An Analysis of the Feasibility Of Using Image Processing To Estimate the Live Weight of Sheep

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ABSTRACT

One of the difficulties in successfully managing the supply and use of animal feed in sheep farming is in knowing the live weight of the sheep in the various mobs a farmer may be using. Most farmers make intuitive estimates of whether their sheep are increasing, maintaining or loosing weight. A few farmers will weigh samples from the mobs, but this is an expensive and tedious operation, and consequently not carried out very often. If an inexpensive and simple method could be devised for quickly obtaining the average live weight of a mob of sheep this would markedly aid their successful management. This discussion paper contains outlines of the various methods that might be used as well as the problems with each method. There are also discussions covering the efforts made, as explained in the literature, for use in estimating the live weight of other species. This provides a means of generating ideas. The discussion paper concludes with recommendations on what appear to be the most promising approaches that might be further investigated. If such a system could be devised there is no doubt many farmers around the world would utilise it to assist in the management of their feed supplies, and consequently improve the efficient production of meat and wool.

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1. Introduction

The live weight of sheep is an important feature that farmers regularly want to know for feed budgeting, calculating drench dose, flock management, sheep marketing, calculating the stocking rate, and identifying suitable animals for slaughter. Without some objective measurement, such as weighing, producers have no accurate method of identifying the heaviest, lightest and average weight of a group of sheep. They could (and often try to) estimate weight by eye – but most farmers are poor judges of sheep weights (Besier et al, 1989).

Presently in New Zealand only traditional mechanical and electronic weighing scales are used to gather weight statistics. In making direct measurement of a sheep's weight with a scale balance, however, a significant amount of time and labour is required to obtain the measurement. As manual weighing with a scale balance cannot be performed frequently enough, a farmer could effectively use, if available, a relatively inexpensive, non-invasive, practical device for the continuous monitoring of weight for a flock of sheep. An automated system such as video image processing (analysis) represents a powerful technique because it can be carried out remotely, without the need to touch or disturb the animal, and because of the quantity of data that can be collected.

Research with pigs, fish and other animals has shown that good estimates of body weight can be made from measurements obtained through visual analysis. Significant progress has been made in the development of a system to make the measurements automatically without human intervention. However, there does not appear to have been any such relevant studies on sheep. The most obvious problem in applying image analysis to sheep is that wool obscures the body making it difficult to calculate relevant measures.

This report will discuss if there is any relationship between sheep live weight and physical body measurements, the feasibility of using image analysis for capturing images and calculating the weight of sheep, and the problems associated with wool.

2. Weight estimation – what indicates an animal's live weight?

2.1 Body measurements

Initial studies on an indirect approach to estimate the weight of sheep without using scales used body measurements (termed barymetry) as a predictor. This involves measuring the length, height, width or circumference at any position of the animal with a tape measure, resulting in an estimation of the weight. Body measurements including body length, height at withers and heart girth have all been used to estimate the weight of livestock.

Bhadula et al (1979) used body length, height at withers, chest depth, chest girth, paunch girth, round the hip, shoulder width, and sternum length measurements as predictors of body weight for Muzaffarnagri sheep. Their studies found that at birth and during early development body length, sternum length, and shoulder width correlated most with weight. However, at later ages heart girth was a more significant predictor of body weight. They suggested that as bone is an early growing tissue and forms a major portion of weight in newly born lambs, measurements associated with bone growth are the best predictors. At advanced ages muscular and fat growth which grow at a relatively greater rate are the best predictors. Huxley (1932) also points out that at birth a lamb is all head and legs, its body is short and shallow, and the buttocks and loin are underdeveloped; but as it grows, the buttocks, loin, etc grow at a faster rate than that of head and legs. Studies by Wiener et al (1974) also showed that the body dimensions of sheep differ in their rate of maturity. For example it was shown that 90% of mature size was reached before 6 months of age for cannon bone and tibia length, in around 10 to 11 months for head width and shoulder width, followed by body length (13 months). These allometric factors must be considered when trying to estimate sheep weight using image processing.

