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A Designing Dairy Cattle Facilities Based on Statics/Dynamic Zoometry by Using Artificial Intelligence

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Abstract

The dairy cattle productivity is very depending on the quality of their facilities and their environment condition. A lot of researches have been done in this area, but it is not developing the knowledge of animal dimensions and behaviours correlated with their facilities design. Complexities of dynamics zoometry is very depending on cow behaviours that it forced to use neural network (NN) approaching. Hence, the purposes of the paper is to create the concept of static and dynamic zoometry approach to guide the ergonomics facilities design and the modern of dairy cattle house based on zoometry data by using artificial neural network. The research is started with study literature of anthropometry, CAD design, dairy cattle, facility design and neural network. The next step is collecting the data of cow dimensions for static zoometry (17 variables) and cow behaviours for developing the concept of dynamics zoometry (5 variables). The static data is used as input factor and dynamic data as desire of Back Propagation NN model. The result of BPNN training is used to design the dairy cattle facilities, e.g. 3D CAD house with minimal length = 357.67 cm, minimal width = 132.03 cm (per tail) and minimal height = 205.28 cm. Finally, the paper is successfully developed the concept of zoometry approach and BPNN model as pioneer of implementing comfort knowledge.

***Keywords**: animal comfort, cattle house, facility design, neural network, zoometry*

1. Introduction

Milk is very important commodity of food in the world for which providers of calcium, phosphorous, magnesium and protein which is all essential for human healthy. Adequate consumption of milk from early childhood and throughout life can help to make the bones more strong and protect them against diseases in their live. Milk provides the following beneficial nutrients in varying quantities, there are calcium, phosphorous, magnesium, protein, vitamin B12, vitamin A, zinc, riboflavin, folate, vitamin C, iodine [1]. The increasing of people to realize how important of milk product in their life boosted the demand of milk production. As consequence, the number of dairy cattle farmers and also the productivity should be increased in the future. Based on Table 1 we can indentify that the ratio between the milk is produced and the number of dairy cow population experienced a downward trend. If this condition occurs continuously, it will make Indonesia will continue to depend on imports from other countries. Addressing required at Table 1 we need an approach that can increase the productivity of fresh milk. One of method to increase the milk productivity is maintaining the cow facilities more comfortable e.g. house, free stall, floor, etc. There are some researchers investigated the dairy cattle comfort including cow house and their facilities. Cook and friends reported that physical accommodation of dairy cattle should provide a relative dry area for the dairy cattle to lie down and be comfortable [3].

Peter Krawczel and Rick Grant in his paper summarized that overcrowding of dairy cow can effect of reducing the resting time, increasing idle standing in alleys, altered feeding behaviour and commonly reducing cow comfort [4]. A study of more than 47 farms in Northeastern Spain explained the significant effect of stall on the productivity of dairy cow. Smith, M.J. Brouk and J.P. Harner investigated the impact of facilities on milk production and cow health [5]. The cow facilities should be constructed to minimize time to reach food and water. Free stall facility is usually selected to minimize the effect of weather changes, improve

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cleanliness and cow comfort. Dairy facilities should be designed to keep the cows and calves comfortable in order to maintain DMI (Dray Matter Intake) and thus maximize economic production. Other studies have reported similar results. Jim Reynolds identified the cow comfort into 5 factors for heat stress, sanitation, free stall design, walking surface and walking distance [6]. In short, dairy cattle facilities are important factor of key success in milk business and it should be designed to keep the cow and calves comfortable in order to maintain milk quality and thus maximize economic production.

