Three-Dimensional Shape Measurement System for Black Cattle Using KINECT Sensor

K.Kawasue, T.Ikeda, T.Tokunaga, and H.Harada

Abstract— In the present paper, a measurement system for cattle using a computer vision technique is introduced. It is important to evaluate the quality of Japanese black cattle periodically during the growth process. Not only the weight and size of cattle, but also the posture and shape, are checked as the primary evaluation criteria. In the present study, the digital point cloud data of cattle are obtained by three-dimensional computer vision devices from different angles simultaneously. These devices are calibrated in advance to have a common coordinate system. The point cloud data obtained from different angles is reconstructed on a common coordinate system, and digital cattle are generated in the computer considering the orientation of the cow. The important specifications for evaluating the cow posture are estimated from the reconstructed cattle on the computer.

Keywords— Computer vision, Point Cloud, Cattle, Measurement, Three-dimensional, Animal, KINECT

I. INTRODUCTION

EVALUATING the quality of Japanese black cattle periodically during the growth process is important. Not only the weight and size of cattle, but also the posture and shape, are checked as the primary evaluation criteria. Since the cattle are large, an equivalently large weighing machine or scale is required. Since few breeders have weighing machines, evaluation is generally carried out by eye without using a reliable measurement device. Since estimations (evaluation) may differ between breeders, the development of a portable quantitative measurement system for cattle is desired.

Recently, computer vision systems using CCD cameras have been used practically in engineering. A number of applications have also been reported in animal science, but most of these applications are limited to two-dimensional analyses, such as color analysis or the extraction of the animal from images. [1-4] Although three-dimensional quantitative measurement of animals is desirable in animal science, movement of the animal prevents three-dimensional data acquisition.

The conventional method, referred to as *shape from structured light* [5-8], is commonly used in three-dimensional measurement. In this method, the measured object is reconstructed by multiple images that include a structured light (slit ray) at different positions. The quantitative measurement is established by considering the geometric configuration between a CCD camera and a structured light. In this method, the measured object must be stationary while the structured light (slit ray) is scanned over the surface of the object. Therefore, moving objects, such as animals, cannot be measured using this method.

In recent years, devices such as the Microsoft KINECT [9-12], which detects comprehensive three-dimensional point cloud data (a set of vertices in a three-dimensional coordinate system), have become inexpensive. The device detects thousands of point cloud data in color at a frame rate of approximately 30 fps.

In the present paper, a measurement system for cattle using KINECT sensors is introduced. Two or three KINECT sensors detect the point cloud data for cattle simultaneously from different angles. These KINECT sensors are calibrated in advance to have a common coordinate system. The point cloud data obtained from different angles is transformed to a common global coordinate system on the computer. The important specification for evaluating the shape and posture of the cow is estimated using the cow reconstructed on the computer.

II. MEASUREMENT SYSTEM

The measurement system is shown in Figure 1 and the photograph is shown in Figure 2. The measurement system can be closed to be compact as is shown in Figure 3.

KINECT sensors are used in our measurement system. The KINECT sensor consists of an infrared laser projector, an infrared camera and an RGB camera. The depth information is obtained by triangulation process. To obtain the depth information, a constant pattern of speckles created by the laser source is projected onto the scene and recorded by the infrared camera. Then, this pattern is correlated against a reference pattern. The reference pattern is obtained by capturing a plane at a known distance from the sensor. As a speckle is projected on an object, the position of the speckle in the infrared image is shifted in the direction of the baseline between the laser projector and the perspective center of the infrared camera. All shifts of speckles are measured by the image correlation procedure, which yields a disparity image. Each pixel at a distance to the sensor can be corrected from the corresponding disparity. Fig. 4 illustrates the depth measurement from the infrared image and the depth image

Here, the images recorded by the infrared camera are depth images that show the depth information of the measurement point with a brightness level. The size of the depth image is 640x480 pixels, and the harmony per one pixel is 16 bits. The

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3D coordinates of the object points are calculated by triangulation process. The 3D coordinates of the object points are expressed as a depth coordinate system with its origin at the perspective center of the infrared camera on the Kinect sensor. As shown in Fig. 5, the Z axis is orthogonal to the image plane towards the object, and the X axis is perpendicular to the Z axis in the direction of the baseline between the infrared camera center and the laser projector, the Y axis is orthogonal to X and Z, making a right-handed coordinate system. Fig. 6 shows the 3D shape of a plaster bust measured by the Kinect sensor.