Perhaps the most significant measurement common amongst all studies, heart girth, appears to be the single parameter which correlates best with body weight. The heart girth measurement has been used successfully as a predictor of body weight in cattle, horses, pigs, sheep and goats. Heart girth measures the circumference in the chest region as close to the forearms as possible. Studies on sheep measurements appear to be minimal and the only literature found was from studies performed in countries where the practical means of measuring weight (using scales) were inconvenient. Early studies of Nigerian dwarf sheep (Orji, 1981) used heart girth, height at withers, body length and length of forelimbs. The body weight of the sheep was correlated against their linear body measurements and regression equations relating the variables were established. The study showed that the heart girth was the best predictor of weight (accounted for 93.8% of the total variation in the body weight, $r = 0.99$). Further Orji demonstrated that inclusion of height at withers and body length did not improve significantly on formulae based on heart girth.

Weight prediction studies of sheep in north Cameroon (Thys et al, 1991) also used heart girth measurements based on Orji's findings. Although the findings were not as conclusive as Orji's (explained 86.5% of the variation of body weight in rams and 90.8% in ewes), it still provides a good prediction variable.

Similar studies have also been done on Nguni goats in South Africa (Slippers et al, 2000) and working oxen in Ethiopia (Goe et al, 2001), where variation in body weight was again explained by heart girth. Insufficient studies have been done on New Zealand sheep species to justify using heart girth measurements, but previous research has shown it may be a feasible means of estimating their weight and perhaps there is the possibility of taking measurements using video image analysis.

2.2 Condition scoring

Body condition scoring is simply a means of subjectively assessing the degree of fatness or condition of an animal (used on sheep, cattle and other livestock). Russel et al (1969) showed that a sheep's condition score was closely related to the amount of chemically determined fat in sheep and that it could provide an acceptable and useful means of estimating the proportion of fat in the animal body and hence the nutritional status. Russel (1984) demonstrated that condition score is assessed by palpation of the sheep in the lumbar region, on and around the backbone in the loin area immediately behind the last rib. Animals are then awarded a score from 0 – 5 (can have half scores), 0 being extremely emaciated and 5 extremely fat.

Farmers can gain a great deal of information about conformation and composition of an animal through palpation. Although subjective, with practice a high level of repeatability both between measurement and between scorers can be obtained. One of the advantages of using condition scoring, as a tool in flock management is that it overcomes differences in body size and weight, which exist between individuals within a flock and between flocks of different breeds. Findings have also shown that there is a relationship between condition score with live weight changes in animals.

Studies by Zygoyiannis et al (1997) evaluated to what extent the general estimates of mature weight could be improved if body condition score and ewe age were taken into account, and to develop a method for incorporating this information into mature weight estimates. They identified problems in estimating the mature weight of a given group of sheep as the mean weight will be affected by such things as nutritional status, nutritional history, genetic composition, age structure of the flock and physiological state at the time of measurement. They found condition scoring overcame some of these problems. The live weight, condition score and age data were used for three breeds of sheep to estimate the regression of weight on condition score within each age. It was found that regression coefficients relating live weight to condition score were directly proportional to the mature weights of the breeds. Further, the condition score and age were shown to be excellent indicators of live weight.

Studies on cattle by Msangi et al (1999) used an experiment to establish the relationship between live weight, body measurements and condition score. It was observed that there was a linear relationship between condition score and live weight for mature animals but not for calves. Earlier findings (Peters et al, 1995) have shown that there is a relationship between body measurements, especially body condition score and heart girth with live weight changes of cattle. Msangi's results showed a linear relationship between condition score and live weight changes for cows and heifers (determination coefficients were 89% and 99% respectively) but not for calves (perhaps due to allometric factors). The study also illustrated a linear relationship between heart girth, body length and weight.

The results of these studies have shown that condition scoring can be used as a viable means of predicting weight. Perhaps, in conjunction with other body measurements more accurate estimates of weight could be found using condition scoring. Obvious problems exist in trying to evaluate a sheep's condition score with visual analysis, as condition scoring by nature is subjective as well as requiring an operator to manually feel the sheep's back. Realistically, it would not be feasible to use image processing to estimate the condition score of an animal especially with the additional problems associated with wool on sheep. Alternatively a farmer could estimate an average condition score for a flock of sheep and the figure added as an extra variable to any weight estimation calculations. In any mob of sheep on the same paddock it is unlikely that condition will range over more than two scores at any one time (Russel, 1984). Further, unusual condition scores in a paddock would likely be attributable to unwell animals. This aspect would enable a farmer to appraise one whole mob fairly accurately only using a small sample. For example a farmer could assess the condition of a mob of sheep that the video images will be analysing, by evaluating a sample of say 4 or 5 sheep. The image processing could be used to calculate a sheep's length and heart girth. Then the age and condition score variables added to subsequent calculations to estimate the weight more accurately.

