoft Kinect prototype imaging system. *Computers and Electronics in Agriculture*. 109: 32-35. doi: 10.1016/j.compag.2014.08.008
- Kuzuhara, Y., K. Kawamura, R. Yoshitoshi, T. Tamaki, S. Sugai, M. Ikegami, Y. Kurokawa, T. Obitsu, M. Okita, T. Sugino, and T. Yasuda. 2015. A preliminary study for predicting body weight and milk properties in lactating Holstein cows using a three-dimensional camera system. *Computers and Electronics in Agriculture*. 111: 186-193. doi: 10.1016/j.compag.2014.12.020
- Lu, M., T. Norton, A. Youssef, N. Radojkovic, A. Pe Fernandez, and D. Berckmans. 2018. Extracting body surface dimensions from top-view images of pigs. *International Journal of Agricultural and Biological Engineering*. 11(5): 182-191. doi: 10.25165/j.ijabe.20181105.4054
- Mcbride, W.D., and N. Key. 2003. *Economic and Structural Relationships in U.S. Hog Production*. USDA-Economic Research Service, Washington, DC. Agricultural Economic Report No. 818.
- Mcglone, J. J., B. Vines, A. C. Rudine, and P. Dubois. 2004. The physical size of gestating sows. *Journal of Animal Science*. 82: 2421-2427. doi: 10.2527/2004.8282421x
- Menesatti, P., C. Costa, F. Antonucci, R. Steri, F. Pallottino, and G. Catillo. 2014. A low-cost stereovision system to estimate size and weight of live sheep. *Computers and Electronics in Agriculture*. 103: 33-38. doi: 10.1016/j.compag.2014.01.018
- Mortensen, A. K., P. Lisouski, and P. Ahrendt. 2016. Weight prediction of broiler chickens using 3D computer vision. *Computers and Electronics in Agriculture*. 123: 319-326. doi: 10.1016/j.compag.2016.03.011
- Niemi, J. K., M. Sevón-Aimonen, K. Pietola, and K. J. Stalder. 2010. The value of precision feeding technologies for grow–finish swine. *Livestock Science*. 129(1): 13-23. doi: 10.1016/j.livsci.2009.12.006
- Nir, O., Y. Parmet, D. Werner, G. Adin, and I. Halachmi. 2018. 3D computer-vision system for automatically estimating heifer height and body mass. *Biosystems Engineering*. 173: 4-10. doi: 10.1016/j.biosystemseng.2017.11.014
- O’Connell, M. K., P. B. Lynch, S. Bertholot, F. Verlait, and P. G. Lawlor. 2007. Measuring changes in physical size and predicting weight of sows during gestation. *Animal (Cambridge, England)*. 1(9): 1335-1343. doi: 10.1017/S1751731107000559
- Pallottino, F., R. Steri, P. Menesatti, F. Antonucci, C. Costa, S. Figorilli, and G. Catillo. 2015. Comparison between manual and stereovision body traits measurements of Lipizzan

