Development of Algorithm Using Fuzzy Logic to Predict Estrus in Dairy Cows: Part I

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ABSTRACT

Due to the importance of estrus detection on the reproductive performance this research aimed to develop an algorithm using fuzzy sets to predict the estrus in dairy cows. Three input variables were used: a) dairy cows' behavior (mounting, genital mucous discharge, genital swelling, frequent urination, and restlessness); b) attempting to mount other cows, and c) time since last estrus. The output variable used was the estrus detection rate that is the percentage of correct estrus detection. The analysis was made using MATLAB® 6.5 fuzzy logic toolbox. The results showed that fuzzy logic is a promising way for predicting estrus in dairy cows, and it could help in decision making process related to insemination of the animals.

Keywords: Dairy cows**,** fuzzy sets, estrus detection

1. INTRODUCTION

The efficient estrus detection in cows and heifers deeply influences reproductive performance of the animals, and the livestock farmer profitability (Lopes, 1997). An estrus detection failure brings economical problems to the farmer mainly when artificial insemination or controlled mounting is used. Even if a cow is in good conditions to reproduce it is important to detect the estrus correctly to avoid excessive use of hormones, as the herd's performance is considered appropriated when the dairy cows farrow once a year (Torres, 1987; Camargo, 2000). According to Ferreira et al. (1997) the efficient detection of estrus is directly related to reproduction efficiency. For adequate estrus detection it is necessary to evaluate the animal behavior (Esslemont et al., 1980; Stevenson et al., 1996), having as start point the animal's reproductive cycle. Estrus is defined as the period when dry cows or heifers have their reproductive hormones level increased, and that it occurs every 18 to 24 days (Cardoso, 2002). The estrus main characteristic is when the female accepts mounting, followed by other signals that help the estrus detection, called secondary signals (Camargo, 2000).

Cardoso (2002) enhances the importance to know well about the estrus signals. During the pre-estrus cows attempt to mount other cows, however they do not allow other cows to mount them. At this time they vocalize more frequently, walk close to fences, follow other cows, get alert, and their genitals become red and swollen filled with clear and viscous mucous. The signals are the same during the estrus, and during the post-estrus the cows do not accept that other cows mount them anymore, they present vulva less swollen and they resume the usual behavior. Cano (2002) proposed a study analyzing cases and interactions of sexual behavior of cows with synchronized estrus when mating Nelore[1] breed bulls with high and low libido. In that specific study it was observed sexual behavior such as: detection (smelling vulva, Flehmen's reflexes, accommodation-accompaniment, pursuit), pre-matting (placing the chin on the rump, banging heads, licking other parts of body, attempting to mount), mount-matting (attempt to mount, attempt with exposure, attempt to mount with positive immobility, service or complete mounting) and rest period.

For the estrus detection an observer must be well prepared and know widely the signals that indicate the estrus in order to identify correctly its presence even though this usually does not result in an accurate detection, usually lower than 58% (Liu & Spahr, 1993; At-Taras & Spahr, 2001, Peralta, 2003). Animal behavior should be observed at least twice a day (in the early morning and in the end of the afternoon), and detection efficiency can be improved with the male presence. Devices have been developed to provide an efficient detection, and according to Senger (1994) this technology is more efficient to detect physiological and behavioral events related to ovulation being able to: identifying precisely and automatically the cows in estrus; monitoring constantly the animal during its productive period, and minimizing labor. Nowadays several methods have been used to detect the estrus such as visual observation (Xu et al., 1998; Rae et al., 1999; Cavalieri et al., 2003; Solano et al., 2005), mounting detectors (Nebel et al., 1992; At-Taras & Spahr, 2001; Saumande, 2002), milk progesterone testing (Cavestany & Foote, 1985; Firk et al., 2002; Van der Lende et al., 2004; Xu et al., 2005), combined measurements of temperature and electrical resistance or conductivity of reproductive tissues (Gartland et al., 1976; Foote et al., 1979; Bobowiec et al., 1990; Morais et al., 2006), physical activity measurement using pedometers (Maatje et al., 1997; López-Gatius et al., 2005; Roelofs et al., 2005; Yániz et al., 2006), pressure sensing radio telemetry (Nebel et al., 2000), electrical conductivity of cervical mucous (Cardoso, 2002), and method to analyze vocalization of the cows (Schon et al., 2007). According to Marcinkowski (2004) the factors that influence estrus detection are: the cow (energy balance, body condition, their general health, and reproduction tract among others), the environment (temperature, ventilation, walking area, and grouping) and human factors (knowledge about estrus signs, estrus check daily, labor dedication, observation intensity and responsibility, and observation report).

Fuzzy logic is also called misty sets or diffuse sets, and it is an extension of the classic logic. It was first studied by Lofti Zadeh in the University of California Berkeley, in 1965, when he published a paper titled "Fuzzy Sets" in the journal *Information and Control* (Zadeh, 1965). This new methodology is one of the more recent specialties of the artificial intelligence area that aims to generate techniques to solve problems in several knowledge areas, approaching the computational decision to the human decision. Fuzzy logic uses approximate instead of exact information, imitating the human thinking. Nowadays fuzzy logic is used in control systems and in decision support systems where the problem description approach can not be precise. A fuzzy system is formed of output and input variables. For each variable, fuzzy sets that characterize those variables are formulated, and for each fuzzy set a membership function is built. After that, the rules that relate the output and input variables to their

[1] Brazilian Zebu breed

respective fuzzy sets are defined. The computational evaluation of a fuzzy system is formed of fuzzification (construction of output variables that define the study), inference (fuzzy reasoning application on fuzzy output) and defuzzification (translation of linguistic value to numerical value). The fuzzy reasoning can be implemented by a direct method or indirect method (Tanaka, 1997). This methodology has been used in various areas such as data analysis, expert systems, control and optimization, aircraft control and biomedicine (Ribacionka, 1999; Lopes, 1999; Ortega, 2001; Weber & Klein, 2003). Fuzzy sets theory, fuzzy logic and fuzzy theory potential applications have been promising in the engineering area (Klir & Yuan, 1995). In addition to the applications cited before fuzzy logic have also been used in other agricultural applications (Ali et al., 1999; Cho et al., 2002; Amendola et al., 2004; Saptomo et al., 2004; Amendola et al., 2005; Carvalho et al., 2005; Queiroz et al., 2005; Tassinari, 2006; and Tooy & Murase, 2007).

