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An approach of pig weight estimation using binocular stereo system based on LabVIEW

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ABSTRACT

The change of the daily weight of the pig is significant to the pig's health and process of real production. This study combined the binocular stereo vision system with the LabVIEW development platform to analyze and estimate body size and live body weight using 10 landrace aged from 14 to 25 weeks old at the end under indoor farm condition. The experimental facility was composed of data collection system, image acquisition system, and image analysis system. Data collection system including binocular camera and specially designed limitation fence was used to ensure the pig's ID recognition and image acquisition were implemented automatically. The images were acquired, saved, and processed by the other two systems to analysis the relationship between body weight and body size. Images acquired by binocular cameras were segmented by the depth threshold. The system verified that the body length (BL) and withers height (WH) were estimated with the R^2 ranged from 0.91 to 0.98. The back area and the body weight data obtained by a ground scale were fitted into linear model. According to the result of regression by least square method, the parameters of the function were calculated. Results revealed that live body weight was closely related to the sum of pixel values (SPV) which was calculated from the reconstructed image. Coefficient of determination R^2 value was as high as 0.9931. It meant this procedure performed well in predicting live weight. The whole automatic systems have the potential to be applied in the real farm environment.

1. Introduction

Live weight of an animal is an essential reference in various studies, such as animal growth, feed conversion, health condition and disease occurrence (Wang et al., 2008; Menesatti et al., 2014). The weight of growing animals provides a valuable parameter or indicator for keeping them at suitable level of nutrition and environment (Wang et al., 2008). The profit from the animal is usually closely related to the balance between income and costs (Emmans and Kyriazakis, 2000), as it depends on its weight and size of production. Animal scientists and breeders who endeavor to meet the desire quality of customers and yield certain production with the cheapest input (Pathumnakul et al., 2009) give rising interests in economic importance (Menesatti et al., 2014). For one thing, that the "least cost formulation" is needed to control the input as least as possible. For another, animal breeding decisions are made to keep the animal at suitable weight to follow standard growth curve and give a reference of the management quality (Mollah et al., 2010). The variation in pig weight in a herd is usually dependent on pig genotype (D'Souza and Mullan, 2002), feed intake, temperature, and competence (Oliveira et al., 2009). Although the difference is natural and inevitable, this is likely to make contribution to unsuitable size pigs during the process of growth without management (Apichottanakul et al., 2012). Consequently, breeders end up with different sizes of pigs and obvious pork cuts (Khamjan et al., 2013). Therefore, matching suitable weight by real-time monitoring could prevent the production ineffectiveness by reducing or increasing the feedstuff for individuals. The ability to accurately estimate pig weight along with procurement plans and growth process is the key to get the biggest potential profit for the managers.

Currently, in order to control feed intake of pigs, there are typically two kinds of methods to measure body weight which are direct weighing and indirect estimation (Yeo and Smith, 1977). Physically stressful to both pigs and breeders occur when direct weighing is used to put a pig on a ground scale (Doyle and Leeson, 1989) which may have negative effects of feeding on pigs for days. Instead, indirect methods by tape or calipers or image analysis system have developed to change this circumstance (Stajnko et al., 2008). Most estimation methods of live pigs are carried out by eyes or hands.

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Body measurements suggested for estimating live body weight (Slippers et al., 2000; Topal and Macit, 2004) are simple and easily measured. Heinrichs et al. (1992) built the relationship between hip widths, body length, withers height, and heart girth and body weight to do the estimation. Enevoldsen and Kristensen (1997) evaluated live cow weight by body size measurements. Girth measurement was one of the main indirect ways and also applied in pigs weighing (Pope and Moore, 2002). However, high labor intensity and inevitable contact were always needed during the processes of measurement.

The non-contact measurement method can effectively reduce the stress behavior of animals. Therefore, the automatic weighing systems such as radio frequency identification system (Schwartzkopf-Genswein et al., 2002), fuzzy-logic dynamic weighing system (Cveticanin and Wendl, 2004) and strain gauge balance devices (Pastell et al., 2006), are another estimating ways and have been developed and used in cattle to analysis the side view of the cow that passing through the certain route (Tasdemir et al., 2011; Viazzi et al., 2014).