Table 1. Ratio between Fresh Milk Production and Dairy Cattle Population 2011-2016 in Indonesia [2]

Period	Fresh Milk Production	Dairy Cattle Population	Ratio
2011	974694	597213	1.632071
2012	959731	611940	1.568342
2013	786849	444266	1.771121
2014	800749	502516	1.59348
2015	805363	525171	1.533525

To cover the problem of comfort design for dairy cow facilities, the physical ergonomics knowledge is needed. The important knowledge of physical ergonomics area for human body is defined as anthropometry. It studies the variation of the human body dimensions in static and in dynamics condition [7]. Using same analogy, the paper converts the concept of anthropometry into the concept of zoometry to study the impact of variation of animal body dimensions. This analogy imagines that animal (cow) need feel comfort in order to produce milk, it's like human too. Human need feel comfort at work in order to reach high productivity. Zoometry is created from Greek language ζώο (zǫ́o) that means an animal and μέτρον (metríste) that means a measurement. Zoometry concept is defined as static and dynamics measurement of animal dimension in order to know the physical variation of specific animal population. The research used zoometry concept of dairy cattle to design their facility (house, free stall, floor, etc.) with the result that it will increase the dairy cattle comfort and milk production. This study considers static and dynamic measurement because of representing main activity at cattle. There are three main activity of cow at cattle that affected by static and dynamic condition such as feeding, lying and standing or transition events between lying and standing. The concept of zoometry can reduce the risk of cattle from annoyances of uncomfortable facility. It is a pioneer strategic to improve the cow comfort by using zoometry concept.

2. Research Method

2.1. Physical of Dairy Cattle

There are many kinds of dairy cattle e.g. fries Holland (Netherland), Shorthorn (UK), Holstein Friesian (Netherland), Jersey (UK – France), Brown Swiss (Switzerland), Red Danish Denmark), Drought Master (Australia), etc. The dairy cattle in Indonesia is dominated by Holstein Friesian which signed by white and black spot or red spot. Holstein Friesian can produce milk around 57.000 Kg per year per cow with content low fat at approximately 3.5 to 3.7% [8].Cow body dimension will influence the horizontal movement of the cow when it gets up or lie down use around 3 m. The moving forward motion is 0.6 m and minimum distance to the bedding from the head or neck of the cow is approximately 0.2 m [9]. The reach of dairy cattle during feed intake depends on the type of tether and the feed alley height. The body length of the cow, from the shoulder area to the tail head the spine is not flexible which make it difficult for the cow to make sharp changes of direction while it is walking. Similar with human dimension, there are several things that can affect dairy cattle dimension as defined in zoometry measurements are species, phase development, age, gender, and clumps.

2.2. Dairy Cattle Behaviours

Dairy cattle behaviours are well developed in the search of feed, environment/ microclimate condition, facilities design, house and social communication. The dairy Cattle are able to distinguish between the colours red, yellow, green and blue, however how to differ between green and blue is poor [9]. Moreover cattle are able to distinguish between differently simple shapes such as triangles, circles and line. It is important information of colours in cow facilities design to increase dairy cattle more comfort. In the free area, the cow is automatically moving from the dark condition to the light area and they are avoiding strong contrast between sun and shadow. Comparing to the hearing of people, the cow almost has same frequency range and able to listen high tones that human cannot hear. Hearing in cattle is important in inter- and intra-species communication [10]. The sense of touch of cattle is important in determining which herbage is rejected or accepted. The secondary/special olfactory system can detect pheromones, volatile chemicals that are important in reproduction and feed selection [11].

Cattle communicate by sending out different signal such us poses, sound and smells [9]. A high density of cattle inside the house limits the freedom movement of the cow and can increase social stress. Cattle have a distinct circadian rhythm, in which the main rest, feed and rumination activities vary according to fixed pattern. Grazing occupies a large amount of time for dairy cows about 8 hours/day. Grazing behaviour is affected by many factors, including environmental conditions and plant species. In a dairy herd of Friesian cows it was found that there was a consistent order for lying down and standing up [12]. The natural lying down behaviour of cattle begins when the animal sniffs at the ground while it slowly moves forward. The head and body of fully developed cow is thrust 0.60 – 0.70 m forward during the lying down process. When a cow wants to get up in natural way it firstly raises to its knees and afterwards the hind part of its body is swung up via the knees, which function as rocking point.

