Novel Technologies: Sensors, Data and Precision Dairy Farming

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Abstract

Increasing herd size, production per cow, economical value of the cow and increased expenses (especially food) as well as socioeconomic progression motivates technological development in the dairy industry. This includes primarily sensors that suppose to provide information that improves decision making. The fact that these sensors record and store on-line data from each cow in the herd led to precision dairy farming (PDF) that can be defined as managing the smallest production unite (the individual cow if possible) in order to enable the cows to express its genetic potential in accordance with economical goals and animal wellbeing. The PDF systems can be divided into two categories: for diagnostic and for management. The same sensor can serve both of them to alarm or elucidate a physiological event or status which improves management decision making. The difference between them is that the former has to alarm ahead or close to the event it supposes to detect and the latter can be more time tolerant. Both include sensors that generates data, a model that gives a physiological interpretation to the data, a management decision making process and finally decision execution. This paper scans novel-technology and under development sensors with special emphasis on data-information-decision making process. Five novel sensors will be described and discussed in more details including applications and possibilities. These are on-line body weight scales, on-line milk composition analyzer, behaviour sensor, rumination and heart rate sensors.

Introduction

The dairy industry leads the technology in precision livestock farming. This process is driven by increasing herd size and production per cow as well as the economical value of the cow and increased expenses (especially food). Growing public concern to animal wellbeing also motivates this process. Technological progress advances the development and use of sensors that can provide detailed on-line data about the individual cow in the herd regardless its size. With proper physiological labeling and interpretation this data can be translated into information which in turn, can support management decision making on the level of the individual cow. In other words precision dairy farming (PDF) down to individual cow level

The definition of precision dairy farming (PDF), is to manage the smallest production unite (the individual cow if possible) in order to enable the cow to express its genetic potential in accordance with the economical goal and animal wellbeing. This approach is expected to improve animal health, wellbeing and profitability of the dairy operation. The "smallest" unite can be the entire herd, a group of cows with common physiological and performance characteristics or the individual cow. The "size" of this unite is determined by the sensors and facilities involved and availability of automatic and easy operation.

A PDF system is constructed of the following component: A sensor that generates data, a model that gives a physiological interpretation of the data, a management decision making process and finally decision execution. The PDF systems can be divided into two categories: those used for diagnostic and those used for management and the same sensor can serve both categories. For example a decline in milk yield can indicate a health problem, but also a nutritional one. Nevertheless, for both categories data have to be labeled and analyzed in order to convert it into meaningful information. Sensors are useless data generators unless there is a model that transfers these data to meaningful physiological information. Both diagnostic and managerial PDF systems are designed to alarm or elucidate a physiological event or status which improves management decision making. The difference between diagnostic and managerial PDF systems is that the former has to alarm ahead or close to the event it supposes to detect (estrous, lameness) and the latter can be more time tolerant. Most of the PDF appliances are of diagnostic nature related to health and reproduction and the motivation for their development was to replace human senses as well as to economize on the dairy operation.

This paper scans long-standing, novel-technology and under development sensors with emphasis on data-information-decision making process and applications possibilities. Special attention will be given to five novel sensors. These are on-line body weight scales, on-line milk composition analyzer, behaviour sensor, rumination and heart rate sensors.

Long-Standing Sensors

The oldest sensor in the dairy industry is probably the “jar” milk mete that measured the individual cow milk production but records had to be done manually. Electronic milk meters did not change this situation until individual cow identification (ID) was developed, more or less, in parallel and opened the age of on-line performance recording. But the real revolution came when personal computers penetrated into the dairy operation. The ID, computing and records-storing power were the key for farther sensors development. The ability to identify a cow in a certain location enables to download data on one hand and execute management decisions on the other hand. The electronic milk meter soon became, in addition to its individual cow performance capabilities, also a diagnostic tool for health and reproduction solitarily or with other sensors that came into practice like milk conductivity for udder health detection and activity tags for estrous detection. In some cases, research preceded application of sensors and in some it was the other way around like with activity estrus detection sensors (steps – S.A.E. Afikim and neck – SCR) that spread in the industry because of their apparent performance success. Another sensor that intensive research (Rajkondawar et al. 2006, Dyer et al. 2007) preceded its application was the BouMatic StepMetrix® lameness detector. A nice illustration how technology and computing power turn existing technologies into a sensor can be the milking parlor facilities that are now acting as “a sensor” for milking parlor and milkers performance. By adding timing to each milking parlor device (gate close and cow release, cluster attachment and detachment, milk meter - milk flow at any given interval) activation, the performance of the parlor and operating team can be evaluated (Maltz et al. 2004).