At present, the development of computer and digital imaging system provides an indirect way to estimate live animal weight from its body feature by image analysis technique. Image analysis method has been successfully used to estimate body weight. White et al. (2004) used visual image analysis system for monitoring size and shape of pigs to determine live body weight as an efficient way. It is an accurate means for reflecting pig live weight by tracking pig changes with time that are sufficiently short for commercial use. Mollah et al. (2010) performed experiments to estimate body weight of broiler. They captured images and analyzed them by raster image analysis software (IDRISI 32) to calculate the body surface area from surface-area pixels with a predicted equation. The estimated results were closed to manually measured body weight. According to Schaefer and Tong (2000), infrared thermal images of animals were applied for predicting the body composition. Kashiha et al. (2014) used shape recognition techniques and ellipse fitting algorithm to get the weight of each individual pig. Kongsro (2014) put the three-dimensional data into estimating the pig body weight of different breeds based on Kinect system of Microsoft.

These methods are all the pioneer work used for estimating the body weight with non-contact involved. However, image analysis method to monitor the pig weight needs the high quality image and the perfect posture of the animal body. The high quality image means that the acquired image should avoid the factors against segmentation such as illumination changes, shadows and background noises as much as possible. The perfect posture represents that the pig body not only keeps straight without bend and the head is as high as back without up or down, but also the pig has to keep standing without lying or sitting on their hind legs. Besides, all of those requirements are the necessary conditions to attain the full automatic pig weight monitoring to the manager in real farm environments. All these issues are urgent and needed to solve timely and effectively.

The objective of this paper was to study: (1) method of automatic monitoring system including ID recognition, image acquisition, image analysis, and data uploading based on internet of things technology; (2) the error of binocular stereo vision system for calculating the three-dimensional data of pig body size; (3) the relationship between live body weight and back area in the process of growth, and the validity of this method to estimate pig weight.

2. Materials and methods

2.1. Animals

In this study, a total of the 10 fattening barrows of landrace in HUI KANG pig farm in China were divided into 2 groups which were Y_1 and Y_2 (Y_1 and Y_2 were the year of 2014 and 2015, respectively). At the beginning of experiment, the pigs' ages were between 14 and 15 weeks old and the weight ranged from 30 to 40 kg, until which reached about 25 weeks old and the weight ranged from 90 to 110 kg at the end. The pig's body length and withers height were manually measured by a tape during the feeding period every morning for comparing with the computed values by image processing. The total samples of manually measured BL (Body Length) and WH (Withers Height) were 1460.

3. Experimental method

The whole experimental period was nearly 80 consecutive days for 12 h a day (07:00–19:00) in each group. There was a ground scale with pressure sensors under the farm floor of the drinking area to measure body weight of pig when it came to drink. The data of the body weight, ear-tag number and the image would be recorded and saved in the database in real time, as shown in Fig. 1. The purpose of pig weight data collection was for the comparison between real value and estimated value which was determined by body area. The body weight data volume estimated by image analysis was the same as those measured by weighing method. It was 730.

The experimental facility was composed of data collection system, image acquisition system, and image analysis system. The data collection system collected and uploaded the pig's ID and the actual weight to the database. The image acquisition system acquired and saved image data for evaluating the pig's body weight. The image analysis system processed image to generate the segmented body contour and the reconstructed pig image.

In order to explore the relationship between the pigs' body weight and size, the regression analysis between measured weight and the SPV of the daily reconstructed image on 10 pigs was done. The measured body weight and SPV was fitted into linear model and regressed with the following equation:

$$W = AS + B \tag{1}$$

The weight estimation parameters were obtained by the Eq. (5). *W* and *S* in the function was the measured weight and the SPV. To estimate body weight with an efficient model, least square method was used to calculate the parameters *A* and *B*. The minimum deviation is realized by:

$$Min\sum_{i=1}^{n}[W_i - (A + BS_i)]^2 \tag{2}$$

The partial derivative of Eq. (2) is expressed as:

$$\begin{cases} \frac{\partial}{\partial A}\sum_{i=1}^{n}[W_i - (B + AS_i)]^2 = 0 \\ \frac{\partial}{\partial B}\sum_{i=1}^{n}[W_i - (B + AS_i)]^2 = 0 \end{cases} \tag{3}$$