2.3. Dairy Cattle Facility

The facilities should be supported the main cattle activities of resting, drinking, eating and milking. The facilities must guarantee the cattle will get stuck, injuries, and stress behaviours. Finally, the best facilities are indicated by cattle comfort level and increasing milk production from time to time future. Moreover, better floor is not warm and humid to reduce possible skin injuries and more thermal comfort. The other facility is watering system; a watering cup should have an opening of at least 0.06 m^2, approximately 30 cm in diameters or similar opening size [8]. It is recommended that the main of the water supply is ring –connected and that the water is under a constant pressure. The best way watering is supplying via service pipe, it will make sure the fresh water is always supplied. Watering system as possible designed with little dirt as possible is collected. Free stall is very important for cattle to feel in private area concerned with comfort resting. Nigel B. Cook on his research of free-stall design for maximum cow comfort reported that 11.3 hours is needed for time lying down in the stall and 2.9 hours for time standing in the stall a day or totally 14.2 hours per day contacted with free stall (around = 59.17%) [3]. Cow must have free stall design correctly size because of correlating with milk production. A lot of famers reduce stall length and stall width in order to saving construction cost. It will reduce the level of cow comfort and milk production. Free stall should be designed correctly and maintained and should be sloped front to back and comfortable surface provided.

2.4. Research Methodology

The zoometry data of dairy cattle are collected from two regions in Malang and in Blitar with average age between 3.5 to 6 years (optimal daily milk). The total of cow being sample in Malang was around 300 and in Blitar were around 200 samples. Generally, the measurement is divided into two sections for static dimension (mentioned later as static zoometry) data and for cow movement (dynamic zoometry) data. To do the research some equipment was prepared, such us: paper sheet, pen, ruler, stopwatch, and Handy Cam. The static measurement focused on cow body dimension e.g. length of body, length of leg, wide of body, length of neck, etc. The dynamic zoometry is taken under the cow engaged some physical activity. The measurement focused on how the cow movement (walking), moving the tail, moving head during drink or eating and moving from stand up to lay down or conversely. To do detail measurement some videos have been taken during the measurement process. Briefly, statistic test for normality and validity data are presented in zoometry data analysis.

Figure 1 shows one example of measuring the static zoometry for dairy cow. To control the steps of the research are logically right, flowchart of developing and implementing the zoometry concept are presented as can be seen in figure 2 below. According to the graph, the next step after collecting the static and dynamic data is doing the statistic test for checking the data quality. The best zoometry data is used to develop the zoometry concept that same as the anthropometry concept. To looking for the best correlation between static and dynamic data, the neural network model is employed. As a result, the zoometry concept is strengthened to use as guiding for cattle facilities design in 3D CAD model.

Figure 1. Zoometry Measurement of Dairy Cattle for Static and Dynamic Data

Genetic algorithms have to solve this problem because this method has been used extensively to find the optimum conditions for example in studies following, algorithm genetics is used to predict the onset of tachyarrhythmias ventricle provides an opportunity to reduce the loss due to sudden cardiac death [13], genetic algorithms integrate thinking immunity the biology of the immune system [14], and in the determination of optimal parameter through simulation [15]. The BPNN will train the database with genetic algorithm (GA) optimisation in 2 hidden layers. Mean square error (MSE) is employed to evaluate the training quality until convergence solution is achieved. The detail of BPNN structure is presented below, working in 2 hidden layers, initial neurons = 20 for first hidden layer and 10 for second hidden layer, Delta Bar Delta learning algorithm with initial values for learning rate and momentum are 0.500000 and 0.0166, sigmoid transfer function, number of population is 50 chromosomes and generation number for maximum 100, initial network weight factor is 0.1074. Mutation probability is 0.01, Using heuristic crossover.

