# Animal welfare, etológia és tartástechnológia

# Animal welfare, ethology and housing systems

**Volume 2 Issue 1**

**Gödöllő**
2006

# THE APPLICATION OF FUZZY LOGIC IN PROGRAMS FOR MASTITIS DETECTION IN DAIRY HERDS

*Otto Kaufmann*[1], *Stefan Koehler*[2]

[1] Humboldt-Universität zu Berlin, Faculty of Agriculture and Horticulture, Institute of Animal Sciences, Philippstrasse 13 Haus 10, D-10115 Berlin.

[2] Institute of Agricultural and Urban Ecological Projects at Humboldt-Universität zu Berlin (IASP), Invalidenstrasse 42, D-10115 Berlin.

**Abstracts**

An important factor influencing milk production is the health of the animals. In quality assurance programs for milk, the health of the cows is the most outstanding parameter. In the case of *Automatic Milking Systems* (AMS), the udder health becomes especially important due to the lack of visual control by the milking staff. On the other hand, AMS facilitate the opportunity to measure a lot of parameters of the milk and the milking process specifically for the single quarters of the udder. From this collected data, conclusions can be drawn towards possible udder diseases. The objective of the investigation was to elaborate an analysis system serving to supervise the udder health using the concatenation of selected milk- and milking process parameters. *Fuzzy-Logic* was selected as an appropriate method of dealing with vague data and diffuse relations. Based on the data of a thorough investigation in a dairy farm with two AMS, three different methods of modeling were selected, analyzed and compared with one another: models of a single parameter (threshold models), models of indices and *Fuzzy logic*. While the threshold models showed higher values of specificity, the best results of sensitivity were calculated for the models of indices. However, the optimal result was obtained with *Fuzzy logic*. The corresponding modeling featured the smallest statistical probability of wrong classifications (5.9 percent of incorrect diagnoses).

The results confirm the hypothesis that *Fuzzy logic* is a manageable and effective method to uncover the relations between parameters of milk and the milking process as well as the udder health.

*Keywords:* Fuzzy logic, animal health, mastitis, modeling of parameters, Automatic Milking System

# A Fuzzy Logic alkalmazása a masztitisz érzékelő programokban tejelő teheneknél


## Összefoglalás

A tejtermelést befolyásoló egyik legjelentősebb tényező az állatok egészségi állapota. A tejminőségre irányuló minőségbiztosításban a tehenek egészsége a legfontosabb paraméter. Az automata fejési rendszerek alkalmazása esetén a tőgyegészség különös jelentőséggel bír, mivel ez esetben a fejő személyzet nem ellenőrzi ezt vizuálisan minden fejésnél. Másrészt viszont ezek a rendszerek lehetővé teszik a tej és a fejési folyamat számos paramétereinek mérését, tőgynegyedenként, amely adatokból következtetni lehet bizonyos tőgybetegségekre.

A szerzők célja volt egy olyan rendszer kidolgozása, amely értékeli a tőgy egészségi állapotát, a kiválasztott tej és a fejési paraméterek összefüggései alapján. A *Fuzzy Logic*-ot választották, amely megfelelő módszer a szórt adatok kezelésére. Az adatokat egy tejelő tehén tehenészetben rögzítették, ahol két automata fejőrendszer működik. Három modellezési módszert vizsgáltak és hasonlítottak össze egymással: egy paraméteres modellek (határérték modellek), index-modellek, és *Fuzzy-Logic* modell. Míg az egy paraméteres modellek nagyobb specificitást mutattak, a legnagyobb érzékenységet az index modellek esetén figyelték meg. Az optimális eredményt azonban a *Fuzzy Logic*-kal érték el. Ez a módszer mutatta statisztikailag a legkisebb valószínűséget a helytelen minősítésre (helytelen diagnózis:5,9%).

Eredményük megerősíti, hogy a *Fuzzy Logic* kezelhető, és hatékony módszer a tej, és fejési paraméterek, valamint a tőgyegészség összefüggéseinek felfedésére.


*Kulcsszavak*: Fuzzy Logic, állategészség, tőgygyulladás, modellezés, automata fejési rendszer

## Introduction and Problem Identification

The meaning of the term "*quality in the food sector*" has dramatically changed in the last few years. At least since the presence of *Mad Cow Disease* and problems with contaminated feeds it became clear that within the production of food originating from animals the quality target has moved from simple product quality to complex process quality. For example, attention must not be paid simply to milk as a product, but also to the whole process of its production.