Eq. (3) is sorted and showed as Eq. (3),

$$\begin{cases} \sum_{i=1}^{n}[W_i - (B + AS_i)S_i] = 0 \\ \sum_{i=1}^{n}[W_i - (B + AS_i)] = 0 \end{cases} \tag{4}$$

Eq. (4) can be solved and the expression of the best *A* and *B* with the known conditions are derived as follow:

$$\begin{cases} A = \frac{\sum_{i=1}^{n} W_i \sum_{i=1}^{n} S_i - N\sum_{i=1}^{n} W_i}{N\sum_{i=1}^{n} S_i^2 - \left(\sum_{i=1}^{n} S_i\right)^2} \\ B = \frac{\sum_{i=1}^{n} W_i \sum_{i=1}^{n} S_i^2 - \sum_{i=1}^{n} W_i \sum_{i=1}^{n} S_i}{N\sum_{i=1}^{n} S_i^2 - \left(\sum_{i=1}^{n} S_i\right)^2} \end{cases} \tag{5}$$

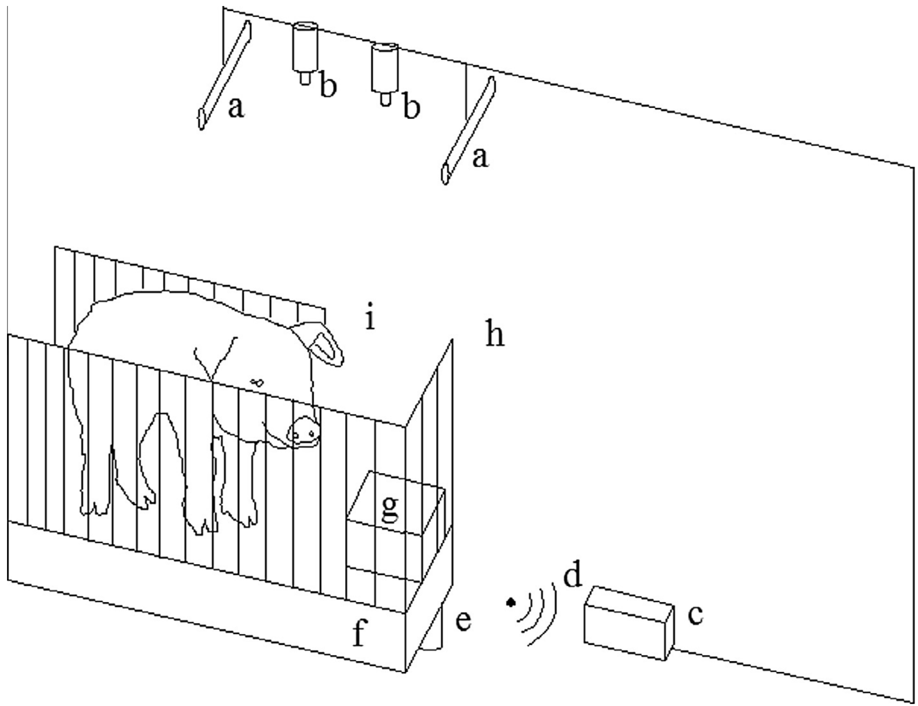

Fig. 1. Experimental facility. (a) Lighting lamp; (b) digital camera; (c) RFID reader; (d) RFID signal; (e) pressure sensor; (f) ground scale; (g) drinker; (h) limitation fence and (i) pig.

3.1. Data collection system

The pig body image was taken by the binocular stereo vision acquisition system which was composed of two "Basler acA-1300-30gc" digital cameras with 1294 ∗ 964 pixel resolution. A "Raybaca RBC-A04" RFID reader, which was 134.2 kHz operating frequency and long distance ISO 11784/11785 ear-tag reader, identified the pig and triggered the camera which captured image in drinking area. This area was equipped with specially designed limitation fence for entrance of only one pig, as shown in Fig. 2. The NI (National Instruments) EVS-1463 (Embedded Vision System) connected the camera, ground scale, and RFID reader with gigabit interface, analog acquisition module and RS 485 serial interface (the core of the internet of things system). Therefore, the image, pig's weight and ID were synchronously acquired and uploaded to database automatically through the designed software system based on EVS when pig was drinking.