KINECT sensors (KINECT-0 and KINECT-2) are placed on the right and left sides of the cow, and a third KINECT sensor (KINECT-1) is placed above the cow. KINECT-1 is installed at a height of 3 m from the ground, and the other two KINECT sensors are placed 2 m from the cow. KINECT-0 and KINECT-1 are attached to a rigid frame, and KINECT-2 is placed on a separated stand. A tilt sensor is also attached to the rigid frame. These sensors (including the tilt sensor) are controlled by a computer and detect the data simultaneously. Since each KINECT sensor and the tilt sensor originally have individual coordinate systems, these coordinate systems must be transformed to a common coordinate system (global coordinate system). The origin of the global coordinate system is located on the ground. Since the ground condition in the breeding farm is generally not flat, the measurement frame may not be parallel to the horizon. So, the tilt sensor is attached to the rigid measurement frame to detect the tilt of the frame.

Fig. 1 Measurement system for cattle.

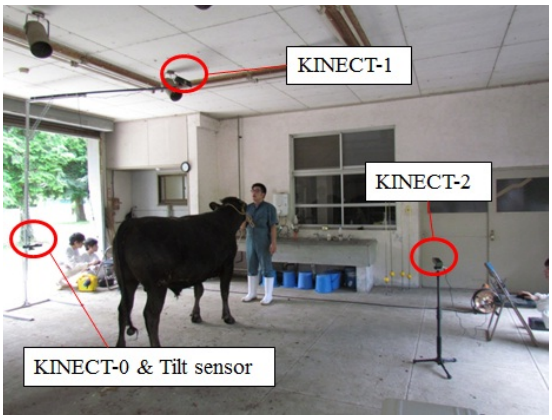


Fig. 2 Measurement scene

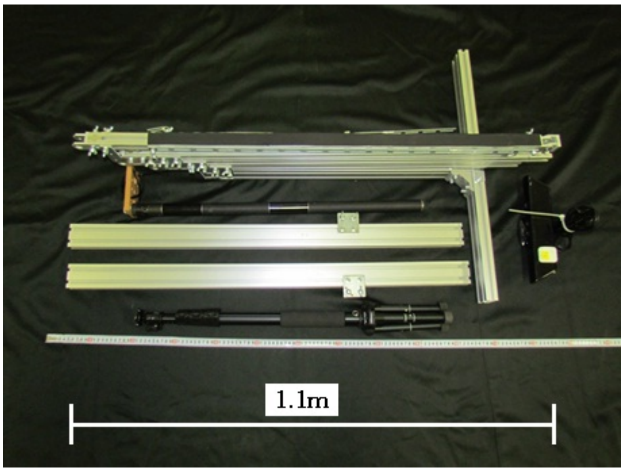
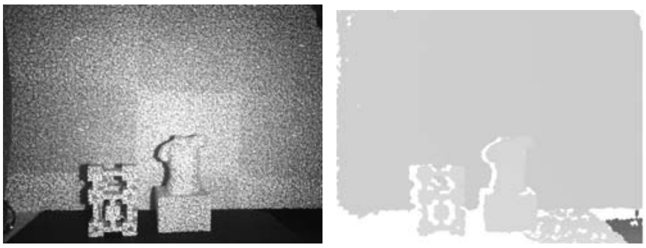


Fig. 3 Folded system as compact



(a) Infrared image (b) Depth image

Fig. 4 Depth measurement from the infrared image and the depth image

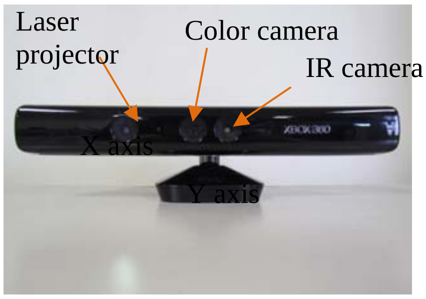


Fig. 5 Origin of the world coordinates on the Kinect sensor

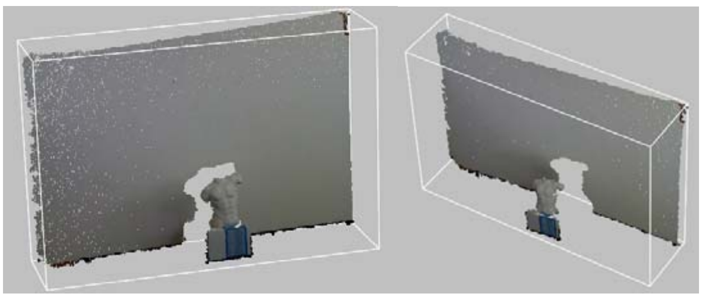


Fig. 6 3D shape of an object.