- horses. *Computers and Electronics in Agriculture*. 118: 408-413. doi: 10.1016/j.compag.2015.09.019
- Pezzuolo, A., M. Guarino, L. Sartori, L. A. González, and F. Marinello. 2018. On-barn pig weight estimation based on body measurements by a Kinect v1 depth camera. *Computers and Electronics in Agriculture*. 148: 29-36. doi: 10.1016/j.compag.2018.03.003
- Pope, G., and M. Moore. 2002. DPI Pig Tech Notes: Estimating Sow Live Weights without Scales; Department of Primary Industries: Queensland, Australia.
- Que, Y., F. Cabezón, and A. P. Schinckel. 2016. Case Study: Evaluation of methods to estimate the magnitude of sorting errors for market pigs. *The Professional Animal Scientist*. 32:507-515.
- Que, Y., F. Cabezón, N.M. Thompson, and A.P. Schinckel. 2017. Evaluation of the effect of errors in the sorting of pigs for market on financial loss at a range of marketing ages. *The Professional Animal Scientist*. 33:575-584. doi: 10.15232/pas.2017-01617
- Schinckel, A.P., P. Preckel, K. Foster, N. Thompson, and F. Cabezón. 2020. Current status of marking hogs in North American and future potential for refinement. *Journal of Animal Science*. (Abstr). 98:44-45. doi: 10.1093/jas/skaa054.080
- Schinckel, A. P., and De Lange, C F M. 1996. Characterization of growth parameters needed as inputs for pig growth models 1,2. *Journal of Animal Science*. 74: 2021. doi: 10.2527/1996.7482021x
- Schofield, C. P. 1990. Evaluation of image analysis as a means of estimating the weight of pigs. *Journal of Agricultural Engineering Research*. 47: 287-296. doi: 10.1016/0021-8634(90)80048-Y
- Schofield, C. P., J. A. Marchant, R. P. White, N. Brandl, and M. Wilson. 1999. Monitoring pig growth using a prototype imaging system. *Journal of Agricultural Engineering Research*. 72(3): 205-210. doi: 10.1006/jaer.1998.0365
- Wang, Y., W. Yang, P. Winter, and L. Walker. 2008. Walk-through weighing of pigs using machine vision and an artificial neural network. *Biosystems Engineering*. 100(1): 117-125. doi: 10.1016/j.biosystemseng.2007.08.008
- Wang, Y. 2006. Non-contact sensing of hog weights by machine vision. *Applied Engineering in Agriculture*. 22(4): 577-582. doi: 10.13031/2013.21225
- Wang, Y., W. Yang, L. T. Walker, and T. M. Rababah. 2008. Enhancing the accuracy of area extraction in machine vision-based pig weighing through edge detection. *International Journal of Agricultural and Biological Engineering*. doi: 10.3965/j.issn.1934-6344.2008.01.037-042
- White, R. P., C. P. Schofield, D. M. Green, D. J. Parsons, and C. T. Whittemore. 2004. The effectiveness of a visual image analysis (VIA) system for monitoring the performance of growing/finishing pigs. *Animal Science (Penicuik, Scotland)*. 78(3): 409-418. doi: 10.1017/S1357729800058811

- Whittemore, C. T., and C. P. Schofield. 2000. A case for size and shape scaling for understanding nutrient use in breeding sows and growing pigs. *Livestock Production Science*. 65(3): 203-208. . doi: 10.1016/S0301-6226(99)00136-0
- Wu, J., R. Tillett, N. McFarlane, X. Ju, J. P. Siebert, and P. Schofield. 2004. Extracting the three-dimensional shape of live pigs using stereo photogrammetry. *Computers and Electronics in Agriculture*. 44(3): 203-222. doi: 10.1016/j.compag.2004.05.003
- Yeo, M. L. and P. Smith. 1977. A note on relationships between girth measurements and sow live weight change. *Experimental Husbandry*.
- Zhou, Z., and B. M. Bohrer. 2019. Defining pig sort loss with a simulation of various marketing options of pigs with the assumption that marketing cuts improve variation in carcass weight and leanness. *Canadian Journal of Animal Science*. 99(3): 542-552. doi: 10.1139/CJAS-2018-0195

CHAPTER 2:
ACCURATE AND RAPID WEIGHT ASSESSMENT OF FINISHING PIGS

ABSTRACT

Accurate pig body weight assessment is an important factor in managing swine herds and imperative when determining acceptable market weights. Pigs marketed outside the desired weight range established by the packer can lead to severe economic loss to the producer. A producer can gain a premium if the carcass weight falls within the ideal range but may lose up to \$99,000 on a 2,400 head barn in a worst-case scenario. A multitude of methods have historically been tried and evaluated in terms of accuracy and practicality. These include but are not limited to body measurements, individual or pen scales, human observation, and cameras. This study's objective was to validate new weight measurement technologies and determine their usefulness on swine farms. Accuracy of three methods were evaluated: human observation, a walk-across platform scale (CIMA; Correggio, Italy), and PigVision mounted cameras (Asimetrix Inc; Durham, NC). Weights were validated with a calibrated livestock scale in all three studies. In the first study, a trained individual selected pigs estimated to be market weight at two sites. Site one had 468 pigs and an accuracy of 84.4%, site two had 522 pigs and an 82.5% accuracy. Accuracy was measured by whether the pig was marked correctly in the market weight range. A 16-week study was then conducted to determine PigVision camera accuracy over time from placement to market. Cameras were mounted above 12 pens. Weights were validated every two weeks. The accuracy for pigs that weighed 32.7 kg (87.7%) was lower ($P < 0.05$) than the accuracy for pigs that weighed 117.5 kg (97.6%) or 125.7 kg (96.6%). The overall accuracy from placement to market was 94.1%. A final study at market compared human observation, the walk-across scale, and PigVision. A total of 91 pigs were weighed with each method. The accuracy for the walk-across scale was 98.2%. The walk-across scale did not register a weight for six pigs. Final accuracies were 88.2% for human observation, and 96.6% for PigVision. PigVision and the

walk-across scale accuracy were measured by the distance from the individual pig weight recorded. Human observation is the chosen method in many operations today yet offers the lowest accuracy. The walk-across scale is easy to operate but requires tactical animal movement. PigVision is the least arduous option, provides constant data, but does require maintenance.