Morag et al. (2001) proposed the use of a decision support system by using fuzzy logic where cows' traits such as body weight, dairy production and breast-feeding period were evaluated under a controlled diet. Firk et al. (2003) used fuzzy logic approach to show the benefit of combining cows' activities and the period after the last estrus, in order to detect whether the cow is in the estrus period or not, reporting the insemination prediction improvement when compared to other methods.

2. OBJECTIVE

Due to the difficulties in accurate prediction of dairy cows estrus this research aimed to develop a fuzzy model for estrus detection.

3. METHODOLOGY

The following input variables were defined for the Fuzzy system development: the main behavioral signs that show whether the cow is in the estrus period or not (number of behavior observations – NBO), the occurrence period of attempts of mounting other cows – APM (hours), and the period since last estrus – PSLE (days). The Fuzzy system predicts the estrus detection rate – EDR (%), percentage of correct estrus detection, based on the input variables (Figure 1). The analysis was developed by using the software MATLAB® 6.5, making use of Mamdani Method as the inference method, and the defuzzyfication was performed by using the Gravity Center Method, as proposed by Amendola & Souza (2004).

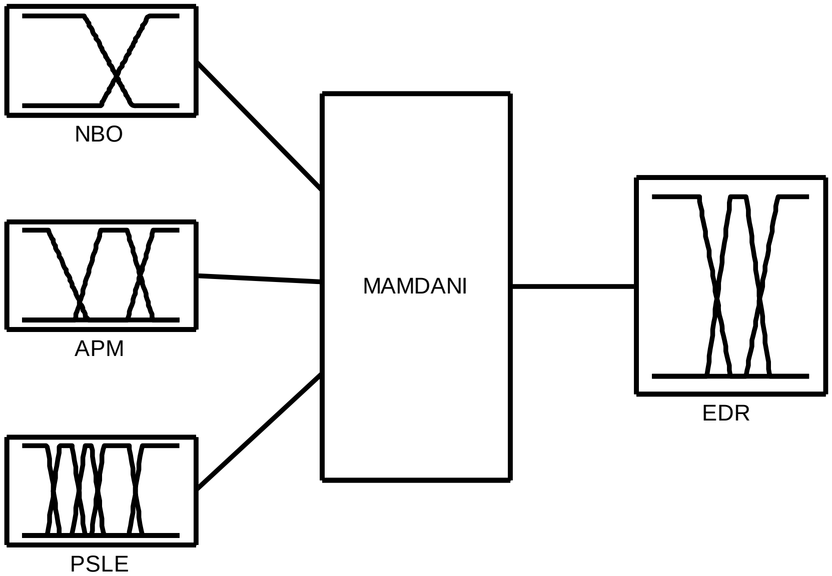


Figure 1: Fuzzy system layout

Trapezoidal-type membership functions were used to represent the three independent variables since those functions adjust better to its profile as reported in other studies (Firk et al., 2003) and reported by an animal reproduction specialist.

The behavioral observations considered in the analysis are the presence of clear mucous, swollen genitals, frequent urine, attempt to mount other cows and restlessness, as these are the main characteristics described in literature for estrus detection (Gray & Verner, 1992). Then, the fuzzy sets and their respective pertinence functions were fixed as shown in Table 1 based on practical information obtained from cow's reproduction handling and use of Heatwatch® estrus detection system (CowChips, L.L.C.) (M. A. Lopes, 2005, invited specialist). The pertinence functions were generated by using the software MATLAB® 6.5, and based on the fuzzy sets defined for NBO (Figure 2).

Table 1: Linguistic terms used for input variable classification – number of behavior observations

Fuzzy Sets	Interval
Low	[0, 3.5]
High	[2.5, 5]

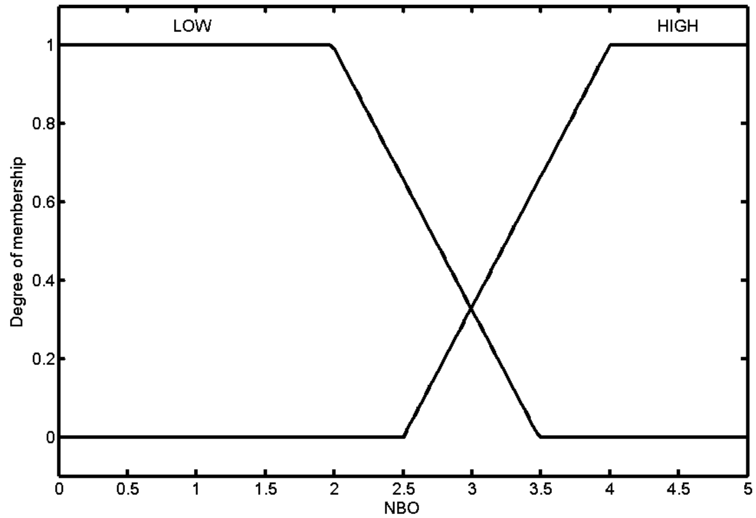


Figure 2: Fuzzy sets membership functions admitted by the input variable number NBO

The fuzzy sets described as ideal, critical and acceptable were defined for APM according to Torres (1987). The intervals admitted by the membership functions and the type are shown in Table 2 and Figure 3 respectively.