III. Measurement Flow

Figure 7 shows the flow of the measurement. Three KINECT sensors are synchronized, and the instantaneous point cloud data is obtained in order to avoid the influence of movement of the animal. Since these KINECT sensors have been calibrated in advance to the global coordinate system, the point cloud data obtained from each KINECT sensor are transformed into global coordinates, and the cow is reconstructed in the computer. Since the measurement frame is usually tilted with respect to the horizon, the reconstructed cattle must be tilt-corrected considering the tilt of the measurement frame. The measurement data for cattle evaluation can be extracted easily after the reconstructed cattle body is aligned along the global coordinate system.

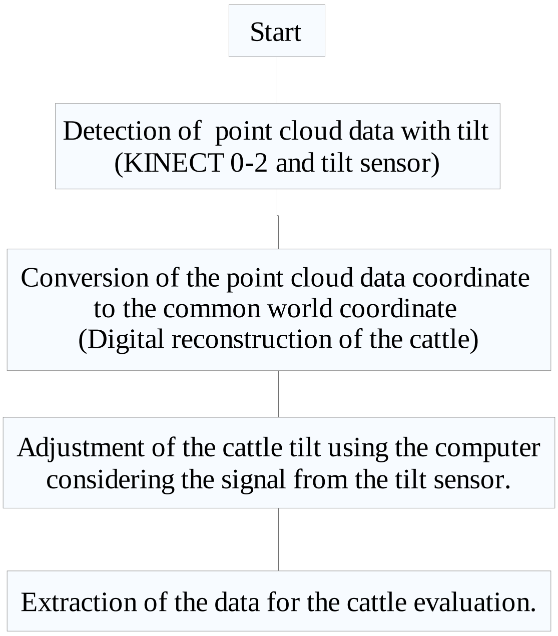


Fig. 7 Measurement flow.

IV. System Calibration

Figure 8 shows the calibration setup for the KINECT sensors. Four poles with spheres are placed on the ground before the measurement of cattle. The spheres are used to define the standard positions between the KINECT sensors. The KINECT sensors detect the three-dimensional position of the spheres, and the detected results are used to register the KINECT sensors. Each KINECT sensor has a unique coordinate system, which is transformed to the global coordinate system (x_0, y_0, z_0). In the proposed system, the coordinate system of KINECT-0 is defined as the global coordinate system (base coordinate system). The conversion can be performed using the following formula [13-20]:

$$\lambda \begin{bmatrix} x_k \\ y_k \\ z_k \\ 1 \end{bmatrix} = \begin{bmatrix} h_{11} & h_{12} & h_{13} & h_{14} \\ h_{21} & h_{22} & h_{23} & h_{24} \\ h_{31} & h_{32} & h_{33} & h_{34} \\ h_{41} & h_{42} & h_{43} & 1 \end{bmatrix} \begin{bmatrix} x_0 \\ y_0 \\ z_0 \\ 1 \end{bmatrix} \tag{1}$$

where k is the KINECT # (1 or 2), (x_k, y_k, z_k) are the coordinates of each KINECT sensor, and $h_{i,j}$ is a conversion matrix. The matrices include the rotation and transfer parameters. The matrices can be determined by inputting the corresponding over six positions of the sphere.

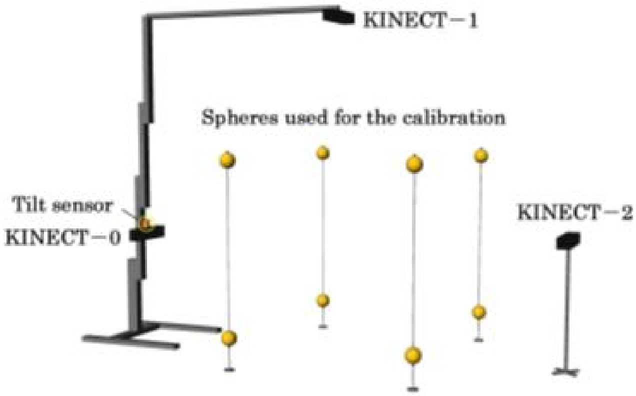


Fig. 8 Calibration setup.