Indications from Schofield (pers com, 2003) are that the Silsoe Research Institute in the UK is examining the use of mechanical devices for tactile sensing to introduce greater objectivity and reliability into the process of body condition assessment by palpation. The electromechanical instrumentation would be used to identify and quantify relevant tactile parameters commonly assessed by manual palpation. If assessment could be done automatically and reliably this would eliminate any problems associated with manually calculating the condition score.

2.3 Growth Models

Linear models of growth in sheep body weight are abundant in the literature and have shown that live weight of sheep follows a constant pattern with age and season. The pattern based on all breeds of sheep is very similar. After an initial period of rapid growth and a fall in weight in the first winter, later growth in weight is marked by seasonal fluctuations (Wiener et al, 1974). There are considerable fluctuations with weight during lambing and during winter. Vetharaniam et al's (2001) model predicts that an animal experiencing consistently long days will grow to be larger than if it experiences fluctuations in day length.

Models produced by Rattray et al (1982) and Geenty (1983) analysed the effects of various grazing regimes during late pregnancy on subsequent ewe and lamb performance. Pasture intakes were input to the model and used to predict pre-lambing and post-weaning ewe live weight, and wool and milk production. Ewes were subject to either high or low herbage allowances during weeks of pregnancy; subsequently, lactating ewes were subject to one of three planes of nutrition (low, medium and high). The results illustrated that live weight will fluctuate with differing amounts of available feed. Both models accurately predicted live weight with prediction errors for both between –8% - 7% (for pregnant and lactating ewes).

The models have been shown to demonstrate a reliable and fairly accurate method for determining sheep live weight. But, growth models do not offer a definitive means of estimating a sheep's weight and should only be used as a guide, as environmental factors may affect different mobs in unrelated ways. However, they do illustrate important points to consider when evaluating weight. Age aside, the other important factors to incorporate into any model is season (day length) and the available feed.

3. Related work

3.1 Image analysis of pigs

So far the most comprehensive studies on using image processing to estimate the weight of live animals has been performed on pigs. Weighing pigs using more conventional weighing platforms was considered to be problematic, the main reasons being: the harsh environment imposed by pigs; the stress caused to them; the lack of convenient weighing equipment and the large labour input required. At this stage there does not appear to be any such studies on sheep, however, Young and Schofield (pers com, 2003) have indicated that studies are underway at the Silsoe research institute in the UK. Schofield commented that the initial research is on using video image analysis for body condition assessment (as indicated previously). He has also suggested that correlations will also be sought between dimensions, image areas, and the live and dead weights of the animal. The results will be available in due course.

It should be noted that all image analysis of pigs to date has only been done on individual pigs as they enter a feeding station. Sheep are not confined to pens and therefore another means of collecting images would have to be investigated.

Specific anatomical dimensions measured using digital image analysis have been shown to predict the pig's weight very accurately. Early studies by Schofield et al (1990) concentrate on estimating weight from dimensions measured from photographs. One suggestion was the shape of a pig could be broken down into several parts and each part represented by a geometric shape. For example, the body can be represented by a cylinder and the head and legs by truncated cones. Calculating the pig's volume and using an appropriate density (Schofield estimated 1050 kg m^{-3}) might enable weight to be calculated accurately. This process is obviously complex and requires a multitude of measurements. Rather than using this process, Schofield investigated the relationship between the plan area (taken from above) of a pig and its weight.

The relationship between plan area and pig weight

Schofield's (1990) initial work involved collecting individual photographs of a batch of maturing pigs at weekly intervals providing a collection of benchmark images. These gave a record of the change in body dimensions with increasing weight. Immediately after each photograph the pig was weighed on a commercial balance. Plan areas adjusted for the distance from the camera were measured in pixels, which were then converted to cm^2. The top view areas were measured for the whole pig, the pig with its head and ears masked out, and for the pig with its head, ears and neck to the shoulder masked out. A regression equation was developed for predicting weight of the pigs in kg from each measured area. Other linear dimensions were also calculated (girth included) and were shown not to be good predictors of weight. From the images it was shown that the measurement of top view area less head and neck, is more highly correlated with weight than the whole top view, or any other dimension analysed. The top view of a pig, less its head and neck, removes variations in area resulting from the observed areas of the ears and head and movement of the pig. The visible area of the head and neck changes considerably when viewed from above, depending on whether the pig has its head lowered or straight out in the air. Subsequently Schofield showed that the head is not a valuable component of the plan view image. The system was accurate enough to allow weight to be estimated with errors of less than 5% for 83% of individual samples. However, there was notable variation with younger, lighter pigs, which is probably explained by allometric variation. The study also showed that gender was not statistically significant on the area to weight relationship.