INTRODUCTION

Weighing pigs can prove beneficial to a producer for a multitude of reasons including management, health status, and feed efficiency. However, it may be the most important when determining when to market a barn and which pigs specifically to market first. Pigs are marketed based on the contract a producer holds with a packer, but one common way is a grid system. Producers are rewarded the full price if the pig falls within a predetermined weight range. If the pig falls below or above that weight range, they will be financially penalized on a per hundred weight basis. This discount is referred to as sort loss (Keeler et al., 1994). If the pig falls severely below the range, it is considered a cull and the plant may turn the animal outright. While discounts may seem small on a per animal basis, those discounts can quickly add up. In a worst-case scenario, a producer could lose up to \$99,000 in marketing one barn of 2,400 pigs (Cheng, 2018).

A common method utilized on farms is sending an experienced individual through each pen to “mark” the animals assumed to fall in the ideal market weight range (McBride and Key, 2003). This requires little movement for the animal but requires an experienced individual. However, the lack of sufficient research on sort loss makes it difficult to draw conclusions on the accuracy of visual evaluation. Additionally, moving pigs to an individual or pen scale may be impractical and is unlikely to occur for all pigs on a farm. Measuring animals to estimate weight and reduce sort loss is a laborious method that is also difficult to request producers to utilize. As early as 1999, researchers have been investigating cameras as a tool to evaluate pig weight (Schofield et al., 1999). Multiple camera options have been used; some two-dimensional (Wu et al., 2004; Pezzuolo et al., 2018), some three-dimensional (Konsgro, 2014). Previous research has also used image positioning variations between multiple angles, top-down, or side and used the

images to extrapolate dimensions and predict a weight (Brandl and Jørgensen, 1996; Wang et al., 2008; Lu et al., 2018), some utilized existing algorithms for immediate weight results (Wu et al., 2004; Pezzuolo et al., 2018). Ultimately, none have proved to be readily available to install and utilize on farm to reduce sort loss. This further illustrates the gap that exists in the industry lacking a consistent, non-arduous, yet accurate method to capture market weights. The objectives of this study were to determine the accuracy of multiple options available currently for pork producers to assess the weight of finishing pigs. In order to accomplish these objectives, three individual, yet connected, trials were conducted.

MATERIALS AND METHODS

Human Observation

Two sites were included in the accuracy study on human observation, they will be referred to as Site One and Site Two. At Site One, 522 pigs were estimated. Each concrete-slatted pen contained approximately 20 to 25 pigs, four nipple drinkers, and access to two feeder locations. An employee that is familiar with the genetics, management, and nutrition of the barn marked the pigs. This site marked pigs in four categories: cull (<100 kg or a physical hindrance that would cause the animal to be turned away by the plant), light (100-122.5 kg), market (122.5-131 kg), and heavy (>131 kg). This employee did not see the animals daily. One half of the pigs were weighed individually within 24 hours after they were marked, and the other half were weighed within 36 hours post-marking using a calibrated livestock scale. As the pig was weighed individually, it was noted which category they were marked. Accuracy was determined by whether the animal was marked in the correct category of the four by using the following equation:

$$(\text{Number of pigs marked in the correct category} / \text{total number of pigs in the category}) \times 100$$

Site Two had a total of 468 pigs observed. This location held five pigs per pen, two nipple drinkers, and access to one feeder. The floors are solid concrete without slats. A third-party familiar with the pigs and their management, genetics, and nutrition marked only market weight pigs (122.5-131 kg). The individual saw the pigs approximately once a month. The pigs were marked in the morning and weighed in the afternoon. At that time, it was noted whether they were marked by the individual and believed to be market weight. Accuracy was determined

by whether the pig was correctly marked as market weight or not using the same equation as above:

$(\text{Number of pigs marked in the correct category} / \text{total number of pigs in the category}) \times 100$