(1) is transformed as the following formula.

$$\begin{cases} (h_{41}x_0 + h_{42}y_0 + h_{43}z_0 + 1)x_k = h_{11}x_0 + h_{1,}y_0 + h_{13}z_0 + h_{14} \\ (h_{41}x_0 + h_{42}y_0 + h_{43}z_0 + 1)y_k = h_{21}x_0 + h_{22}y_0 + h_{23}z_0 + h_{24} \\ (h_{41}x_0 + h_{42}y_0 + h_{43}z_0 + 1)z_k = h_{31}x_0 + h_{32}y_0 + h_{33}z_0 + h_{34} \end{cases} \tag{2}$$

Furthermore,

$$\begin{cases} x_k = h_{11}x_0 + h_{12}y_0 + h_{13}z_0 + h_{14} - h_{41}x_0x_k - h_{42}y_0x_k - h_{43}z_0x_k \\ y_k = h_{21}x_0 + h_{22}y_0 + h_{23}z_0 + h_{24} - h_{41}x_0y_k - h_{42}y_0y_k - h_{43}z_0y_k \\ z_k = h_{31}x_0 + h_{32}y_0 + h_{33}z_0 + h_{34} - h_{41}x_0z_k + h_{42}y_0z_k + h_{43}z_0z_k \end{cases} \tag{3}$$

Thus we can write the equations that correspond to the different calibration pairs in matrix form. In order to accurate the $h_{i,j}$ values, fifteen equations are needed. Therefore, at least six points will be necessary for the calibration. Eighteen equations with fifteen unknown parameter will be obtained.

$$B = AH \tag{4}$$

where

$$A=\begin{bmatrix} x_{01} & y_{01} & z_{01} & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -x_{k1}x_{01} & -x_{k1}y_{01} & -x_{k1}z_{01} \\ 0 & 0 & 0 & 0 & x_{01} & y_{01} & z_{01} & 1 & 0 & 0 & 0 & 0 & -y_{k1}x_{01} & -y_{k1}y_{01} & -y_{k1}z_{01} \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & x_{01} & y_{01} & z_{01} & 1 & -z_{k1}x_{01} & -z_{k1}y_{01} & -z_{k1}z_{01} \\ \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots & \vdots \\ x_{06} & y_{06} & z_{06} & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -x_{k6}x_{06} & -x_{k6}y_{06} & -x_{k6}z_{06} \\ 0 & 0 & 0 & 0 & x_{06} & y_{06} & z_{06} & 1 & 0 & 0 & 0 & 0 & -y_{k6}x_{06} & -y_{k6}y_{06} & -y_{k6}z_{06} \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & x_{06} & y_{06} & z_{06} & 1 & -z_{k6}x_{06} & -z_{k6}y_{06} & -z_{k6}z_{06} \end{bmatrix}$$

$$B=\begin{bmatrix} x_{k1} \\ y_{k1} \\ z_{k1} \\ \vdots \\ x_{k6} \\ y_{k6} \\ z_{k6} \end{bmatrix}, \qquad H=\begin{bmatrix} h_{11} \\ h_{12} \\ h_{13} \\ \vdots \\ h_{41} \\ h_{42} \\ h_{43} \end{bmatrix}$$

In order to obtain the value of the matrix *H,* the pseudo-inverse matrix is adapted.

The formula (3) with the error vector *e* is as following.

$$B = AH + e \tag{5}$$

The expression of the error is the norm of the vector *e*. To minimize this error

$$e^t e = (B - AH)^t (B - AH) = B^t B - 2H^t A^t B + H^t H A^t A \tag{6}$$

It is sufficient to differentiate with respect to *H* and to equal what results to zero,

$$A^t AH - A^t B = 0 \tag{7}$$

in which

$$H = (A^t A)^{-1} A^t B \tag{8}$$

The pseudo-inverse A^* can be written as following,

$$A^* = \left(A^t \times A\right)^{-1} \times A^T \tag{9}$$

Therefore matrix *H* can be determined by use of the pseudo-inverse matrix as following.

$$H = A^* \times B \tag{10}$$

(2) is also converted as following

$$\begin{cases} (h_{11}-h_{41}x_k)x_0 + (h_{12}-h_{42}x_k)y_0 + (h_{13}-h_{43}x_k)z_0 = x_k - h_{14} \\ (h_{21}-h_{41}y_k)x_0 + (h_{22}-h_{42}y_k)y_0 + (h_{23}-h_{43}y_k)z_0 = y_k - h_{24} \\ (h_{31}-h_{41}z_k)x_0 + (h_{32}-h_{42}z_k)y_0 + (h_{33}-h_{43}z_k)z_0 = x_k - h_{34} \end{cases} \tag{11}$$

It is written as matrix formula.