Preliminary analysis by Schofield showed that a strong relationship exists between pig weights and areas, which can be measured using image analysis, even when a single image of each pig was analysed. He also argued accuracy could be improved by taking measurements from many consecutive images collected directly using a video camera, so the effect of small changes in apparent pig area caused by body movements (stretching, inhalation, and exhalation for example) could be reduced. This initial study gave the impetus for more studies as it was shown that the development of a practical imaging system for weighing pigs was feasible.

Subsequent publications by Schofield et al (1999) continued to use the top plan view of the individual pigs for analysis. This also seems appropriate for image analysis of sheep, as an aerial view would enable estimating the weight of several sheep (or possibly a flock) simultaneously. As it was shown that the head is not a valuable component of the plan view image, Schofield et al worked on improving the determination of the pig boundary (area less head and neck). An automated system using a camera permanently placed over a feed station, capturing the images of pigs as they feed has now been developed by the Silsoe Research Institute and used successfully.

Further work by Schofield et al (1999) in producing a prototype imaging system proved to be successful. It was able to work unattended in a piggery environment for the six-month trial. Discarding images which failed acceptability tests, the prototype captured one set of satisfactory image data every 40 seconds. This resulted in the system collecting the equivalent of over 140 sets of measurements per pig for each day. The mean weight of the pigs could be estimated to within 5%, and in a certain weight range, the errors were reduced to below 3%. As a result of the success of the Silsoe VIA system there is now a commercial version for estimating pig weight available from Osborne (Europe) Ltd.

Other research on pigs

Brandl et al (1996) used spline functions to express the relationship between the plan area of a pig and its live weight. Although the precision was comparatively low (errors between 8-9%) they indicated that image analysis techniques for weight determination of pigs looked promising because it was relatively inexpensive, was possible for numerous pigs to be analysed, and it could be used for surveillance purposes in herds.

As well as determining the weight of pigs from the projected area viewed from above, Minagawa (1994) used a device using a video camera and a mesh imaged slide projector (Minagawa et al, 2001). While pigs where drinking water, the video camera showed shadow lines projected on the pig and on the floor. Once a geometric relationship was established between the parallax (from the lines on the pig and on the floor) it was possible to estimate the pig's height. Minagawa suggested that the relationship between pig weight and a volumetric measure derived by multiplying the projected image area by pig height was more accurate than the relationship between pig weight and projected image area (as in Schofield's studies). The results showed that using height as an additional parameter indeed improved the results as the weights could be estimated to within 2.1% accuracy (compared to 3-5% in Schofield's work).

Minagawa also utilised stereo photogrammetry on pigs (Minagawa, 1995) and cattle (Minagawa, 1994) to determine their surface area and other measurements. This research demonstrated that measurements could be made accurately (1.2% relative error for the pig surface area), and the surface area, volume, and projected area from the side of cattle were exponentially related to their live weight. He concluded that the close relationship between projected area from side images and weight can be applied to estimate the weight of cattle by using image analysis.

3.2 Estimation of live weight of salmon using stereo image analysis

Effective fish farm management requires accurate information on fish weight in order to guide feeding regimes and harvesting. Current methods for estimating fish weight involve culling or anaesthetising before manual weighing. Therefore, the ability to remotely predict fish weight has been tested using a non-invasive, digital stereo camera system.

Studies by Beddow et al (1996), McFarlane et al (1997) and Lines et al (2001) have used stereo image techniques to estimate the weight of salmon effectively. The techniques comprise automatic methods for identifying video frames, which contain good images of fish, for identifying the outline of the fish in 3D space, and for determining mass from linear measurements taken from this outline. Lines et al (2001) used a pair of vertically oriented cameras set up permanently, with a base line of 0.5m and with optical axes converging at a known distance. The advantage of using stereo pair video images vertically aligned, is that it allows the relatively well-defined top and bottom edges of the fish to be used to identify the distance of the fish from the cameras. In order to measure the depth of a point it must be visible to both cameras and the point must be identifiable from both images. This solves the geometrical problems faced when using one camera. Lines et als' work describes the techniques used for identifying target fish, calculating its distance (therefore relative size), locating its physical boundaries and then estimating its mass. Studies have shown stereo image techniques have been used to estimate the weight of Atlantic salmon to within 0.4% of the real value.