PigVision by Asimetrix mounted cameras over time

A total of 12 pens measuring 2.44 meters wide and 3.05 meters long had PigVision by Asimetrix camera mounted above them. The cameras were installed prior to placing pigs in the pens. Each camera was mounted on the ceiling and had 2.13 meters between the camera lens and the slatted floor. An extension was mounted in the ceiling to lower the cameras to the desired height. Each pen had one feeder and at least two nipple waterers, with some containing four nipple waterers. Each pen contained eight pigs at the beginning of data collection. Pigs were weighed on a professionally calibrated pen scale at the start of the trial. The average weight of the pigs at the beginning of collecting images was 17 kilograms. The pen average was 137.4 kilograms. The cameras were set to capture an image anytime a pig was in proper position for weight estimation (i.e., full body in camera, standing). Average individual weights were reported once a day to the PigVision by Asimetrix portal interface. Pen weights were taken 11 times using a pen scale corresponding with a change in feed phases (d4, d14, d24, d33, d48, d53, d67, d81, d96, d110, and d120). Individual weights were also collected the last four weigh days (d81, d96, d110, and d120). The pen scale utilized was calibrated with a 25-kilogram weight each time it was utilized. An individual average weight was recorded the same day from the portal to compare with weights taken at the farm. The camera lenses were cleaned weekly with lens wipes unless the image became unclear, then they were cleaned upon request from PigVision by Asimetrix employees. Pen scale weights were compared to the PigVision estimation at all days

listed above. Accuracy is represented by the difference of the pen weight to the PigVision estimation using the following equation:

$$100 - ((\text{Pen weight} - \text{PigVision weight}) / \text{Pen weight})$$

Comparison of multiple weight assessment methods

At the time of marketing the pigs utilized in the mounted camera trial, the accuracy of three different weight assessment methods were compared. Human observation, PigVision cameras, and a walk-across scale (CIMA, Correggio, Italy). The CIMA walk-across scale was 70 centimeters wide with a 9-centimeter angled lip on each side. The length of the scale was 200 centimeters. The scale sat off the ground approximately 8 centimeters. The scale was placed in an alley 90 centimeters wide, leaving approximately 10 centimeters on either side between the scale and the wall. The base of the scale has a telescopic arm that holds the scale head, the scale head also has RFID scanning and data storage capabilities. Neither of which were used in this scenario.

A third-party individual marked pigs believed to weigh more than 122.5 kilograms with a livestock marker approximately 12 hours prior to weighing. Pigs were first weighed by pen on a calibrated scale, then individually on the same scale. After being released from the pen scale, each individual pig was walked down an alley that contained the walk-across scale, which collected weights immediately. A rattle paddle was shaken to ensure consistent movement as the pigs walked. After the pig walks across the scale, the scale head sounds an alarm and reports a weight. This was recorded immediately both on the device and manually by an observer.

Accuracy for the PigVision camera and walk across scale were determined by how close the weight was to the validated weight using the same equation as above:

$$100 - ((\text{Pen weight} - \text{PigVision weight}) / \text{Pen weight})$$

Human observation accuracy was determined by whether the pig was correctly marked as market weight or not using the same equation as above:

$$(\text{Number of pigs marked in the correct category} / \text{total number of pigs in the category}) \times 100$$

Accuracy measures were then compared between weight assessment methods.

Camera data collection

Images were collected during the Human Observation and Comparison trials to assist in development of a handheld device in collaboration with the Department of Biological and Agricultural Engineering at North Carolina State University. Photos were collected using an Intel RealSense Depth Camera (D435i) at four different locations with multiple replicates at each site. Images and videos were collected from all angles, not restricted to top-down imaging. A total of 764 videos containing 3,065 frames in various formats (RGB, depth values, and point clouds) were collected. All pigs were individually weighed to help train the algorithm to predict weights. 76 of the imaged pigs were also measured for length, width, and girth. Data collected for this work is being published in Anh Nguyen's (NC State University) master's thesis.

Statistical Analysis

All data was analyzed using the GLM procedures of SAS (SAS Inst. Inc., Cary, NC). In Study 2, (PigVision) the pen was used as the experimental unit for accuracy and analyzed with repeated measures in time. Differences were considered statistically significant at $P \leq 0.05$ and tendencies were considered when $0.05 \leq P \leq 0.10$. Least squared means were reported with the SEM where appropriate.

RESULTS

Human observation

The accuracy of Site One's four categories is reported in Table 2.1 in addition to the overall accuracy for Site Two. A total of 522 pigs were evaluated for Site One. The overall accuracy for Site One was 81.8%. A total of 468 pigs were evaluated for Site Two.