$$\begin{bmatrix} h_{11}-h_{41}x_k & h_{12}-h_{42}x_k & h_{13}-h_{43}x_k \\ h_{21}-h_{41}y_k & h_{22}-h_{42}y_k & h_{23}-h_{43}y_k \\ h_{31}-h_{41}z_k & h_{32}-h_{42}z_k & h_{33}-h_{43}z_k \end{bmatrix} \begin{bmatrix} x_0 \\ y_0 \\ z_0 \end{bmatrix} = \begin{bmatrix} x_k - h_{14} \\ y_k - h_{24} \\ x_k - h_{34} \end{bmatrix} \tag{12}$$

The coordinate system of KINECT-k (k=1 or 2) can be converted to the global coordinate system by the following equation.

$$\begin{bmatrix} x_0 \\ y_0 \\ z_0 \end{bmatrix} = \begin{bmatrix} h_{11}-h_{41}x_k & h_{12}-h_{42}x_k & h_{13}-h_{43}x_k \\ h_{21}-h_{41}y_k & h_{22}-h_{42}y_k & h_{23}-h_{43}y_k \\ h_{31}-h_{41}z_k & h_{32}-h_{42}z_k & h_{33}-h_{43}z_k \end{bmatrix}^{-1} \begin{bmatrix} x_k - h_{14} \\ y_k - h_{24} \\ x_k - h_{34} \end{bmatrix} \tag{13}$$

V. Adjustment of Cattle Data on Common Coordinate Systems

In order to estimate the specifications (chest, height, etc.) of the cow body from the detected point cloud data, the direction of the body should be justified the global coordinate system. The tilt of the measurement system with respect to the ground should be considered because the ground is generally not flat. The tilt of the cow with respect to the direction of gravitational acceleration is detected using the tilt sensor and the yaw around the direction of gravitational acceleration is detected using the image processing technique. The global coordinate system is shown in Figure 9.

Fig. 9 Point cloud data in the global coordinate (common coordinate) system.

5.1 Detection of roll and pitch

Roll (around the X axis) and pitch (around the Z axis) exist when the measurement system is tilted in relation to the ground. This tilt can be easily detected because the measurement system has a tilt sensor (ATR-Promotions: WAA-010). The sensor measures the tilt by detecting the direction of gravitational acceleration. The point cloud data is rotated in the global coordinate system according to the amount of roll and pitch.

5.2 Detection of yaw

An example of shape data of cattle is shown in Figure 10. Here, H is the top position of the cow from the ground, and the horizontal area (A-A') is set in the body. The height of the horizontal area (A-A') is set at 2/3H so that the area is contained in the body. The extracted cross-section at the horizontal area (A-A') is shown in Figure 11. The body is tilted by θ_y around the y axis in this Figure 11. In order to detect the angle of the tilt, the cross section is approximated as an ellipse using the least squares method. The approximated ellipse is shown by the green curve in Figure.11. The tilt of the cross-section of the cow can be detected as the tilt of the ellipse. The approximated ellipses are estimated around A-A' every 10 cm and the average rotation around the y axis is determined as the amount of rotation of the cow around the y axis. The body of the cow is rotated by this amount, and the cow is aligned according to the global coordinates in the computer.

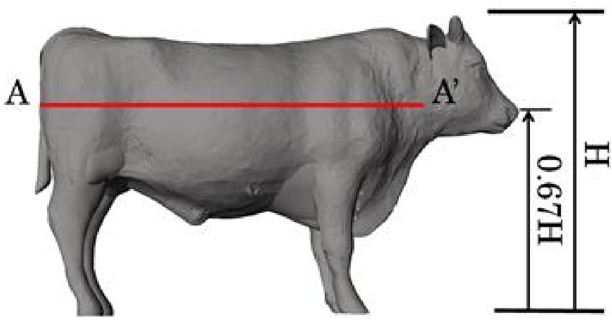


Fig. 10 Horizontal area set contained in the body.

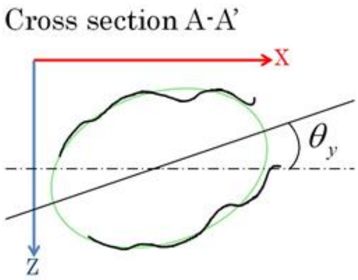


Fig. 11 Horizontal cross section in the body.