Stereo imaging shows potential as a practical method for monitoring sheep and estimating their dimensions from images. It solves some geometric problems, as an object's distance from the camera can be estimated and hence the relative area can be defined. The techniques discussed by Beddow et al (1996) and Lines et al (2001) also demonstrate a practical means of capturing images. Perhaps it is possible to leave a pair of video cameras unattended in a paddock collecting suitable images i.e., only images of sheep with full body views as they walk past the cameras within a certain distance. These images could then be processed later and an assessment made of sheep condition and weight.

4. Capturing and processing images

4.1 Methods for image capture

Methods for capturing images of sheep that have been discussed include: aerial photos taken from a camera attached to a helium balloon, standard panoramic photos taken by a farmer as a mob of sheep is rounded up, and stereo images taken of sheep as they walk by. Ideally it would be best to analyse individual sheep one at a time (as with the pigs), as this solves any problems associated with distinguishing individuals amongst a group of sheep. However, to be practical any system would have to be able to distinguish individuals in a flock. Due to the uniformity in colour of a flock of sheep it would be hard for image processing to discriminate between individuals (especially for side on images of sheep which are being obscured by other sheep). Therefore a process which alleviates this problem, or ideally extinguishes it, would be ideal. In the meantime it may be more feasible to study aerial, or side on, images of individual sheep until a more efficient method for processing is available.

4.2 Processing Techniques

Establishing a technique to segment an object from its environment can require a considerable amount of interactive guidance in order to get satisfactory results. Automating models is difficult because of noise, shape complexity, illumination, inter-reflection, shadows and variability within and across individual objects (Liu, 1999). In image analysis, algorithms are needed to locate a sheep's image from a scene, accurately define its outline, identify and mask out any obscuring sheep, and then take, or make, the relevant measurements and relate them to weight. Analysing images of individual sheep relieves some of these problems. It should be relatively straight forward segmenting the shape of an individual sheep from its background using simple, currently available image processing techniques.

Techniques discussed in literature

Following on from Schofield's work on the 'plan area' of pigs - once an image is firstly corrected for lens distortion, an image processing technique called 'thresholding' is used to determine the boundary, and hence area, more accurately. Thresholding selects pixels in an image which are above (hence brighter than) a chosen grey level. This takes advantage of the fact that the animal's body appears brighter than its surroundings. Next, an approximate outline is encoded by marking the outline of the selected area using a Freeman chain code (Davies, 1990). The boundary is then improved by searching outwards from each chain code for a high value of image gradient, the process is then repeated once more to give the improved boundary. The process of removing the tail, head and neck are described in Schofield's work. Also described are the problems associated with designing an automated image analysis algorithm. Scaling the pixels into dimensional units was relatively straightforward. The scale factors were derived by capturing an image of a grid pattern then relating image measurements of the grid to actual dimensions. However, it was found that correcting for camera height is more difficult as the height of a point on the animal's apparent boundary is not known. Secondly, as a pig's body is curved, the physical points that make up the apparent boundary change if the camera is moved or the pig image is seen from a different angle. The geometrical details of the problem are not discussed in Schofield's work, but these findings are an obvious problem to be considered if any image analysis is to be performed on sheep. To offset this problem Schofield used model parameters of the pigs shape and height using published tables. As it is not known if any such tables exist for sheep it may be necessary to include them with any feasible system together with some method for height measurement, such as using an ultrasonic sensor mounted near the camera (or developing similar tables for sheep). The results of Schofield's work again showed a high correlation between the plan area and weight, which was well represented by a straight line, where the slope was the same for each pig (s.e. of the slope was 3.5 kg m^{-2}). However, although the slope of the curves for each pig was effectively constant, there was some variation in the intercept values (the mean was -15.6 kg) between individual pigs. This is due to natural variations in shape between pigs. For example, some pigs are short and wide while others are deeper. This factor will also need to be investigated on sheep.