A major influential factor for milk quality is animal health. Within programs for certification of quality milk production, animal health remains the most important criterion. From the point of view of animal health, *udder infections* (Mastitis) in particular, can influence milk quality. In conventional milking parlors as well as in *automatic milking systems* (AMS) there are three basic problems regarding the evaluation of milk quality:

1. The usual criteria of controlling milk quality (e.g. number of somatic cells and germs) can neither be instantly nor continuously measured. If an immediate evaluation of milk quality has to be carried out to avoid infected milk entering the collecting tank, then other factors, such as auxiliary parameters need to be measured and analyzed.
2. With most of these parameters it is the case, that single diagnosis results in the milk are only possible at the level of one quarter of the udder. It is almost impossible to diagnose the collected milk of all udder quarters, because firm limits cannot be defined –due to the many mixing possibilities- (*NN,* 1994).
3. While acute clinical mastitis is normally discovered by the milking personnel, sub-clinical udder infections are difficult to diagnose. The latter go undetected, without palpable infected tissue. Those infections can be characterized by an increased number of cells and the presence of pathogens within the secretions. The chemical consistency of the milk changes (*NN,* 1994; *Wollrab,* 1989). In AMS udder health is of an additional special importance because there is no visual control by the milking personnel (*Schön et al.* 2001).

The development of improved sensors is leading to a steadily growing amount of data, which could be relevant for the control of udder health and milk quality. This amount of data is most profitable when integrated systems are used. Those systems combine sensor information, data sources and mathematical information with expert knowledge (*Maltz, Metz,* 1994; *Frost et al.* 1997; *De Mol, Woldt,* 2001; *Köhler,* 2003) .

The aim of this investigation was to work out basics for *an analysis system*, which through a *combination of selected parameters* under the use of *Fuzzy logic* helps to control *udder health* and to *guarantee milk quality* as final aim.

## Material and Methods

### *Investigation*

AMS offer the opportunity to ascertain udder quarter specific milk- and milking parameters The received data allows conclusions to be made on possible changes. The investigated farm keeps *105 Holstein cows* that produce an *average amount* of 6500 – 7000 kg milk each, which are milked by two AMS *Astronaut*® (Lely). The health status of each udder quarter was evaluated following recommendations by the *German Society of Veterinary Medicine* (1994). The evaluation included measuring the number of cells as well as the bacteriological examination of the premilk and the clinical examination of the udder. Udder quarters with more than 100.000 cells were diagnosed as "obviously sick" and with a positive bacteriological result. "*not obvious*" means less than 100.000 cells and a lack of a positive diagnosis. In the case of a positive diagnosis, clinical changes in secretions or proof of disease in udders (Mastitis pathogens) were classified. Important clinical changes in udder have been recognized (atrophic, hard and bulky, big tissue knots). The so received partition was used as the basis for the following modeling:

### *Parameters*

On five consecutive days in March 2002, in two AMS, the milk from all udder quarters was continuously measured by eight instruments of the *type LactoCorder*® low flow, *WMB AG* (4.762 measures). The following parameters were measured and analyzed:

- *Milking interval:* time difference between present and last milking
- *Milk synthesis rate:* Quotient of present amount of measured milk from one quarter and the corresponding milking interval. The result gives the figure for milk secretions of the udder quarter.
- *Milk flow:* relation between presently measured amount of milk and corresponding duration of milking one quarter
- *Electrical conductivity:* An easily measurable parameter but almost unreliable indicator, because it is modified by a number of influential factors

In order to recognize changes more easily, standardization of current measurements is necessary. For the current investigation parameters have been standardized as follows:

- Milk synthesis rate: $w_{norm} = w / (mean – 0.5 * s)$
- Milk flow: $x_{norm} = x / (mean – 0.5 * s)$
- Milking interval: $y_{norm} = y / (mean + 0.5 * s)$
- Electrical conductivity: $z_{norm} = z / (mean + 0.5 * s)$

$w_{norm}$ , $x_{norm}$ , $y_{norm}$ and $z_{norm}$: standardized parameters

w, x, y and z: absolute measures,

s: standard deviation of the sample

0.5: factor for one interval, within which limit deviations from the arithmetical mean can still be tolerated as "physiologically normal"

***Fuzzy Logic***

This method delivers an opportunity to deal with unclear parameters and vague connections/ readings. It is based on the concept of undefined amounts (*Fuzzy Set*). This can be seen as a common term for the conventional concepts of the set. For this, the clear data of the conventional binary logic, which are included in the Yes/No-statement, are divided into partial groups between 0 and 1.