Table 2: Linguistic terms used for input variable classification – attempt period of mounting other cows

Fuzzy Sets	Interval
Ideal	[6, 11]
Critical	[10, 16]
Acceptable	[14, 18]

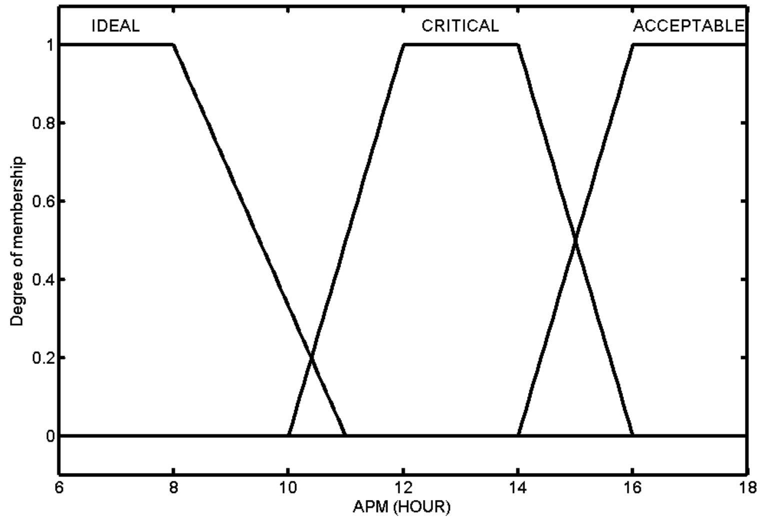


Figure 3: Fuzzy sets pertinence functions admitted by the input variable APM

The fuzzy sets were nominated as very short, short, normal, long and very long for the input variable PSLE based on literature (Firk et al., 2003). Table 3 shows the fuzzy sets classification, the intervals admitted by the pertinence functions and the pertinence function type used. Figure 4 shows the pertinence functions generated according to the fuzzy sets defined for PSLE.

Table 3: Linguistic terms used for input variable classification – period since last estrus

Fuzzy Sets	Interval
Very short	[0, 12]
Short	[8, 20]
Normal	[16, 26]
Long	[22, 38]
Very long	[34, 50]

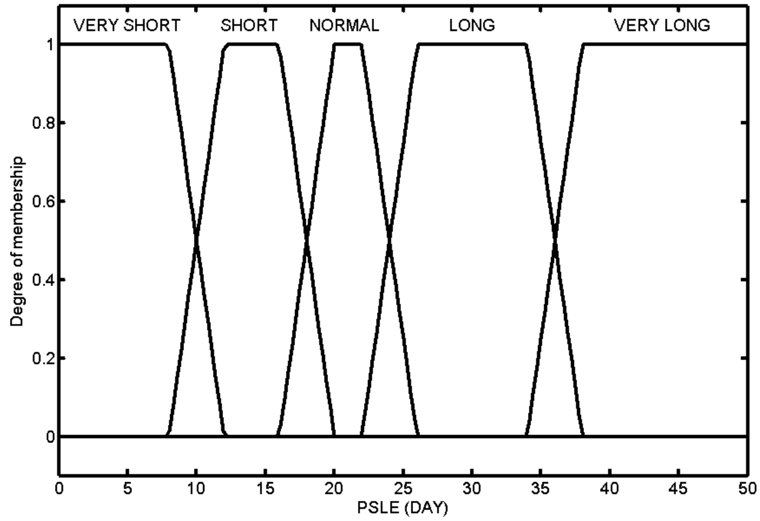


Figure 4: Fuzzy sets membership functions admitted by the input variable PSLE

The output variable EDR (%) that account the percentage of correct estrus detection, was defined as a result of the uncertain issues related to the moment when the animal presents the estrus, as proposed by a specialist, and the fuzzy sets are classified as low, medium, and high, as indicated in Table 4, and Figure 5.

Table 4: Linguistic terms used for output variable classification – estrus detection rate

Fuzzy Sets	Interval
Low	[0, 50]
Medium	[35, 75]
High	[60, 100]

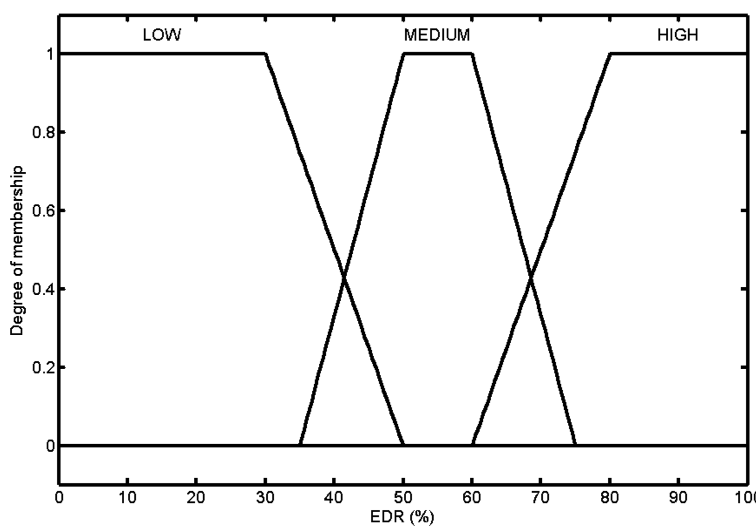


Figure 5: Fuzzy sets membership functions admitted by the output variable EDR

4. RESULTS AND DISCUSSION

The rules development was based on information provided by cattle reproduction specialists. A total of 30 rules were defined (Table 5) correlating the input variables (NBO, APM and PSLE) and the output variable (EDR), and its respective fuzzy sets. Once the output and input variables were defined and the rules set were developed, the model was generated by using the software MATLAB® 6.5.