Body Weight – Walk through Scales

The first walk-through weigher for dairy cows was developed in 1979 in the National Institute of Agricultural Engineering, Bedford, GB (Filby et al. 1979). The authors suggested that routinely monitoring the body weight (BW) of individual cows, combined with daily milk yield (MY) recording, may improve management strategies.

Though the significance of BW was recognized, technical difficulties prevented its incorporation into the dairy management. And even for those who were willing to invest the labor in periodical manual weighing, evident BW fluctuations due to intake (eating and drinking) on one hand and output (urination, defecation and for this matter also milking) on the other hand built an inner resistance among farmers and researchers alike to use this parameter for management. Indeed, BW does fluctuate diurnally (Peiper et al. 1993), daily and periodically (Maltz et al. 1997, Maltz 1997, Van Straten 2008), but this was answered by technology and methodology.

A significant step toward the realization of the concept of using BW for individual management was made in the Institute of Agriculture Engineering in ARO, the Volcani Center, in Israel since 1987 by Peiper, et al. (1987, 1993) dealing with the technical and Maltz et al. (1987, 1991, 1992, 1997, 2004, 2009) Maltz (1997) and Spahr et al. (1993) dealing with the conceptual aspects. The initial system was based on coupling ID with electronic scales and dedicated real-time software and special algorithms to obtain accurate weights on-line. A slows down step just before the scale and an adequate plate length completed the system (Peiper, et al. 1993). The weighing system was located in the outlet path of the milking parlor thus with the potential to obtain the weight of each cow in the herd 2 or 3 times daily at the same time. This system got rid of the labor required for weighing. The BW measurements of the individual cow several times daily at the same time under the same routine and the calculation of daily or weekly averages prevent the typical error that occurs during a single weighing due to occasional gastro-intestinal fill or milking. In addition, BW data smoothening and standardizing techniques help to expose and illuminate physiological events and status that can be used for PDF on the individual cow level (Maltz et al. 1997, Maltz 1997, van Straten et al. 2008).

S.A.E. Afikim Co utilized that knowledge to develop the commercially available system for automatic walk through cows body weighing – the Afiweight®. Recognition of the significance of BW patterns and changes for management is reflected by the number of publications involving BW in the professional publications of recent years in a variety of aspects. The association between body weight and milk urea (Hojman et al. 2005), Association of daily body weight patterns and reproduction variables (van Straten et al. 2008, 2009) and somatic cell counts (van Straten et al. 2009). Heritability of daily BW and correlations with yield (MY), dry matter intake (DMI) and body condition (BC) (Toshniwal et al. 2008, see below), BW changes in relation to health (Ostergaard and Grohn 1999, Moallem et al. 2002) and calving problems (Berry et al. 2007), feeding in relation to BW changes (Bossen et al. 2009, Bossen and Weisbjerg 2009, Maltz et al. 2009) The Automatic weighing contributes to this process. The automatic weighing systems are probably the most economic sensor in the industry. One system can serve the whole dairy in a conventional milking parlor or about 60 cows in a robot milking system.

Visual Analysis of Body Weight Curves as an Indication for Energy Balance Changes Throughout Lactation