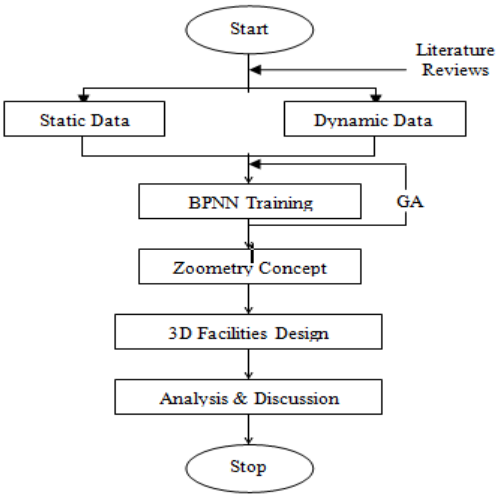

Figure 2. Flowchart of Developing and Implementing the Zoometry Concept using BPNN model

3. Results and Analysis

The research investigated zoometry for dairy cattle for both of static and dynamic zoometry measurement. To do a zoometry concept is important to understand the dairy cattle lives. First step to do the Zoometry concept is defining the zoometry dimension in both of static and dynamic measurement of cattle body dimensions and cattle behaviours. There are 16 dimensions of static zoometry for dairy cattle. Figure 3(a) and 3(b) defined the entire dimension

(D_1, D_2, D_3, D16) of static zoometry in the 2D picture. The dimensions of D_1 to D_{10} explain the position in front view of dairy cattle (lengthwise direction) and the dimension of D_{11} to D_{13}describes in lateral direction of dairy cattle. The D1 is for height of head, D2 is height of body, D3 is the length of neck + head, D14 is head wide, D15 is length of tail, and D16 is length of horns.

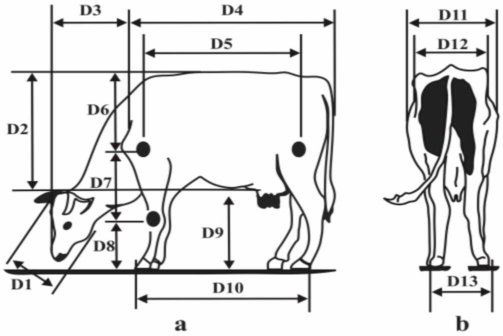

Figure 3. Static zoometry dimensions; a. front view of cow dimensions (D_1 to D_{10}), b. backside of cow dimensions (D_{11} to D_{13})

Table 2 shows some of the results of static zoometry measurement in 16 dimensions as mentioned before with 25 data respectively. According to the data, the average of data and the deviation standard are calculated for all dimensions (D1 –D16), as example D1 has average $\overline{D}$= 39.64 and deviation standard (σ_1) = 2.68. Moreover, D1 has lower control limit (LCL) = 34.17 and upper control limit (UCL) = 44.47 is categorized in homogeneity data. The same way, the other static cattle dimensions (D2 – D16) also categorized in homogeneity data. As a result the data measurement is ready to use for next step of sufficient data test.

Table 2. Data measurement results from 500 number of source data of cattle for static dairy cattle dimension

No	Explanation	Dairy Cattle Dimension				
		1	2	-	499	500
D1	Height of head	36	38	-	38	40
D2	Height of cow body	77	78	-	78	79
D3	Length of head + neck	104	106	-	104	105
-	-	-	-	-	-	-
D15	Length of tail	114	113	-	115	120
D16	Length of corn	9	14	-	10	8

Sufficient data test for static cattle dimensions is determined based on formula 1. To calculate the number of data requirement (N'), the research select confidence level of collecting data 95% (k =2) and error = 5% (s = 0.005) has N' = 7. As a result the data D1 can be categorized in sufficient data (N' < N). Using the same way, the data of the other dimension D2 – D16 all are categorized in sufficient data.

$$N' = \left[\frac{\left(k/s \sqrt{N \sum_{i=1}^{N} x_i - \left(\sum_{i=1}^{N} x_i \right)^2} \right)}{\sum_{i=1}^{N} x_i} \right]^2$$

Where: N'= Data should be taken
N = Data have been collected
k = Level of confidence
s = Level of error
x_i = Observation data

There are 7 dimensions for D_{17} to D_{23}. In purposing of comfort rising or lie down movement, the resting area must provide cattle with the easy movement for vertical, forward and lateral movement without obstruction, injury or fear. A rising motion of cattle includes the freedom to lunge forward, bob the head up or down, and stride forward. A resting motion of cattle also includes the freedom to lunge forward and bob the head. Each time the cow lies down, they puts about two-thirds of her body weight on her front knees then her knees drop freely to the floor from a height of 20 to 30 centimetres. It is therefore very important to have the best quality bedding, as consequence the cow can painlessly lie down whenever she wants to. The easy method to know the comfort level is to look at and check how fast a cow lies down in a cubicle.