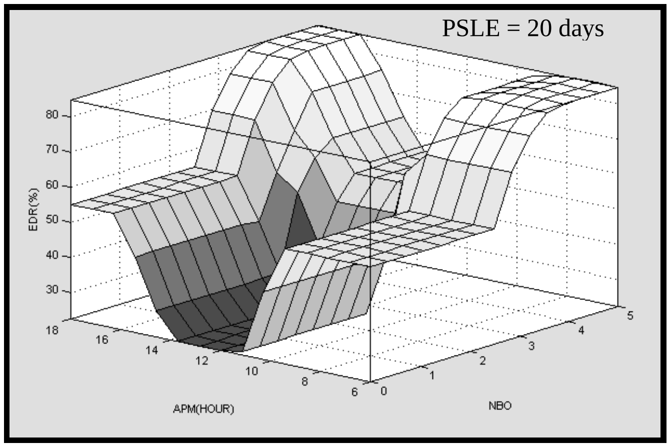
Table 5: Composition of the rules set used in the fuzzy inference for the following variables: NBO, APM, and PSLE

NBO	APM	PSLE	EDR		NBO	APM	PSLE	EDR
Low	Ideal	Very short	Low		High	Ideal	Very short	Low
Low	Ideal	Short	Low		High	Ideal	Short	Medium
Low	Ideal	Normal	Medium		High	Ideal	Normal	High
Low	Ideal	Long	Low		High	Ideal	Long	Medium
Low	Ideal	Very long	Low		High	Ideal	Very long	Low
Low	Critical	Very short	Low		High	Critical	Very short	Low
Low	Critical	Short	Low		High	Critical	Short	Low
Low	Critical	Normal	Low		High	Critical	Normal	Medium
Low	Critical	Long	Low		High	Critical	Long	Low
Low	Critical	Very long	Low		High	Critical	Very long	Low
Low	Acceptable	Very short	Low		High	Acceptable	Very short	Low
Low	Acceptable	Short	Low		High	Acceptable	Short	Medium
Low	Acceptable	Normal	Medium		High	Acceptable	Normal	High
Low	Acceptable	Long	Low		High	Acceptable	Long	Medium
Low	Acceptable	Very long	Low		High	Acceptable	Very long	Low

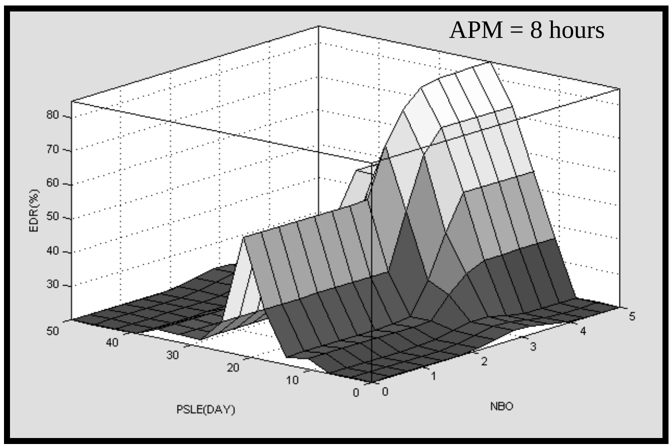
The Fuzzy system was implemented by using the fuzzy logic toolbox of software MATLAB® 6.5, and subsequently it was tested in distinct scenarios. Figure 6 shows three response surfaces generated based on the fuzzy sets theory for a period of 20 days after the last estrus (PSLE, Figure 6a), eight hours as the attempt period of mounting other cows (APM, Figure 6b), and number of behavior observation equals to 2 (NBO, Figure 6c).

In Figure 6a it can be seen that EDR increases with the increase of NBO, and it is in agreement with the Cardoso (2002) who reported the importance of the estrus signals expression. On the other hand the lower values of EDR for APM ranging from 11 a.m. to 14 p.m. is due to the effect of the high temperature incidence during that time, influencing negatively the reproduction (Torres, 1987; Chicoteau et al., 1989; Orihuela, 2000). For the response surface for APM equal to eight hours (Figure 6b) the peak of EDR at PSLE at 21 days agrees with the observations made by Firk et al. (2003), and shows that this may be the best time for the cow expresses the subsequent estrus. The peak of PSLE at 21 days and the low values of APM at the hottest hours of the day was found again when NBO is set to 2 (Figure 6c).