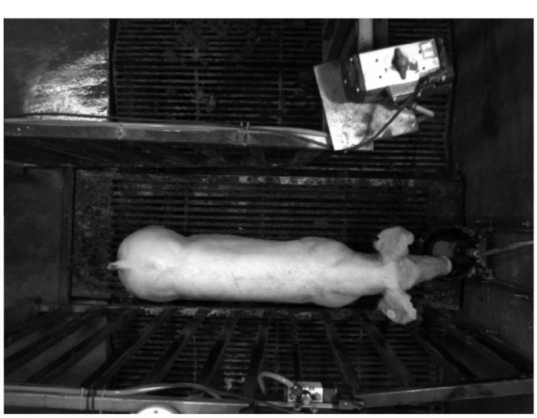

Fig. 2. An example of pig in drinking area.

The field of view of the drinking area determined the height of the dual camera. The camera was mounted 2.2 m above the farm floor by the Eq. (6).

$$BL = \frac{OS}{FL} * WD - OD \tag{6}$$

In the above equation, OS is the optical size (4.8 mm ∗ 3.6 mm). BL is the maximum body length. OD is the optical center distance of the dual cameras (115 mm). WD is the working distance which is the subtraction of the height of the body and the dual camera. FL is the focus length (5 mm).

3.2. Image acquisition

The images were acquired by the image acquisition system using LabVIEW (Laboratory virtual instrumentation engineering workbench, 2015) with the VDM (vision development module). The images, which acquired by this system, were saved in the specified location and sorted by date automatically to build database for body weight estimation.

3.3. Image analysis

The image was analyzed after the calibration of the binocular camera which was implemented based on the machine vision module of the LabVIEW system. In order to have a better pig body contour and more precise pixel values of the image, the depth threshold was used to eliminate the disturbance of background instead of the traditional gray threshold segmentation. The depth image was computed by processing program using a block matching method for the left and right images acquired by the binocular camera which was shown in Fig. 3(a). And then the depth image was calculated according to the disparity map. The pig contour was segmented from the depth image and the SPV which was read from the segmented pig automatically (Fig. 3(b)). The reconstructed pig image removed the head, ears and tails for the reason that the accuracy of the estimated weight would be greatly improved by removing those body parts (Wang et al., 2008) as shown in Fig. 3(c).

4. Results

The measured BL and WH were regressed with estimated values. The results of R^2 and the root mean square error (RMSE) of the estimated BL and WH from a total of 1460 samples of the 10 pigs in 80 days are shown in Table 1. RMSE ranged from 1.73 to 2.05 cm of BL and 0.71 to 0.92 cm of WH indicated that the estimated results were very close to the true value. The accuracy of estimation of this method exceeded 90% based on binocular stereo vision system which provided the basis for subsequence research.

Through the linear regression analysis by Eq. (1), the relationship between the pig weight acquired by ground scale and SPV of the pig contour is shown in Fig. 4.

The fitting parameters A and B of the linear regression are listed in Table 2, and all the coefficients of determination (R^2) are very high, nearly closed to 0.99, suggest that the pig body weight is strongly related to the pig body size. Each pig's value of parameter A or B is also closed, which indicates that there is a good representation in the respects of body weight estimation.

The parameter estimation of A and B, which is deduced by Eq. (5), is 0.568 and −15.612, respectively. Eq. (1) is substituted the estimated value of A and B, then a linear model for calculating the estimated weight is acquired. Which is:

$$W = 0.568S - 15.612 \tag{7}$$

The estimated body weight is calculated by Eq. (7). The result of the comparison of the body weight between measured and estimated value is shown in Fig. 5 with the R^2 of 0.9931 and the standard error of 1.988 kg. With this estimated method, the body weight can be calculated from SPV precisely.

5. Discussion

The estimation of WH observed the lower error than the estimated BL. It had gradually become apparent that the estimated BL was higher than the measured values due to the variation of height was neglected during the image processing. The closer the distance between object and lens, the larger the object in image. The high R^2 and low RUME showed in Table 1 seem to indicate that the new method was capable of measuring WH and BL. The high correlation ship between body weight and SPV gave a new enlightenment to explore the more accurate method. The validity of this method to estimate pig weight had been verified. In addition, Eq. (7) can be used to estimate body weight if the value of SPV was acquired. Under this circumstance, the method had the capability to replace the traditional contact and weighing method as a standard method for estimating body size and pig weight timely and effectively.