Table 2.1. Accuracy of Pig Weights Measured by Human Observation

	<u>Cull</u>	<u>Light</u>	<u>Market</u>	<u>Heavy</u>
<u>Site 1</u>				
<i>n</i>	88	208	140	86
Accuracy, %	100	97.6	42.4	88
<u>Site 2</u>				
<i>n</i>	3	205	195	67
Accuracy, %	-	-	82.5	-

PigVision by Asimetrix mounted cameras over time

The accuracy by weight over a 16-week period is shown in Figure 2.1. Accuracies increased significantly ($P < 0.05$) over time. The overall accuracy from placement to closeout was 94.1%.

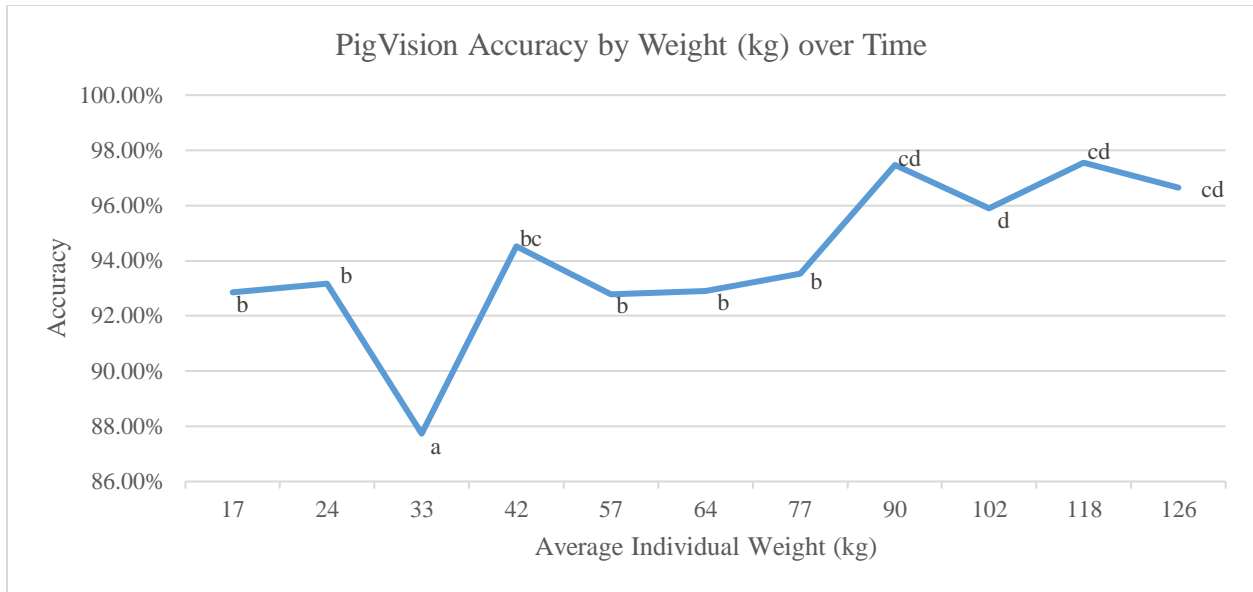


Figure 2.1. PigVision Accuracy by Weight over Time.

^{a, b}Differences of $P \leq 0.05$ in the accuracies between weights are marked with different superscripts.

Comparison of multiple weight assessment methods

The accuracy of each of the three methods is divided into four categories: cull, light, market, and heavy. They were compared on a group of 91 pigs prior to closeout. The average individual weight taken using the calibrated pen scale was 125.9 kilograms at the time of marketing. These are reported in Table 2.2. The overall accuracy for human observation was 88.2%. The overall accuracy for the walk-across scale was 98.2%. The overall accuracy for PigVision was 96.0%. The walk across scale missed six data points out of 91 when the pig did not step correctly on the scale. These were not added to the accuracy calculation.

Table 2.2. Accuracy (%) of Three Methods of Pig Weight Assessment

	<u>Cull</u>	<u>Light</u>	<u>Market</u>	<u>Heavy</u>
<i>N</i>	8	30	18	35
Human Observation	100	70	94.4	97.1
Walk-Across Scale	97.5	97.9	98.1	98.7
PigVision	93.1	97.9	96.8	94.5

DISCUSSION

Human observation was incredibly low considering this is the method utilized as an industry standard. When Que et al. (2017) evaluated sort loss, no accuracy was reported. Schinckel et al. (2020) reported accuracies around 48, 52, and 56% in 2020. However, with this being the only study to report sorting accuracy, it is still difficult to determine how the accuracies found in this study measure up to others or across the industry. Nonetheless, an accuracy of 82% or 42.4% at market weight is less than desirable for a producer trying to maximize economic return.