5.3 Adjustment of cattle data along the global coordinate systems

The roll (around x), yaw (around y), and pitch (around z) are expressed, respectively, as follows:

$$r_x = \begin{bmatrix} 1 & 0 & 0 \\ 0 & -\cos\theta_x & -\sin\theta_x \\ 0 & \sin\theta_x & \cos\theta_x \end{bmatrix} \tag{14}$$

$$r_y = \begin{bmatrix} \cos\theta_x & 0 & \sin\theta_x \\ 0 & 1 & 0 \\ -\sin\theta_x & 0 & \cos\theta_x \end{bmatrix} \tag{15}$$

$$r_z = \begin{bmatrix} \cos\theta_x & -\sin\theta_x & 0 \\ \sin\theta_x & \cos\theta_x & 0 \\ 0 & 0 & 1 \end{bmatrix} \tag{16}$$

The original coordinate system (x,y,z) of the cow data is aligned along the global coordinate system (x',y',z') according to the following equation:

$$\begin{bmatrix} x' \\ y' \\ z' \end{bmatrix} = \begin{bmatrix} r_x \cdot r_y \cdot r_z \end{bmatrix} \begin{bmatrix} x \\ y \\ z \end{bmatrix} \tag{17}$$

VI. Results of Measurement

6.1 Evaluation of system performance

In order to evaluate the system performance, rectangular parallelepiped with known cattle size was used for the measurement object. The distance from KINECT to the object was changed from 1.0 m to 2.5 m every 0.5 m. Figure 12 shows the result of the experiment. The error was less than 0.003 m and the performance of the system is enough for the measurement of the cow

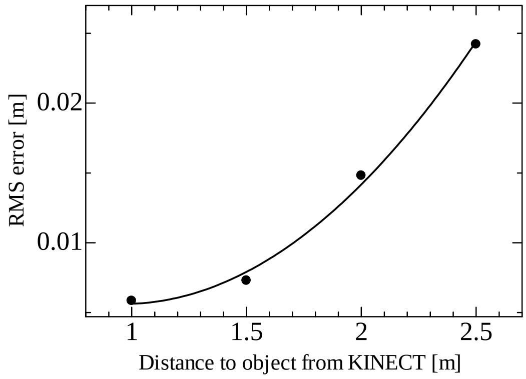


Fig. 12 Accuracy test of the proposed system

6.2 Measurement results of cattle

The photograph of measured cattle is shown in Figure 13. The age is 18 months, weight 533kg, height 131.2 cm, body length 153.2cm, chest girth and width are 196.0cm and 50.0cm respectively in manual measurement. Figure 14 shows the manual measurement scene. The point cloud data detected by each KINECT is shown in Fig.15. The each point cloud data is connected using the method mentioned before. Constructed point cloud data of cattle is shown in Figure 16. The number of the data is about 250,000 and the data is consisted of (x,y,z) coordinates and RGB color data of the cow surface. Figure 17 shows the measured portions in cattle body. The cross-sections (H1-H6) are measured horizontally by every 100 mm and four major sections (L1-L4) are selected vertically as is shown in Figure 18. Once the body is constructed, the major specification to evaluate cattle can be estimated easily on the computer. Especially, chest girth, hip height and body length etc. are important parameter to evaluate the growth of cattle. For example, the weight can be estimated accurately from these parameters. [21].

The measurement values of the chest, hip height are important parameter to evaluate the growth of cattle. In our system, the approximated circle of the chest girth is used to estimate the chest girth.

Fig.13 Measured cattle

The green circle in the Fig.18 is the approximated circle. The difference between the estimation and the manual measurement was in less than 5%. The difference of the hip height between the computer vision and manual measurement was less than 7%. One of the results of the difference is caused by the body hair of cattle.