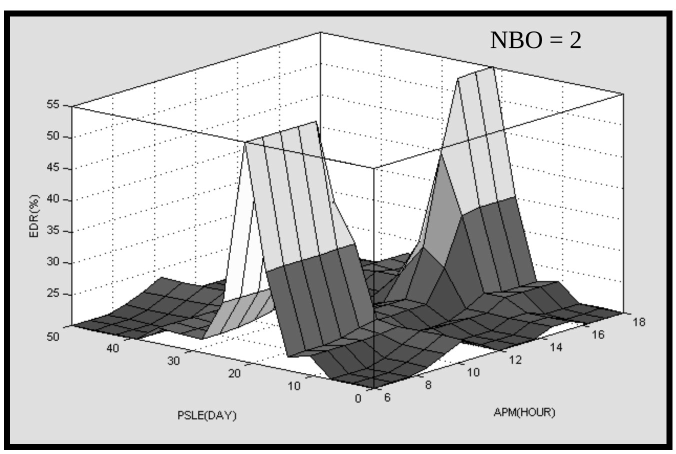
Performing a two-dimensional analysis by fixing two input variables and varying the remaining one, a more detailed projection of the scenario preset according to the estrus detection rate can be obtained. With PSLE equal to 21 days and APM of eight hours, NBO influences EDR as shown in Figure 7. Considering this scenario EDR reached values between 55 and 85% with NBO varying from 0 to 5. APM influences on EDR variation (Figure 8) and the occurrance considering NBO equal to 4 when PSLE equal to 21 days. Lower detection rates were obtained from the day's hottest period, as shown by Torres (1987). It was observed an EDR variation approximately between 20 and 85.3% according to the period after last estrus for NBO equal to 4 and APM of 8 hours (Figure 9). EDR varied as expected, with its maximum value at 21 days after last estrus and decreasing as PSLE decreases or increases.



(a)



(b)



(c)

Figure 6: Estrus detection rate (EDR) as a function of: (a) number of behavior observations (NBO) and attempt period of mounting other cows (APM), (b) NBO and period since last estrus (PSLE), and (c) APM and PSLE

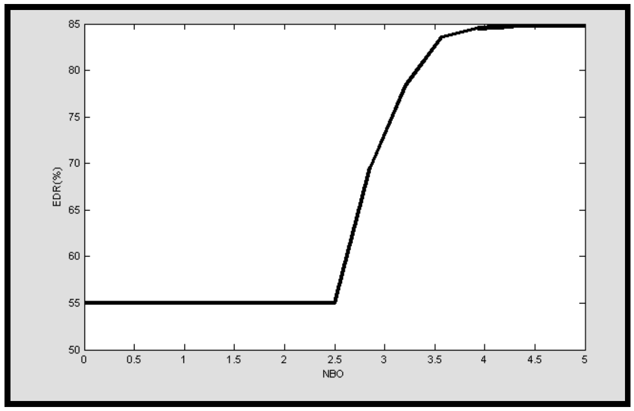


Figure 7: Estrus detection rate (EDR) as a function of number of behavior observations (NBO) for period since last estrus (PSLE) equal to 21 days and attempt period of mounting other cows (APM) equal to 8 hours

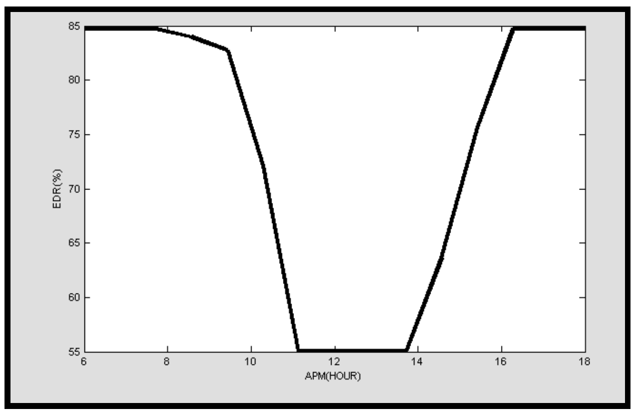


Figure 8: Estrus detection rate (EDR) as a function of attempt period of mounting other cows (APM) for number of behavior observations equal to 4 (NBO) and period since last estrus (PSLE) equal to 21 hours

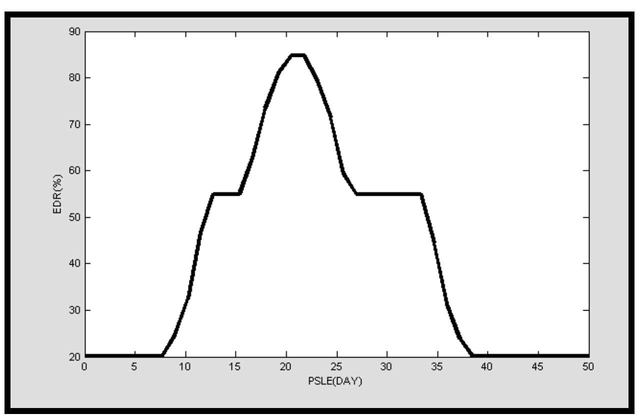


Figure 9: Estrus detection rate (EDR) as a function of period since last estrus (PSLE) for number of behavior observations (NBO) equal to 4 and attempt period of mounting other cows (APM) equal to 8 hours

Figure 10 shows the entire fuzzy inference system process in the Matlab Fuzzy Logic Toolbox for the three input (NBO, APM and PSLE) and one output (EDR) membership functions. Each row of plots correspond to the rule listed in Table 5, and the vertical line on each input membership functions implies the input value and its effect on each input membership grade that it intercepts. For a hypothetical scenario in which NBO equal to 5, APM of seven hours and PSLE of 21 days were adopted, only the rule 18 was used where the pertinence degree of each input variable is equal to 1. Thus, each value of the grade is projected onto the output membership function to obtain the EDR through the gravity center, resulting in a estrus detection rate of 84.7% and classified as high value. In this condition it is possible to move the vertical lines that define the independent variable values (NBO, APM and PSLE), resulting in a new EDR value, which defines a new scenery. According to practical information obtained from cow´s reproduction handling and use of Heatwatch® estrus detection system (CowChips, L.L.C.) (M. A. Lopes, 2005, invited specialist) the adopted methodology allowed to obtain satisfactory results showing that fuzzy analysis was helpful for estrus detection. Table 6 shows some results obtained from simulations considering various hypothetical scenarios.