The basic principle of *Fuzzy logic* based modeling is firstly to translate (fuzzyfy) the numeric ("*clear*") data - aided by correlating formulas - into linguistic ("*unclear*") terms (Fuzzy Sets). This is followed by the approximate data (*Fuzzy interference*) being combined with operators and rules. The "If…then…."-relations of these regulations can also be interpreted as unclear formulae. In a third step the un-sharp results received from every single combination will be put together ("*defuzzyfy*") to produce a single "*sharp*" end figure. Interference diagrams are used to demonstrate these steps.

***Model Construction***

After the standardization, a usable number of 433 "*apparently normal*" records und 41 "*obviously infected*" records of udder quarters remained. On this basis, very different *Fuzzy logic models* have been developed, tested and optimized. *Model No. 5* was a result of the earlier direct transmission, with other data material constructed models onto the *474 results* of this examination which have to be evaluated. This model, in particular, has undergone further development by modifications within the *Fuzzy interference* (model 5a). Model 6 is based on a totally different method of modeling, which, after evaluation of its diagnostic reliability has been mainly optimized by adaptation of its belonging functions (*model 6a*). To make a comparison, the common integrated monitoring system in the milking automats was used.

***Evaluation Criteria***

As criteria for the evaluation of the diagnostic capability of the models sensitivity, specificity and probability of false classifications were used. Sensitivity measures the percentage of udder quarters characterized by the model as "*obvious*" in relation to the whole number of really "*obvious*" quarters. Specificity measures the percentage of udder quarters diagnosed as being „*not obvious*" in relation to really „*not obvious*" udder quarters. The probability of wrong classifications results comes from the relation between the sum of wrong diagnoses and the total number of all events. The following formulae were used in order to create the named criteria:

- Sensitivity = (true positive/ (true positive + false negative)) * 100
- Specificity = (true negative / (true negative + false positive)) * 100
- Possibility of false classifications = ((false positive + false negative) / (true positive + false positive + true negative + false negative)) * 100

## Results and Discussion

Models that can detect udder diseases must have a balanced relation between the precise detection of abnormally changed quarters and the accurate identification of healthy quarters. When short term economical criteria are taken into consideration, a specificity of less than 90 per cent can be seen as a necessary lower limit. In order to sustain good animal health, it is necessary that a qualified majority of ill udder quarters is identified. In practice, the decision on whether to use a model of higher sensitivity or higher specificity is based upon the two following conditions within the farm:

- the frequency that udder diseases appear within the herd and
- how motivated the farmer is to increase spending to evaluate the measured data in order to secure a high detection rate of udder diseases.

*Table 1* shows a summary of selected results of constructing models.

***Table 1:* Results of Modeling with Fuzzy Logic Systems**

| Traits(1) | Vet. diagnosis (2) | Model 5 (3) | Model 5a (4) | Model 6 (5) | Model 6a (6) | AMS (7) |
|---|---|---|---|---|---|---|
| Total(8) | 474 | 474 | 474 | 474 | 474 | 474 |
| True positive(9) | 41 | 24 | 31 | 29 | 32 | 7 |
| False positive(10) | | 26 | 51 | 34 | 19 | 2 |
| True negative(11) | 433 | 407 | 382 | 399 | 414 | 431 |
| False negative(12) | | 17 | 10 | 12 | 9 | 34 |
| Sensitivity(13) | | 58.5 % | 75.6 % | 70.7 % | *78.0 %* | 17.1 % |
| Specificity(14) | | 94.0 % | 88.2 % | 92.1 % | 95.6 % | *99.5 %* |
| False diagnoses(15) | | 9.1 % | 12.9 % | 9.7 % | *5.9 %* | 7.6 % |

*1. táblázat: A modellezés eredményei a "fuzzy logic" rendszerrel*

*Tulajdonságok(1), állatorvosi diagnózis(2), modell 5(3), modell 5a(4), modell6(5), modell6a(6), automata fejőrendszer(7), összesen(8), valós pozitív(9), téves pozitív(10), valós negatív(11), téves negatív(12), érzékenység(13), specificitás(14), téves diagnózisok(15).*

The unsatisfactory sensitivity of *model 5* has been improved by changes within *model 5a*, but only at the expense of a decreased specificity. This lead to an increase in false diagnoses. No better result was achieved through the modification of the Fuzzy interference in *model 5a* compared to *model 5*. This lead to a situation in which either the sensitivity or the specificity changed, but never both of them at the same time. *Model 6* with its number of linguistic terms widened with three out of four variables and the resulting totally new formation of corresponding functions showed at first –compared with draft 5- neither an increased number of correct diagnoses nor a decreased number of false diagnoses. The improvement in *model 6a* was gained by a decisive targeted adaptation of the functions. According to all the evaluation criteria this model produced the best result. Because of its high sensitivity and its reduced number of false diagnoses, it is distinctly better than the monitoring system of the AMS. Therefore for *model 6a***,** the used linguistic terms and their functions in the example of the milk secretion rate, are shown in graph form (*Figure 1*).