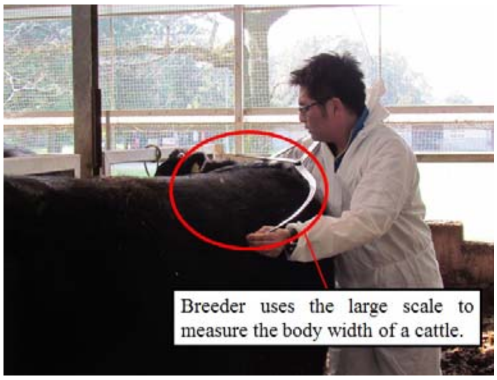


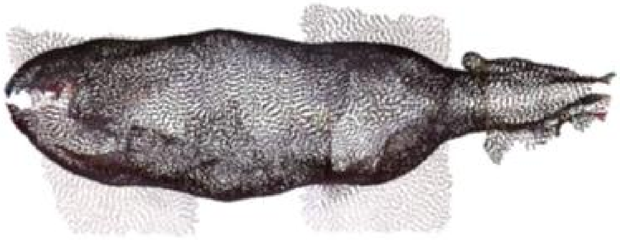
Fig. 14 Manual measurement scene

a. Side view from KINECT-1

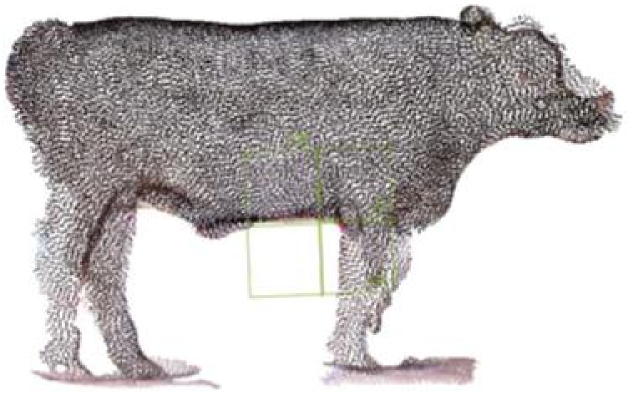
b. Top view from KINECT-2

c. Side view form KINECT-0

Fig. 15 Point cloud data detected by each KINECT



a. Top view



b. Side view

Fig. 16 Constructed point cloud data

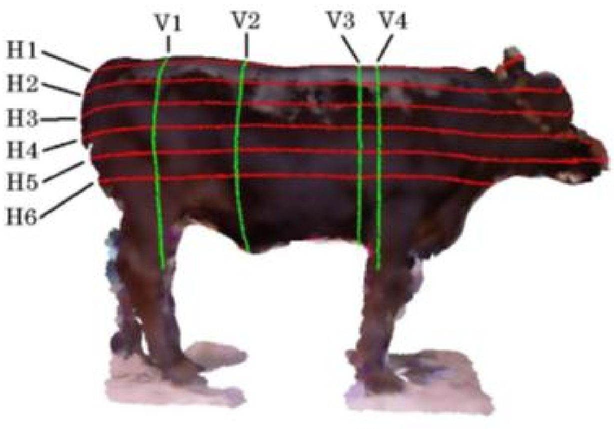
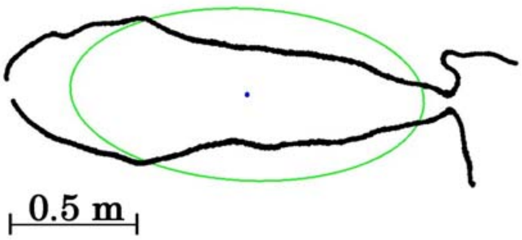
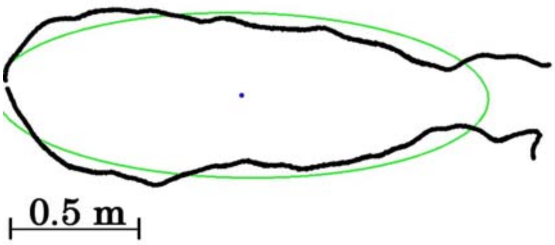