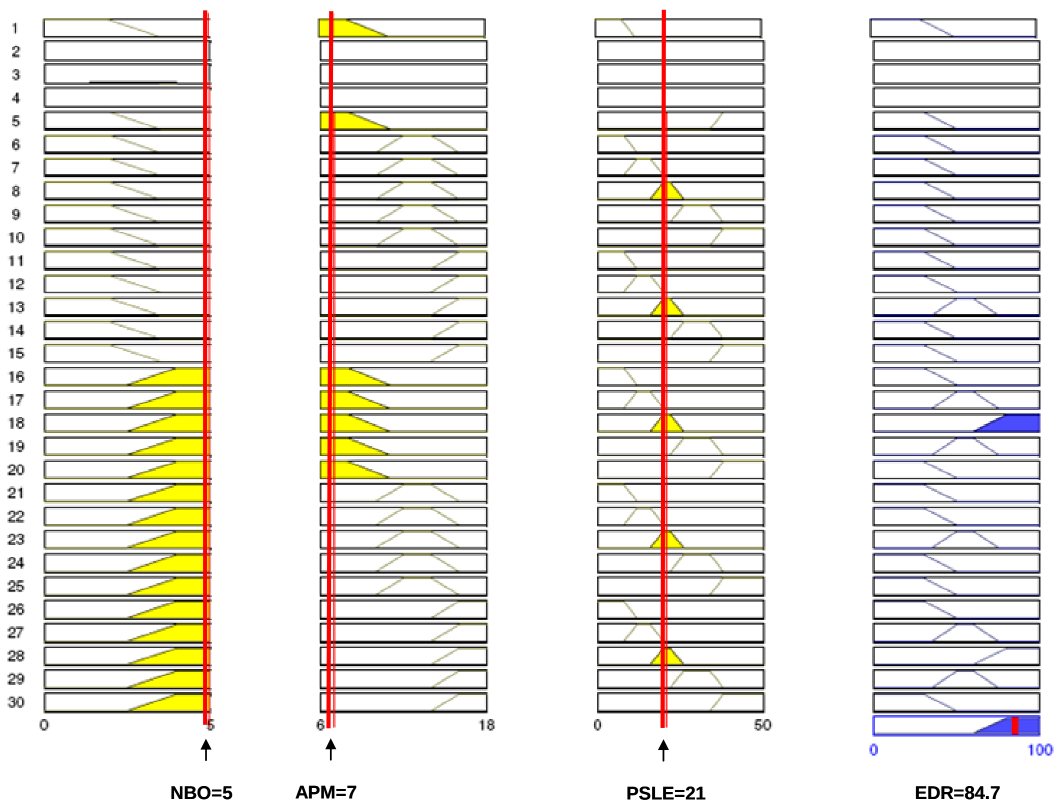


Figure 10: Composition of the rules set used in the fuzzy inference

Table 6: Estrus detection rate (EDR) simulation for seven scenarios as a function of number of behavior observation (NBO), attempt period of mounting other cows (APM) and period since last estrus (PSLE)

Scenario	NBO	APM (hour)	PSLE (day)	EDR (%)
1	1	12	15	20.2
2	5	14	15	22.3
3	5	14	25	32.9
4	1	6	18	36.3
5	2	17	21	55.0
6	3	7	21	73.5
7	5	7	21	84.7

For scenario 6 considering that the main behavioral observations listed by Gray & Verner (1992) and by a cattle reproduction specialist are equal to three, that the attempt period of mounting other cows considered ideal is seven hours (the time that most cows shows estrus according to Torres, 1987), and that the period since last estrus is 21 days, all values are within the interval considered normal by Cardoso (2002) and Firk et al. (2003). Under this condition estrus detection rate is equal to 73.5% and considered a medium detection rate with level of pertinence equal to 0.100 or high with pertinence level of 0.675. This result agrees with Vanzin (2005) who asserts that no-return-to-estrus rate (pregnancy at first trial) must be maintained higher than 75% to be considered good, and must be maintained between 65 and 70% to be considered medium. The preliminary results of simulations were consistent with the profile expected for EDR as a function of NBO, APM and PSLE. Further calibration needs to be performed to ensure the accuracy of the model response.

5. CONCLUSION

Preliminary results suggest that fuzzy logic is a promising method for dairy cows estrus detection. The developed fuzzy model can be easily implemented, and it is flexible to the construction of cases for estrus detection rate prediction as the used input variables can be easily observed. Further tests will be carried out for better validate this estimative in field.

6. ACKNOWLEDGEMENTS

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7. REFERENCES

Ali, Z., W. T. O’Hare, T. Sarkodie-Gyan, and B. J. Theaker. 1999. Gas sensing system using an array of coated quartz crystal microbalances with a fuzzy interference system. Journal of Thermal Analysis and Calorimetry Vol. 55: 371-381.

Amendola, M., M. J. Castanho, and I.A. Naas. 2004. Análise Matemática de Conforto Térmico para Avicultura usando a Teoria dos Conjuntos Fuzzy. *Revista Biomatemática* 14:87-92.

Amendola, M.; M. M. Neto, and V.F. Cruz. 2005. Using Fuzzy Sets to analyze environmental condition in order to improve animal productivity. *Revista Biomatemática* 15: 29-40.

Amendola, M. and A. L. Souza 2004. *Manual do Uso da Teoria dos Conjuntos Fuzzy no MATLAB 6.1*. Campinas: FEAGRI/UNICAMP. 30p.

At-Taras, E.E. and S. L. Spahr. 2001. Detection and Characterization of Estrus in Dairy Cattle with an Electronic Heatmount Detector and an Electronic Activity Tag. J. Dairy Sci. 84:792–798

Bobowiec, R., T. Studzinski, and A. Babiarz. 1990. Thermoregulatory effects and electrical conductivity in vagina of cow during oestrus cycle. Arch. Exp.Veterinarmed, 4 (44):573–579.