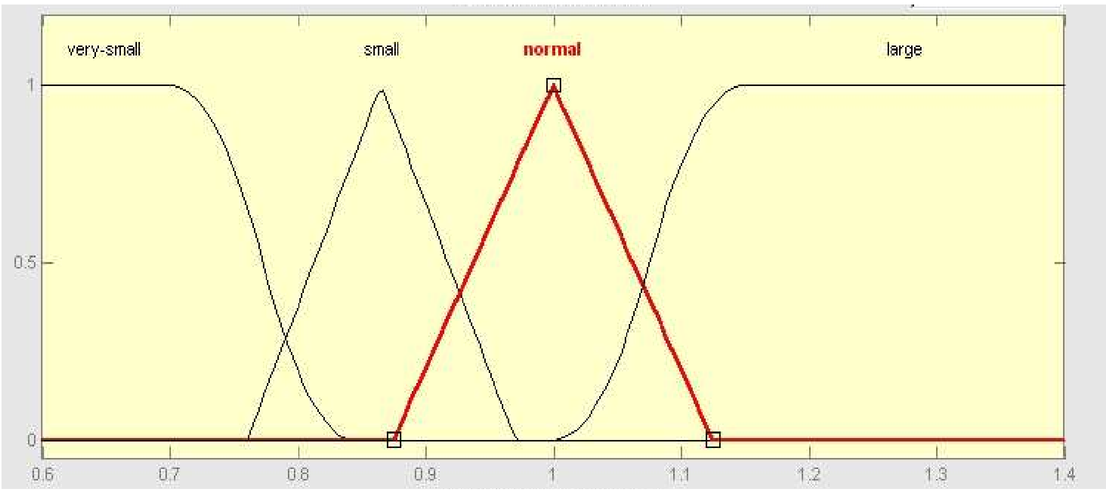


***Figure 1:*** **Terms of the variable "Standardized Milk Secretion Rate" in model 6a.**
(drawn with Fuzzy Logic Toolbox, MATLAB® Student Version. The Math. Works, Inc.)

*1.ábra: A standardizált tejszekréciós ráta alakulása a 6a modellben.*
*Nagyon alacsony, alacsony, normál, magas.*

It has become obvious that using a combination of several aiding parameters remains a good method for "*Detection of Mastitis*" despite the fact that individually, they are sometimes very limited in their ability to meet this aim. This way, milking parameters and milk synthesis parameters can be used for online-recognition of obviously contaminated milk. A system which supports decisions on the basis of such a real-time-diagnosis offers new prospects for herd management (control of udder health) as well as for prophylactic consumer protection (separation of milk from ill cows).

## References

*De Mol, R.M. Woldt, W.E.* (2001): Application of Fuzzy Logic in automated cow status monitoring. Journal of Dairy Sciences 84, 2 400 - 410, 0022-0302.

*Frost, A. R., C. P. Schofield, S. A. Beaulah, T. T. Mottram, J. A. Line, C. M. Wathes* (1997): A review of livestock monitoring and the need for integrated systems. Computers and Electronics in Agriculture, 17. 139-159, 0168-1699.

*Köhler, S.* (2003): Nutzung von Prozessparametern automatischer Melksysteme für die Erkennung von Euterkrankheiten unter Verwendung von Fuzzy Logic, Diss. Humboldt-Universität zu Berlin (2002), Shaker-Verlag(Agrarwissenschaft), Aachen, 3-8322-1929-3

*Maltz, E., J. H. M. Metz* (1994): An individual approach to manage the dairy cow: A challenge for research and practice. International Symposium, Tumba, Proc. 267-282, 91-630-3340-2.

*NN* (1994): Leitlinien zur Bekämpfung der Mastitis des Rindes als Bestandsproblem. Deutsche Veterinärmedizinische Gesellschaft. Gießen. 3-930511-03-7.

*Schön, H., G. Wendl, M. Klindworth, J. Harms* (2001): Precision Livestock Farming – Konzeption, Stand der Forschung, Zukunftsperspektiven, 5. Tagung Bau, Technik und Umwelt in der landwirtschaftlichen Nutztierhaltung, Hohenheim. 06.-07.03.2001, Tagungsband, 1-8, 3-9805559-5-X.

*Wollrab, J.* (1989): Eutergesundheitsstörungen. Hrg. Busch, W., K. Elze und W. Lange: Grundriss der Tiergesundheitslehre, Gustav Fischer Verlag Jena, 3-334-00291-8.