Lines et als' (2001) work with stereo imaging of salmon found that simple image segmentation techniques, such as thresholding and edge detection, did not work well with images of low contrast captured in the sea. The method they developed for detecting salmon uses a binary pattern classifier (see also: Chan et al, 1999). The typical crescent shape of a fish is recognised using an n-tuple binary pattern classifier. Once the fish head has been recognised by the pattern recognition algorithm, the edges of the fish can then be identified using a point distribution model (PDM). In this technique, the computer holds a shape template, which comprises the relative locations of a number of points on the fish shape together with the principal modes of variation of this shape. This shape is then fitted by working through a series of iterations where the strength and proximity of local edges are used to identify fish edges, which are then tested against the template.

McFarlane et al (1997) constructed a 3D Point Distribution Model (PDM), representing the means and variances of the shape, size, position and rotation of fish from a sample. PDMs, consisting of a set of landmark points and their modes of variation, are a convenient and trainable method of modelling the variable shape of biological objects. The aim of the work was to create a 3D PDM of a salmon by training the model on landmarks placed on stereo images of fish and to develop an image analysis algorithm for fitting the PDM automatically to images of fish. The PDM converged on the fish in 73% of the cases, with minor problems in locating the tail accurately. This was despite a great deal of image noise in the form of shadows, neighbouring fish, and shading patterns on the fish themselves.

Liu et al (1999) describe a method for detection and recognition of objects using deformable shape templates based, in part, by the minimum description length. Training images are needed to train a model. Once trained, the system autonomously segments deformed shapes from the background, while not merging them with adjacent objects or shadows. The method uses template images of a variety of objects including bananas and fish. During segmentation, the template is deformed to match compatible shapes from an image. The system is able to obtain a satisfactory segmentation despite variation in illumination, overlapping of objects and shape deformation. Based on the template, the algorithm described can detect the whole image correctly, while at the same time, avoid merging objects with background and shadow, or merging adjacent multiple objects.

From the wealth of literature available on image processing, specifically shape detection, it would not appear that evaluating images of sheep will be a problem. Schofield's work illustrates how pigs are identified from their surroundings and how outlines of shape are prepared. Considering the colour of sheep and the environment in which they live in it should not be difficult to segment individual sheep from their background. However, it may be difficult when evaluating a mob due to the uniformity of colour and the difficulty in finding the apparent boundaries of each individual sheep. The active contour model described in detail by Lee et al (2002) demonstrates how to locate the contours of objects that may have non-uniform brightness; this model may help in edge detection, but we need to assess the whole outline of a sheep. Liu et al's model may alleviate some problems, but is it fair to assume that the shape of one sheep can be based on that of a template. The method may be the most practical for segmenting panoramic images of sheep when individuals are obscured from one another. But assuming shape and image area, based on incomplete boundaries, may be inaccurate.

5. Other techniques for weight estimation worth investigating

Studies have been underway for some time on using such techniques as dual-energy x-ray absorptiometry (Clarke et al, 1999), computed tomography and ultrasound for carcass evaluation. These techniques assess the composition of an animal measuring fat, protein and lean content. From this it may be possible to estimate the weight of a sheep, however, these techniques are impractical for on farm use.

The possibility of using thermal imaging and infrared for evaluating sheep was also investigated. It was suggested that perhaps the weight of a sheep might be related to the amount of heat it gives off. Thermal imaging may also resolve the problems associated with wool coverage as we may be able to define a sheep's body conformation more accurately by distinguishing wool from skin. However, due to the lack of sufficient literature based on the topic, an in-depth investigation was not possible.

6. Problems with wool and possible solutions

Wool is the most obvious problem when evaluating an image of sheep as it obscures the body prohibiting catching the true body conformation of the animal. It is desirable to be able to analyse a "naked" image of a sheep. However this is only possible after shearing, which does not occur frequently enough. To make image processing worthwhile the ability to evaluate sheep with differing amounts of wool is essential. If it was possible to estimate the depth of wool on a sheep it may be possible to mechanically "undress" the sheep and evaluate its weight. There is plenty of literature on wool growth but not specifically on wool depth. Prediction models for wool growth (Bowman et al, 1993. Finlayson et al, 1995 and Hong et al, 2000) have been defined with a fairly high degree of accuracy. However wool growth does not define wool depth on the sheep body.