The quality of image plays an important role in estimation results and it is difficult to get a good quality image of the perfect posture pig at a time (Wongsriworaphon et al., 2015; Kongsro, 2014). Therefore, the new methods have been proposed to decrease the number of low quality image.

The height of the trough and drinker were the same to avoid the phenomenon of pig head down while manually measured the BL during the eating process. Thus, the error between measured and the estimated value would be decreased. The body of pig kept standing and rarely moved when it was eating or drinking, so the cameras mounted on the drinking area were the best option. Meanwhile, the photoelectric sensors and pneumatic door devices were used to transform the drinking area into a one-way street that only one pig can enter, and the limitation fence to make sure the pig cannot turn round. The pneumatic door closed automatically as soon as the signals of pig entrance into the drinking area were found by the photoelectric sensor, and if other sensors recognized the pig left the drinking area, the closed door would open. So the better quality images can be obtained.

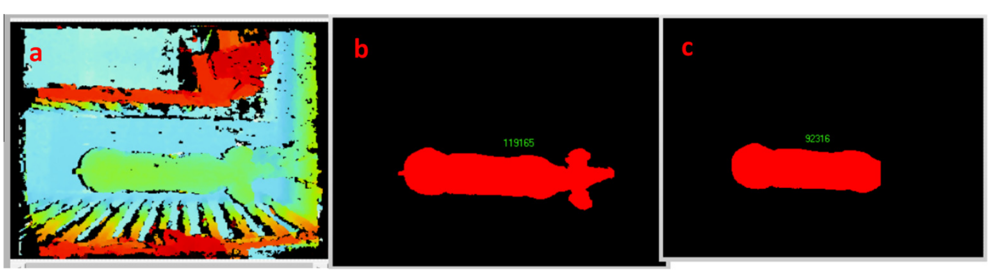

Fig. 3. Automatic process of the reconstructed image. (a) Depth image; (b) pig contour and (c) reconstructed pig image.

Table 1
The results of estimated value on 5 pigs.

ID	Sample volume		BL				WH			
			R^2		RMSE, cm		R^2		RMSE, cm	
	Y_1	Y_2	Y_1	Y_2	Y_1	Y_2	Y_1	Y_2	Y_1	Y_2
1	70	78	0.92	0.93	1.97	2.01	0.98	0.99	0.87	0.73
2	72	73	0.93	0.93	1.73	1.89	0.98	0.98	0.80	0.90
3	73	75	0.91	0.92	2.03	1.86	0.98	0.98	0.92	0.88
4	68	69	0.92	0.94	1.91	2.05	0.99	0.97	0.74	0.89
5	75	77	0.93	0.91	1.78	1.75	0.99	0.99	0.71	0.74

BL = Body Length; WH = Withers Height. Y_1 and Y_2 is the year of 2014 and 2015, respectively.