Camargo, L. S. A. Identificação de Cio. EMBRAPA Gado de Leite, 2000. Available at <http://www.cnpgl.embrapa.br/pastprod/textos/folha47.html> Acessed on Jan 26 2005.

Cano, C. J. Z. 2002. *Comportamento sexual a campo de machos e fêmeas Bos taurus indicus submetidas a um protocolo de sincronização da ovulação*. 45p. M.S. diss., Federal University of Minas Gerais, Belo Horizonte.

Cardoso, D. L. Métodos de Detecção de Cio em Bovinos. 2002. 63p. Undergraduate diss., Veterinary Medicine Department, Federal University of Lavras, Lavras.

Carvalho, V., I. A. Nããs, M. Mollo, and V. Massafera-Jr. 2005. Prediction of the occurence of lameness in dairy cows using a fuzzy-logic based expert system. – Part I. Agricultural Engeneering International: the CIGR Ejournal. Vol VII. Manuscript IT 05 002: 12p.

Cavalieri, J., L.R. Flinker, G.A. Anderson, and K.L. Macmillan. 2003. Characteristics of oestrus measured using visual observation and radiotelemetry. Animal Reproduction Science 76:1–12.

Cavestany, D. and R.H. Foote. 1985. The use of milk progesterone and electronic vaginal probes as aids in large dairy herd reproductive management. Cornell Vet., 75(3):441-453.

Chicoteau, E., E. Mamboue, C. Cloe, and A. Bassinga. 1989. Oestrous behaviour of Baoule cows (*Bos taurus*) in Burkina Faso. Anim. Reprod. Sci. 21:153-159.

Cho, S.I., S.J. Chang, Y.Y. Kim, and K.J. An. 2002. Development of a three-degrees-offreedom robot for harvesting lettuce using machine vision and fuzzy logic control. *Biosystems Engineering*, 82(2): 143-149.

Esslemont, R.J., R.G. Glencross, M.J. Bryan and G.S. Pope. 1980. A quantitative study of pre-ovulatory behaviour in cattle. Appl. Anim. Ethol. 6:1-17.

Ferreira, A. M., W. F. Sá, and M. F. A. Pires. 1997. *Reprodução e Ambiência*. In: Passos, L. P., M. M. Carvalho, O. F. Campo. Embrapa 20 anos. Juiz de Fora: Embrapa, p. 179-219.

Firk, R., E. Stamer, W. Junge, and J. Krieter. 2002. Automation of oestrus detection in dairy cows: a review. 2002. Livestock Production Science, 75:219–232.

Firk, R., E. Stamer, W. Junge, and J. Krieter. 2003. Improving oestrus detection by combination of activity measurements with information about previous oestrus cases. *Livestock Production Science* 82: 97-103.

Foote, R.H., E.A. Oltenacu, J. Mellinger, N.R. Scott, and R.A. Marshall. 1979. Pregnancy rate in dairy cows inseminated on the basis of electronic probe measurements. J. Dairy Sci., Jan, 62(1):69-73.

Gartland, P., J. Schiavo, C.E. Hall, R.H. Foote, and N.R. Scott. 1976. Detection of estrus in dairy cows by electrical measurements of vaginal mucus and by milk progesterone. J Dairy Sci., 59(5):982-985.

Gray, H. G. and M. A. Verner. 1992. *Signs of estrus and improving detection of estrus in the cattle. Dairy integrated Reproductive Management.* University of Rhode Island and University of Maryland, 1992. Available at

<http://www.wvu.edu/~exten/infores/pubs/livepoul/dirm6.pdf>. Acessed on Oct 17 2002.

Klir, G. J. and B. Yuan. 1995. Fuzzy *Sets and Fuzzy Logic*. New Jersey: Prentice Hall PTR. 574p.

Liu, X., and S. L. Spahr. 1993. Automated electronic activity measurement for detection of estrus in dairy cattle. J. Dairy Sci. 76:2906–2912.

Lopes, G. T. 1999. *Proposta de um controlador ótimo de altura da plataforma de corte de colhedoras*. 155p. Ph.D. Diss., Agriculture Engeneering College, University of Campinas, Campinas.

Lopes, M. A. 1997. *Informática Aplicada à Bovinocultura*. Jaboticabal: FUNESP. 82p.

López-Gatius, F., P. Santolaria, I. Mundet, and J.L. Yániz. 2005. Walking activity at estrus and subsequent fertility in dairy cows. Theriogenology 63:1419–1429.

Maatje, K., S.H. Loeffler, and B. Engel. 1997. Predicting optimal time of insemination in cows that show visual signs of oestrus by estimating onset of oestrus with pedometer. J. Dairy Sci., 80:1098– 1105.

Marcinkowski, D. 2004. *Heat detection: Problems, Evaluation and Solutions*. University of Maine Cooperative Extension. Available at <http://www.umaine.edu/livestock/publications/heatdet.htm> Acessed on April 21 2005.

Morag, I., Y. Edan, Y. and E. Maltz. 2001. An individual feed allocation decision support system for the dairy farm. *Journal of Agricultural Engineering Research* 79:167-176.

Morais, R, A. Valente, J.C. Almeida, Amélia M. Silva, S. Soares, M.J.C.S. Reis, R. Valentim, and J. Azevedo. 2006. Concept study of an implantable microsystem for electrical resistance and temperature measurements in dairy cows, suitable for estrus detection. Sensors and Actuators A, 132: 354–361.