Unfortunately the wool of all sheep is not the same, which is especially noticeable between breeds. There are a range of characteristics, particularly mean fibre diameter and aspects of fibre crimping (natural wave in wool) that affect the way the fleece lies against the body. Wool does not grow at a constant rate all year in that it is subject to an annual rhythm in response to photoperiod. That is, the growth rate is proportional to the length of daylight with the rate in summer being approximately twice that in winter. Some minority breeds in New Zealand virtually stop growing wool in the winter. In addition, wool growth is responsive to the level of feeding, growing faster with a higher plane of nutrition. As an example, a Romney that is extremely well fed all year may grow 6 kg of wool (not usually achieved under paddock conditions) whereas if the same sheep was poorly fed, as in a drought, it may grow a 2 kg fleece.

According to Hong et al (2000) there is a strong relationship between wool growth and live weight gain. Environmental factors, physiological status, animal size and stocking rate (density of sheep population) can also influence rates of wool growth (White et al, 1979). To further complicate the situation wool growth rate may increase after shearing for 4 to 5 weeks depending on the amount of green feed available. If there is good green feed available and the sheep are growing well there will also be a wool growth response. If, however, feed is short and the animal needs to maximise its energy supply to maintain deep body heat, the protein in the diet will be converted to energy (inefficient). The result of this is that the rate of wool growth relative to that of an unshorn sheep is suppressed.

As wool growth can be fairly well predicted perhaps it is possible to estimate the depth of wool. One possibility would be to develop a model that starts out assuming a constant rate of wool growth and then later substitutes a sine/cosine pattern with a max/min in Jan/July. From this model it may be possible to estimate wool depth using suitable parameters such as sheep breed, initial wool depth or days/weeks since last shearing.

7. Conclusion and Recommendations

Studies have shown that barymetry can be used as a reliable guide for estimating the weight of a wide range of animals with correlations between heart girth and weight being particularly high. In order to be of practical use to New Zealand farmers, a thorough investigation involving the examination of relationships between linear measurements and weight of our local sheep species is required. To make a system of estimating a sheep's weight using body measurements, such as heart girth or condition scoring, further research is recommended on developing a greater database such as the one offered by the American Society of Agricultural Engineers (ASAE, 2001). This includes tables and formulae relating body measurements, days on feed, and age on weight. Predicting weight from dimensions estimated from images may be dependant on the collection of an expanded database of such statistics. Therefore an initial study into the relationships between measurements (including condition scoring) is fundamental to the success of using image processing.

Distinguishing individual sheep from one another in an image of a mob may be problematic unless a useful technique similar to those discussed is successful. With the additional problems associated with wool, any initial image processing technique employed should segment images of individual sheep. If this is proved to be feasible for image capture the technique ought to be further explored. To design a more effective hands-off method to estimate sheep weight by image analysis, further research is needed in developing a mobile version of any device and developing an automatic image processing technique. Also, image analysis of pigs has shown that the image area of a pig is a good predictor of live weight. Although no relevant research has been done on sheep, the possibility for use should be investigated.

Current research has shown that the development of a practical imaging system for weighing pigs and fish is feasible. However, pigs and fish do not have wool concealing their body. Wool cover is a considerable problem that needs to be overcome using methods similar to those discussed. As wool growth models do not predict depth an independent study on wool depth is required. Until more comprehensive research is done in this area reliable assumptions cannot be made. In the meantime it may be more feasible to process images of shorn sheep until a proven method for assessing "woolly" sheep is available.

On the basis of this report it is not yet feasible to say that we can use image analysis to predict the weight of sheep. However, relevant problems have been identified and discussed. If it is possible to surmount these problems, there may be the potential for weight estimation and monitoring using image analysis. Furthermore thermal measurements of body emissions may also be a completely different approach that could be worth exploring. But, again, wool depth would probably be a confounding factor.

Key recommendations:

- Research into relationships between linear measurements and live weight.
- Development of a statistical database with linear measurements such as heart girth and body length showing their relationship with weight. Could also include condition score/weight relationship.
- Research into wool depth on sheep body. Alternatively, methods into overcoming the problems with wool could be investigated (such as thermal imaging?).
- Initial image processing should be performed on individual, shorn sheep.
- Conduct research into image analysis techniques to develop algorithms that locate a sheep's image in a scene, accurately define its outline, and measure its relevant dimensions.

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