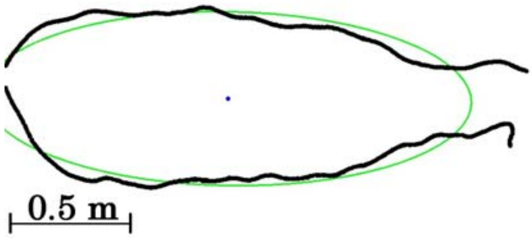
Fig. 17 Measured portions in cattle



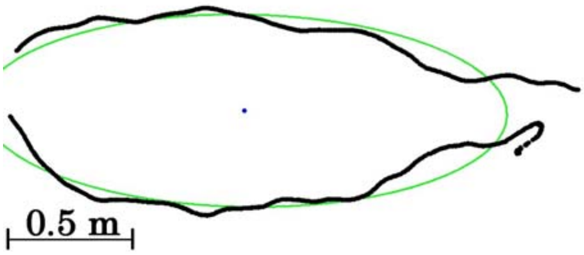
H1



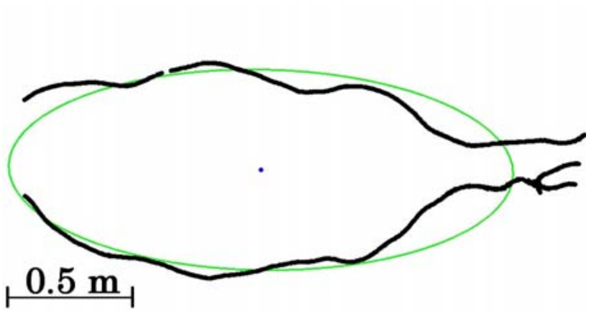
H2



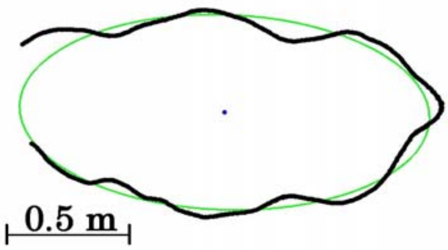
H3



H4

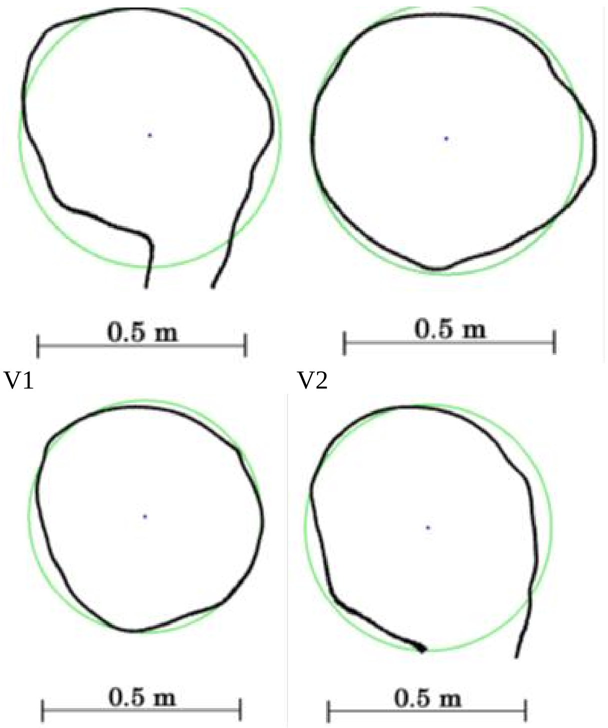


H5



H6

A Horizontal cross sections



B Vertical cross sections

Fig.18 Extracted sections from the point cloud data in the cow

Figure 16 shows the standard (ideal) model of Japanese black cattle. The shape of this ideal model was measured using our three dimensional measurement system and point cloud data was obtained. Figure 17 shows the horizontal cross section at 1/2 height and was magnified to be equivalent with the real size. Figure 18 shows the cross section of the live cattle at same position of the ideal model. Figure 19 shows the comparison result of the cross section between the ideal model and measured cattle. The evaluation can be executed at any positions by comparing the shapes with ideal model.

Fig. 19 Standard cattle model

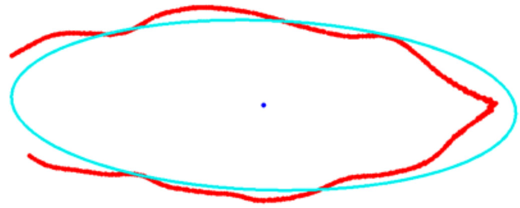


Fig.20 Horizontal cross section of a standard cattle model

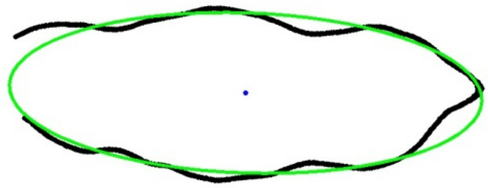


Fig.21 Horizontal cross section of a live cattle

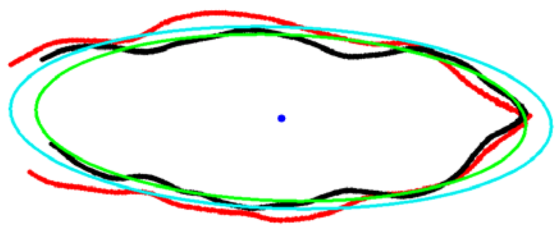


Fig.22 Comparison and Evaluation of shape

VII. Conclusions

In this paper, the measurement system for cattle using a computer vision system is introduced. Two or three KINECT sensors detect the point cloud data for cattle simultaneously from different angles. These KINECT sensors are calibrated in advance to have a common coordinate system. The point cloud data obtained from different angles is connected and transformed to a common global coordinate system on the computer. The important specification for evaluating the shape and posture of the cow is estimated using the cow reconstructed on the computer. Experimental results show the feasibility of our system but the difference is existed between the results of computer vision and manual measurement. One of the results of the difference is caused by the body hair of cattle. It should be consider the length of the cow hair on the measurement using computer vision.

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