Nebel, R.L., J.H. Bame, and M.L. McGilliard. 1992. Radiotelemetered measures of mounting activity for detection of estrus in lactating dairy cows. J. Dairy Sci. 75 (Suppl. 1):242.

Nebel, R.L., M.G. Dransfield, S.M. Jobst, and J.H. Bame. 2000. Automated electronic systems for the detection of oestrus and timing of AI in cattle. Anim. Reprod. Sci., 60:713– 723.

Orihuela, A. 2000. Some factors affecting the behavioural manifestation of oestrus in cattle: a review. Applied Animal Behaviour Science 70:1-16.

Ortega, N. R. S. 2001. *Aplicação da teoria de conjuntos fuzzy a problemas da biomedicina*. 152p. Ph.D. Diss., Physics Institute, University of São Paulo, São Paulo.

Peralta, O. A. 2003. Comparison of three estrus detection systems during summer heat stress in a large commercial dairy herd. M.S. thesis, Virginia Polytechnic Institute and State University, Blacksburg.

Queiroz, M., I. A. Nããs and C. Sampaio. 2005. Estimating thermal comfort of piglets considering ammonia concentration. Agricultural Engeneering International: the CIGR Ejournal. Vol. III. Manuscript IT 05 004/BC 05 005: 8p.

Rae, D.O., P.J. Chenoweth, M.A. Giangreco, P.W. Dixon, and F.L. Bennett. 1999. Assessment of estrus detection by visual observation and electronic detection methods and characterization of factors associated with estrus and pregnancy in beef heifers. Theriogenology 51: 1121–1132.

Ribacionka, F. 1999. *Sistemas computacionais baseados em lógica fuzzy*. M.S. thesis. Engineering School, Mackenzie University, São Paulo.

Roelofs, J. B., F.J.C.M. van Eerdenburg, N. M. Soede, and B. Kemp. 2005. Pedometer readings for estrous detection and as predictor for time of ovulation in dairy cattle. Theriogenology, 64:1690–1703.

Saptomo, S., B. Setiawan, and Y. Nakano. 2004. Water Regulation in Tidal Peatland agriculture using Wetland Water Level Control Simulator. Agricultural Engineering International: the CIGR Journal of Scientific Research and Development, Vol.VI, Manuscript LW 03 001: 11p.

Saumande, J. 2002. E lectronic detection of oestrus in postpartum dairy cows: efficiency and accuracy of the DEC® (showheat) system. Livestock Production Science 77:265–271.

Schon, P.C., K. Hamel, B. Puppe, A. Tuchscherer, W. Kanitz and G. Manteuffel. 2007. Altered vocalization rate during the estrous cycle in dairy cattle. J Dairy Sci., 90(1):202-206.

Senger, P. L. 1994. The estrus detection problem: new concepts, technologies and possibilities. *Journal of Dairy Science* 77(9): 27-45.

Solano, J., A. Orihuela, C.S. Galina, F. Montiel, and F. Galindo. 2005. Relationships between social behaviour na mounting activity of Zebu cattle (*Bos indicus*). Applied Animal Behaviour Science, 94:197-203.

Stevenson, J.S., M.W. Smith, J.R. Jaeger, L.R. Corah, and D.G. LeFever. 1996. Detection of estrus by visual observation and radiotelemetry in peripubertal, estrus-synchronized beef heifers. J. Animal Sci. 74:729-735.

Tanaka, K. 1997. *An introduction to fuzzy logic for practical applications*. Tokyo: Springer. 138p.

Tassinari, P. 2006. A Methodological Contribution to Landscape Design and Improvement. Agricultural Engineering International: the CIGR Ejournal, Vol.VIII, Manuscript MES 05 006: 17p.

Tooy, D. and H. Murase. 2007. Behavioral Interest Identification for Farm Mechanization Development using Path Analysis and Neuro-fuzzy Models. Agricultural Engineering International: the CIGR Ejournal, Vol. IX, Manuscript IT 07 002: 18p.

Torres, C. L. A. 1987. *Ciclo estral, cio e movimento de cobrição em bovinos*. Boletim Técnico EMPASC, Florianópolis, n. 40, p. 05-20.

Van der Lende, T., L. M. T. E. Kaal, R. M. G. Roelofs, R. F. Veerkamp, C. Schrooten, and H. Bovenhuis. 2004. Infrequent Milk Progesterone Measurements in Daughters Enable Bull Selection for Cow Fertility. J. Dairy Sci. 87:3953-3957.

Vanzin, I. M. 2005. *Manejo Reprodutivo*. Fazenda Greenbeef. Disponível em: <http://www.greenbeef.com.br/dicas_reprodutivas.htm>. Acesso em: 22 dez. 2005.

Weber, L. and P.A.T. Klein. 2003. *Aplicações de Lógica Fuzzy em Software e Hardware*. Canoas: Editora ULBRA, 112p.

Xu, Y.F., M. Velasco-Garcia, and T.T. Mottram. 2005. Quantitative analysis of the response of an electrochemical biosensor for progesterone in milk. Biosens. Bioelectron, 20:2061–2070.

Xu, Z.Z., D.J. McKnight, R. Vishwanath, C.J. Pitt, and L.J. Burton. 1998. Estrus detection using radiotelemetry or visual observation and tail-painting for dairy cows on pasture. J. Dairy Sci. 81:2890–2896.

Yániz, J.L., P. Santolaria, A. Giribet, and F. López-Gatius. 2006. Factors affecting walking activity at estrus during postpartum period and subsequent fertility in dairy cows. Theriogenology, 66:1943–1950.

Zadeh, L. A. 1965. Fuzzy Sets. *Journal Information and Control*. 8: 338-353.