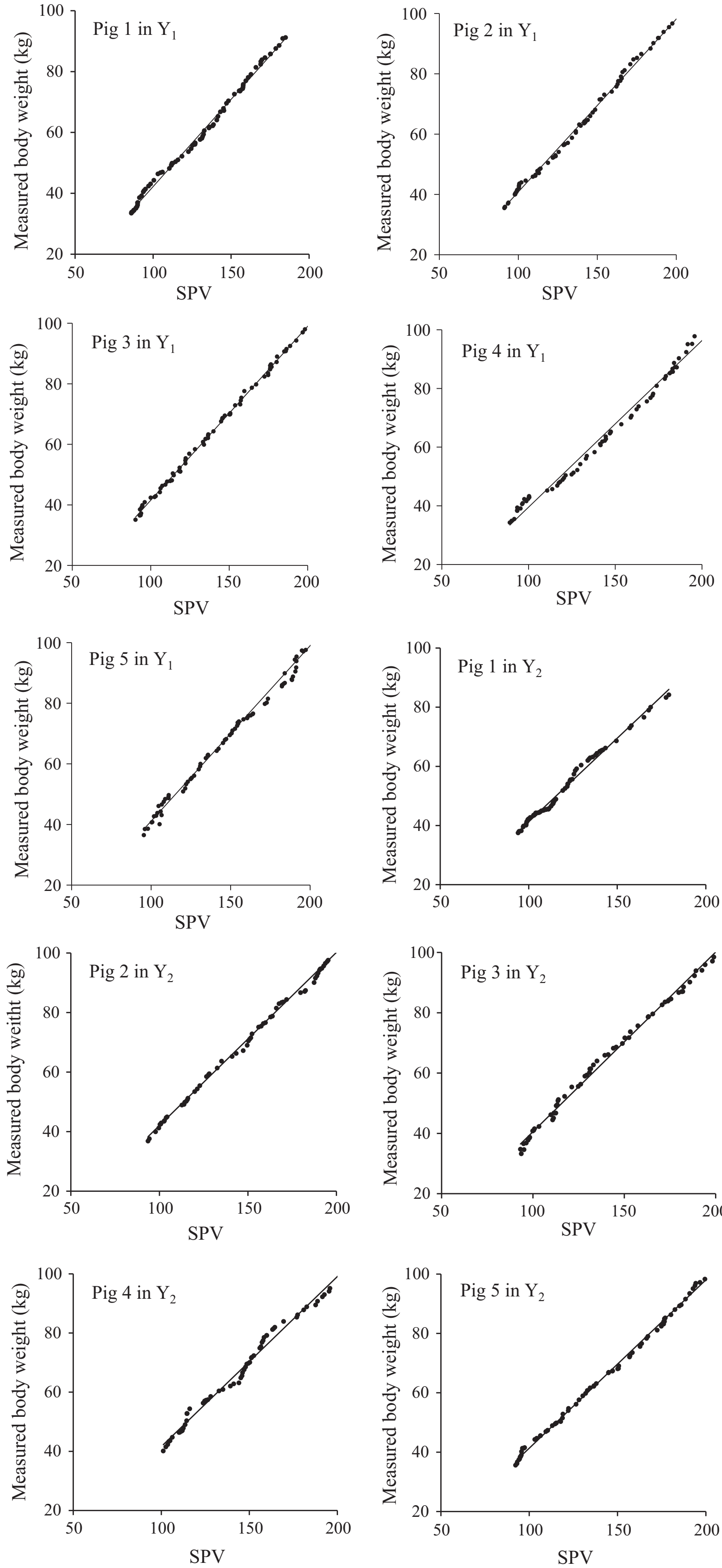

Fig. 4. The relationship between measured body weight and SPV.

Table 2
The result of fitting parameters of pig 1, 2, 3, 4 and 5 in Y_1 and Y_2.

ID	A		B		R^2	
	Y_1	Y_2	Y_1	Y_2	Y_1	Y_2
1	0.5729	0.5655	−15.08	−15.29	0.9959	0.9902
2	0.5732	0.5741	−15.46	−15.40	0.9967	0.9982
3	0.5745	0.5747	−15.90	−15.02	0.9985	0.9920
4	0.5680	0.5747	−17.24	−15.88	0.9874	0.9905
5	0.5708	0.5673	−16.01	−15.40	0.9925	0.9976

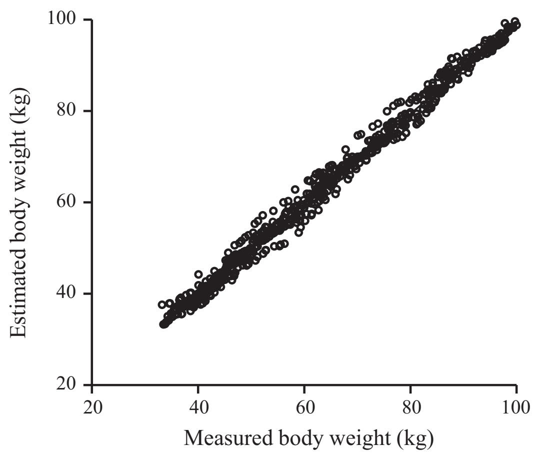

Fig. 5. Comparison of body weight between the measured and the estimated values.