One study evaluating pigs up to 45 kilograms found a 97.5% accuracy for predicting pen weights using a camera mounted above the pen (Kashiha et al. 2014), while PigVision found a 94.5% accuracy. This study was performed on a small pen of pigs with identifiers to aid in individual weight prediction and this type of scenario would be rare in a typical farm and will likely be difficult to duplicate. Lu et al. found a 97.1% accuracy utilizing a mounted Kinect camera above the feeder but only used six pigs approximately 90 days old. Ultimately, PigVision has a slightly lower overall accuracy, but seems to be the most applicable to current production systems.

Originally, the goal of this study was to evaluate multiple camera imaging technologies including two handheld devices and another mounted camera system that seemed commercially available at the time of inquiry. However, when the companies were approached to participate, they declined to provide their equipment or allow us to purchase the systems. This could be due to the fact they are already aware that their product is inferior to those on the market, or they do not actually have a product to offer. This highlights the current problem in the industry of why

these types of weight assessment devices are not commonly used in the industry although many examples are able to be found.

For the three-way comparison, only market weight pigs were marked by the experienced individual for human observation. However, for reporting purposes, they were split into the weight categories to mimic the realistic aspect of how it would occur on a farm. For example, any pig that falls into the “cull” category is turned away by the plant. Light and heavy pigs are less desirable and discounted, but still accepted. Lastly, market weight pigs are the most sought after by a packing plant and often receive premium prices. The animals were split up into these categories post-test to evaluate how each of the methods performed within those categories. Human observation when compared to the other two methods evaluated in the final study was 8% lower than cameras and 10% lower than the walk across scale. The walk across scale missed 6.5% of the measurements taken, so that must be considered if the scale is implemented on a large operation; a 2,400 head barn would miss around 150 animals if numbers from the current study are extrapolated. The studies performed evaluated three methods, two of which provide more than 90% accuracy. Clearly, humans are not perfect in predicting weight and there is plenty of room for improvement. The question to be answered is whether a producer is willing to sacrifice accuracy for labor and time.

IMPLICATIONS

Based on calculated accuracies, the walk across scale was the best option tested. However, if it is unlikely for producers to use a scale or move all animals, PigVision provides more than a 90% accuracy. That is still more accurate than any of the human observations observed and is simple to use. The cameras provide weights each day and require no additional labor, except periodic lens cleaning.

This area of research provides significant benefits to the swine industry and will likely continue to be evaluated to help mitigate the effects of sort loss. In the future, individual weights or identification in pen weights may prove valuable to ensure each animal is marketed at the optimal time. Additionally, handheld cameras will likely be evaluated more as technology use continues to increase on the farm. The ideal weight assessment method would be one that is highly accurate, provides immediate information, and can provide an individual weight with minimal or no handling required.

REFERENCES

- Brandl, N., and E. Jørgensen. 1996. Determination of live weight of pigs from dimensions measured using image analysis. *Computers and Electronics in Agriculture*. 15(1):57-72. doi:10.1016/0168-1699(96)00003-8
- Kashiha, M., C. Bahr, S. Ott, C. P. H. Moons, T. A. Niewold, F. O. Ödberg, and D. Berckmans. 2014. Automatic weight estimation of individual pigs using image analysis. *Computers and Electronics in Agriculture*. 107: 38-44. doi: 10.1016/j.compag.2014.06.003
- Lu, M., T. Norton, A. Youssef, N. Radojkovic, A. Pe Fernandez, and D. Berckmans. 2018. Extracting body surface dimensions from top-view images of pigs. *International Journal of Agricultural and Biological Engineering*. 11(5): 182-191. doi: 10.25165/j.ijabe.20181105.4054
- Que, Y., F. Cabezon, N.M. Thompson, and A.P. Schinckel. 2017. Evaluation of the effect of errors in the sorting of pigs for market on financial loss at a range of marketing ages. *The Professional Animal Scientist*. 33:575-584. doi: 10.15232/pas.2017-01617
- Schinckel, A.P., P. Preckel, K. Foster, N. Thompson, and F. Cabezon. 2020. Current status of marking hogs in North American and future potential for refinement. *Journal of Animal Science*. (Abstr). 98:44-45. doi: 10.1093/jas/skaa054.080
- Wang, Y., W. Yang, L. T. Walker, and T. M. Rababah. 2008. Enhancing the accuracy of area extraction in machine vision-based pig weighing through edge detection. *International Journal of Agricultural and Biological Engineering*. doi: 10.3965/j.issn.1934-6344.2008.01.037-042