Based on Figure 4, the dynamics zoometry data of dairy cattle is collected from the same cattle of the static zoometry data. The measurement results are putted in Table 3 with 25 replication every dimension of dynamic dimension. According to the data, the average of data and the deviation standard are calculated for all dimensions (D_{17} –D_{23}), as example D17 has average $\bar{x}$= 54.40 and deviation standard (σ_{17}) = 4.75.Moreover, D_{17} has lower control limit (LCL) = 44.90 and upper control limit (UCL) = 63.90 is categorized in homogeneity data. The same way, the other static cattle dimensions (D_{18} – D_{22}) also categorized in homogeneity data. As a result the data measurement is ready to use for next step of sufficient data test. Sufficient data test for static cattle dimensions is determined based on formula 1 above. To calculate the number of data requirement (N'), the research select confidence level of collecting data 95% (k =2) and error = 5% (s = 0.005) has N' = 12. As a result the data D_{17} can be categorized in sufficient data (N' < N). Using the same way, the data of the other dimension D_{18}– D_{23} all are categorized in sufficient data.

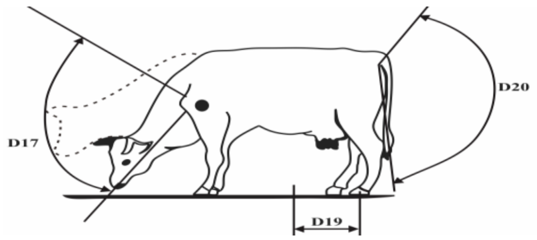

Figure 4. Dynamic Zoometry Dimensions of Dairy Cattle ($D_{17,}$ D_{19}, D_{20})

Same as anthropometric, the zoometry are specified in term of percentiles with population is divided into 100 percentage categories. The percentiles are ranked from least to greatest with respect to some specified type of cattle body measurement. For example 5th percentile is a value whereby 5% of the population are shorter and 95% are taller, 50th percentile is the medians measurement, and 95th percentile is a value whereby 95% of the cattle population are shorter and 5% are taller. Formula 2 show how to calculate the percentile of zoometry for 5th, 50th and 95th.

Table 3. Data Measurement Results of Cattle for Dynamic Dairy Cattle Dimension

No	Explanation	Dairy Cattle Dimension				
		1	2	-	499	500
D17	Vertical head movement (^{0})	50	55	-	43	45
D18	Horizontal head movement (^{0})	200	220	-	225	240
D19	Step walking (cm)	53	72	-	77	64
D20	Cow tail movement (^{0})	120	110	-	112	103
D21	Space for lay down (cm)	313	309	-	312	318
D22	Space for gets up (cm)	300	296	-	299	205
D23	Width space (cm)	132	130	-	120	118

Complexity of dynamic data correlated with cow dimension encouraged authors to employ machine leaning of neural network. In this case, the back propagation neural network

(BPNN) is selected in training process as structured in 3 of research methodology. Figure 5 explains the results of BPNN training using genetic algorithm (GA) optimisation in one replication. According to the graph, the training process will stop in 49 generation with mean square error (MSE) = 0.0287. Finally, the BPNN model is ready to use for predicting of any input data to looking for the output data (dynamics data). The BPNN model is very useful for the user to do some test for looking for cow behaviour correlated with cow dimensions in design process.