The system based on internet of things and consisted of the application and database tiers played an important role in meeting the intelligence management and decreasing the number of low quality images. The quantity of pig in the drinking area controlled by the pneumatic door with two photoelectric sensors which were set at the entrance and exit of drinking area respectively. RFID reader, weighing sensors and dual cameras used to obtain the data of body weight and images of drinking pig were recorded as long as the ear-tag triggered the reader. All the real-time data were transmitted to the EVS through the data collection device such as ART DAM-E and USR-TCP232 via network.

The machine vision module in LabVIEW provided the image processing VI which can be called directly, and made this study be easier and more efficient. Image segmentation using the depth threshold based on LabVIEW played an important role in this research (Kongsro, 2014). First of all, matched the depth image of background without the pig prior to the image segmentation. And then, the images of drinking were collected by the system automatically and processed to be the depth images which were called foreground image. Finally, the contour of pig obtained by binary segmentation from the subtraction image between foreground image and background image (Li et al., 2016). This method had better performance than the gray threshold segmentation when involved the problem of reflection caused by water on the ground of the drinking area and the darkness on the pig body such as mud and shadow.

The calibration of binocular vision camera using a calibration grid with 70 ($10 * 7$) black dots on a flat plate was important and necessary. The distance between every two center of dots was 4 cm and the diameter of the dot was 2 cm. To make sure the binocular vision camera be fixed parallel and would not be moved any more during the process of acquisition. The entire viewing area was divided into 9 parts averagely, and the calibration image needed to be collected from different angles in every part of grid. The accuracy of the calibration was 0.72% of the maximum relative errors and 0.1% of the minimum relative errors. The calibration often failed many times due to the excessive acquisition of grid images and the change of grid angle irregularly, and the matching of images taken by left and right camera was a really difficult process (Wu et al., 2004). Therefore, more new products and technologies should be applied such as the Kinect and other three-dimensional cameras to avoid the complicated calibration.

6. Conclusion

The binocular stereo vision system, which calculated the BL and WH of the body size with the mean error of 1.88 cm and 0.81 cm, estimated the pig's body weight through the processing of the image with the error of 1.759 kg. It validated that the system of binocular stereo vision had the potential for calculation of the three-dimensional data, and the correlation between pig's back area and the body weight not only for the weight estimation, but the evaluation on body type afterward. The point cloud technology and three-dimensional reconstruction can be developed next based on the binocular stereo vision system.

The software platform developed by LabVIEW which had strong robustness and powerful data processing function. The automation of image acquisition, ID identification, and data saving and uploading to the database can be implemented in actual production.

The combination of software and hardware in this research ensured the body weight and size data of pigs were provided to the manager every day and assisted in controlling and preventing the nutrition and disease immediately and effectively.

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References

Apichottanakul, A., Pathumnakul, S., Piewthongngam, K., 2012. The role of pig size prediction in supply chain planning. Biosyst. Eng. 113, 298–307.
Cveticanin, D., Wendl, G., 2004. Dynamic weighing of dairy cows: using a lumped-parameter model of cow walk. Comput. Electron. Agric. 44, 63–69.
D'Souza, D.N., Mullan, B.P., 2002. The effect of genotype, sex, and management strategy on the eating quality of pork. Meat Sci. 60, 95–101.
Doyle, I., Leeson, S., 1989. Automatic weighing of poultry reared on a litter floor. Can. J. Anim. Sci. 69, 1075–1081.
Emmans, G.C., Kyriazakis, I., 2000. Issues Arising from Genetic Selection for Growth and Body Composition Characteristics in Poultry and Pigs. BSAS Occasional Publication, pp. 39–52.
Enevoldsen, C., Kristensen, T., 1997. Estimation of body weight from body size measurements and body condition scores in dairy cows. J. Dairy Sci. 80 (9), 1988–1995.
Heinrichs, A.J., Rogers, G.W., Cooper, J.B., 1992. Predicting body weight and wither height in Holstein Heifers using body measurements. J. Dairy Sci. 75 (12), 3576–3581.
Kashiha, M., Bahr, C., Ott, S., Moons, C.P., Niewold, T.A., Ödberg, F.O., Berckmans, D., 2014. Automatic weight estimation of individual pigs using image analysis. Comput. Electr. Agric. 107, 38–44.

Khamjan, S., Piewthongngam, K., Pathumnakul, S., 2013. Pig procurement planconsidering pig growth and size distribution. Comput. Ind. Eng. 64 (4), 886–894.
Kongsro, J., 2014. Estimation of pig weight using a Microsoft Kinect prototype imaging system. Comput. Electr. Agric. 109, 32–35.
Li, Z., Du, X.D., Mao, T.T., Teng, G.H., 2016. A pig dimension detection system based on depth image. Trans. Chinese Soc. Agric. Mach. <http://www.cnki.net/kcms/detail/11.1964.S.20151218.1148.004.html>.
Menesatti, P., Costa, C., Antinucci, F., Steri, R., Pallottino, F., 2014. A low-cost stereovision system to estimate size and weight of live sheep. Comput. Electron. Agric. 103, 33–38.
Mollah, M.B.R., Hasan, M.A., Salam, M.A., Ali, M.A., 2010. Digital image analysis to estimate the live weight of broiler. Comp. Electron. Agric. 72 (1), 48–52.
Oliveira, J., Yus, E., Guitián, F.J., 2009. Effects of management, environmental and temporal factors on mortality and feed consumption in integrated swine fattening farms. Livest. Sci. 123, 221–229.
Pastell, M., Takko, H., Gröhn, H., Hautala, M., Poikalainen, V., Praks, J., Veermäe, I., Kujala, M., Ahokas, J., 2006. Assessing cows' welfare: weighing the cow in a milking robot. Biosyst. Eng. 93 (1), 81–87.
Pathumnakul, S., Piewthongngam, K., Apichottanakul, A., 2009. A neural network approach to the selection of feed mix in the feed industry. Comput. Electr. Agric. 68 (1), 18–24.
Pope, G., Moore, M., 2002. Estimating Sow Live Weights Without Scales. From the Web Site of the Department of Primary Industries, Queensland, Australia.
Schaefer, A.L., Tong, A.K.W., 2000. Process for Determining a Tissue Composition Characteristic of an Animal. U.S. Patent No. 6,123,451. 26 Sep.
Schwartzkopf-Genswein, K.S., Atwood, S., McAllister, T.A., 2002. Relationships between bunk attendance, intake and performance of steers and heifers on varying feeding regimes. Appl. Anim. Behav. Sci. 76 (3), 179–188.
Slippers, S.C., Letty, B.A., de Villiers, J.F., 2000. Prediction of the body weight of Nguni goats. South African J. Anim. Sci. 30, 127–128.
Stajnko, D., Brus, M., Hočevar, M., 2008. Estimation of bull live weight through thermographically measured body dimensions. Comput. Electr. Agric. 61 (2), 233–240.
Tasdemir, Sakir, Urkmez, Abdullah, Inal, Seref, 2011. Determination of body measurements on the Holstein cows using digital image analysis and estimation of live weight with regression analysis. Comput. Electr. Agric. 76 (2), 189–197.
Topal, M., Macit, M., 2004. Prediction of body weight from body measurements in Morkaraman sheep. J. Appl. Anim. Res. 25, 97–100.
Viazzi, S., Bahr, C., Van Hertem, T., et al., 2014. Comparison of a three-dimensional and two-dimensional camera system for automated measurement of back posture in dairy cows. Comput. Electr. Agric. 100 (1), 139–147.
Wang, Y., Yang, W., Walker, L.T., Rababah, T.M., 2008. Enhancing the accuracy of area extraction in machine vision-based pig weighing through edge detection. Int. J. Agric. Biol. Eng. 1 (1), 37–42.
White, R.P., Schofield, C.P., Green, D.M., Parsons, D.J., Whittemore, C.T., 2004. The effectiveness of a visual image analysis (VIA) system for monitoring the performance of growing/finishing pigs. Anim. Sci. 78, 409–418.
Wongsriworaphon, A., Arnonkijpanich, B., Pathumnakul, S., 2015. An approach based on digital image analysis to estimate the live weights of pigs in farm environments. Comput. Electr. Agric. 115, 26–33.
Wu, J., Tillett, R., McFarlane, N., et al., 2004. Extracting the three-dimensional shape of live pigs using stereo photogrammetry. Comput. Electr. Agric. 44 (3), 203–222.
Yeo, M.L., Smith, P., 1977. A note on relationships between girth measurements and sow live weight gain. Exp. Husbandry 33, 81–84.