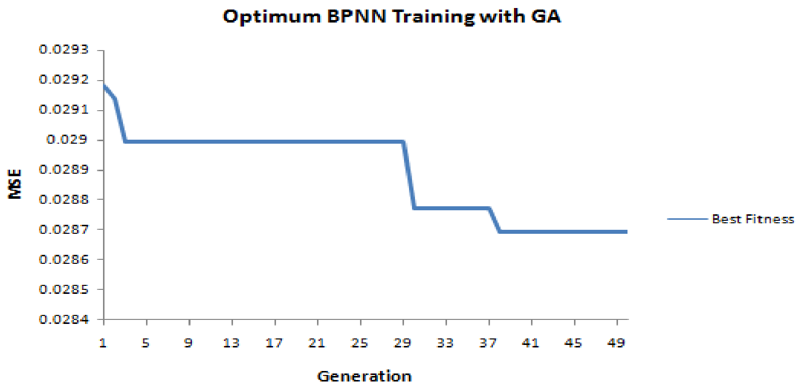

Figure 5. Dynamic Zoometry Dimensions of Dairy Cattle (D_{17}, D_{19}, D_{20})

Next stage is implementing the zoometry concept and BPNN model to evaluate and redesign the cattle facilities. For example, ergonomics cattle house design is presented in this paper. Computer Aided Design (CAD) is used to clarify and to validate the zoometry results. Dairy cattle house is beneficially use 3D CAD model software before making prototype. First step of designing the cattle house is defined the house parameters that are:

1. Length of cattle house (L)

Length of cattle house is defined as the total summation of length for lay down and length for get up minus cattle length or L = $\overline{D}_{21} + \overline{D}_{22} - (\overline{D}_3 + \overline{D}_4)$. L has average 346.67 cm and deviation standard σ = 6.71 cm then by using percentile 95th will produce $L_{zoometry}$ = 346.67 cm + 1.64 x 6.71 cm = 357.67 cm.

2. Width of cattle house (W)

Width of cattle house is defined as the space for lay down or gets up easily or defined in D_{23}. D_{23} has value = 125.96 cm and deviation standard σ = 3.70 cm then by using percentile 95th will produce $W_{zoometry}$ = 125.96 cm + 1.64 x 3.70 cm = 132.03 cm

3. Height of cattle house (H)

Height of cattle house is defined as the summation of $\overline{D}_2 + \overline{D}_9 + (\overline{D}_3 \times \tan(0.5 \times \overline{D}_{17}))$. H has average 194.64 cm and deviation standard σ = 6.49 cm then by using percentile 95th will produce $H_{zoometry}$ = 194.64 cm + 1.64 x 6.49 cm = 205.28 cm.

The design of cattle house is recommended base on the results of zoometry calculation of length, width and height. The cattle house design should be has minimum value of length = 357.67 cm, width = 132.03 cm and height = 205.28 cm. The height dimension of cattle house must consider the other factors such as air circulation, lighting, and the other facilities especially in tropical climate with temperature and relative humidity to higher level. It can increase the heat stress index, which finally reduce milk production. Figure 6 shows an example of dairy cattle house in 3D CAD design based on the implementation of zoometry concept.

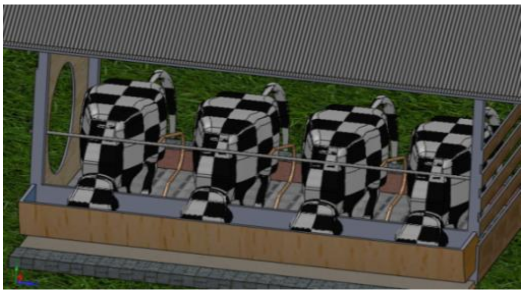

Figure 6. One Example of Implementing Zoometry Concept in Building Dairy Cattle House

4. Conclusion

The paper has successfully developing the concept of zoometry to describe the dimensions of dairy cattle in order to use in facilities design. There are two kinds of zoometry for static and dynamics condition with total number of dimensions is 17 and 7. The paper successfully presented the BPNN training as complexity of dynamic data (cow motion behaviour) correlated with cow dimension The paper also describes how to implement the zoometry concept in order to develop cattle house design. It is a pioneer to do the others facilities such as free stall, watering system, designing floor, and feeding rack. By using 500 number of source data of cattle, the zoometry concept is still fluctuate despite of successfully in homogeny test and data sufficient test. As consequence, there is still need a lot of data dimension to get steady zoometry. The zoometry concept will be an important topic of research in the future correlated with cattle comfort and cattle productivity.

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