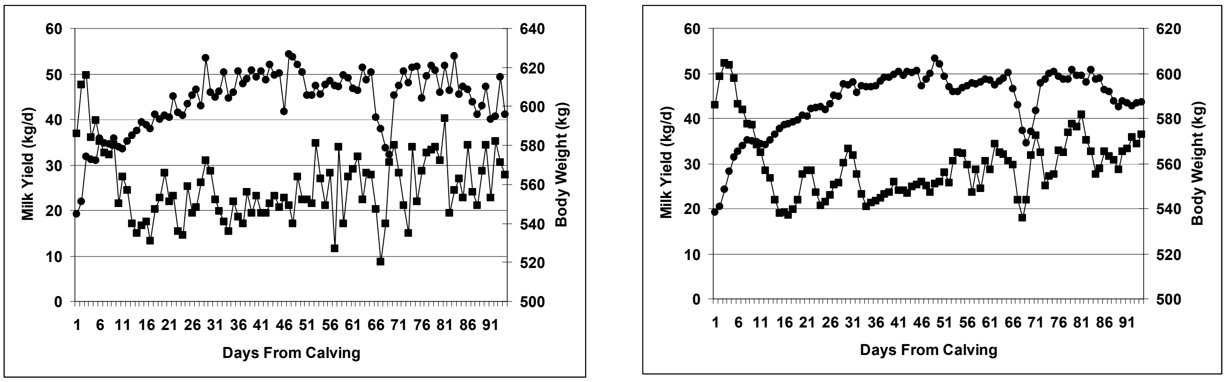
Normally BW changes can be associated with changes in energy balance when loss of weight indicates negative and weight gain, positive energy balance. For the high yielding dairy cow this is an oversimplification. The milk production driving force increases MY in a rate that is draining body reserves exciding that of DMI increasing rate. On the other hand, DMI increase from 7.2 to 16.2 kg DM within two weeks after calving (Silanikove et al. 1997) and may reach over 30 kg DM within 4-5 weeks (personal knowledge). Considering that each kg DM is accompanied in the gastrointestinal tract by 8-10 kg of water, the effect of gastrointestinal fill and enlargement over live BW during transition time can not be ignored. In other words, BW changes reflect two processes with contradictory effects over it. The body reserves mobilization decreases and gastrointestinal enlargement and fill increase it. This process, in changing levels of magnitude and direction, is ongoing throughout lactation. Bearing this in mind visual observation of the BW curves in relations to those of MY can identify several phases. In transition time a moderate BW decline or no change when MY increases after calving indicates that mobilization of body reserves is accompanied by a sufficient increase in DMI and gastrointestinal fill (Fig. 1 cows 5520 and 5702). A steep BW decline after calving may indicate an approaching of a lactation curve collapse (fig 1. cow 333). Later in lactation increase in body weight indicates body reserves deposition. It is quite clear that after peak production the decline in MY indicates that less energy is invested in MY, but it is not clear in which stage DMI changes diverting the contribution of the gastrointestinal enlargement and fill to BW from positive to zero and finally at late lactation to negative. Body condition score (BCS) along lactation is considered to reflect body reserves handling (see Roche et al. 2009). In several works were BW and body condition (BC) were measured in parallel as effected by milking frequency (Bar Peled et al. 1995) or nutritional manipulations (Walsh et al. 2008) it could be seen that for several weeks past nadir BW, BC keeps declining or did not change while BW is increasing. In general we can conclude that until BW nadir and at late lactation BW changes correlate linearly with BC and reflect, but only qualitatively, those of body reserves handling. Between these two stages no conclusions, even quantitative, can be withdrawn regarding body reserves handling from BW changes.

Body Weight and Body Condition Scoring

Roche et al. (2009) Stressed out the significance of body condition score for animal scientists and producers. These authors also stated that "Ongoing research into the automation of body condition scoring suggest that it is a likely candidate to be incorporated into decision support systems in the near future". Mizrach et al. (1998), Bewley et al. (2008), Halachmi et al. (2008) are only few examples in this attempt. However, until this is materialized it may be possible to model BCS by using data from available working sensors. Maltz et al. (2001, 2002) suggested to use on line MY and BW data and the relations between them to develop a model for estimating the BC throughout all lactation stages. As described above, linear relations between BW and BCS can be expected from calving until nadir BW when BW decline reflects also BC decline and in late lactation when BW increase indicates BC increase as well. Between these two periods the relations between BW and BC changes can not be considered as linear. Therefore, it was suggested to model BC in two stages separated by the phase from which the energy investment in MY starts to decline i.e. peak production. This model requires only a single BC scoring after calving. The preliminary results were quite encouraging (Maltz et al. 2002).

Recently an on-line milk composition analyzer was developed (Katz et al. 2007, see below). It is expected that when milk energy value will be incorporated into the model it will improve its performance.

5520



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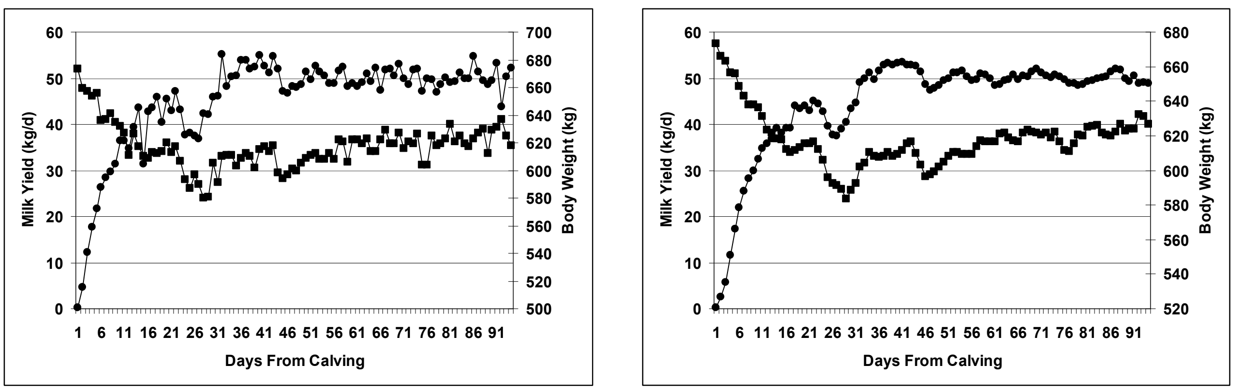

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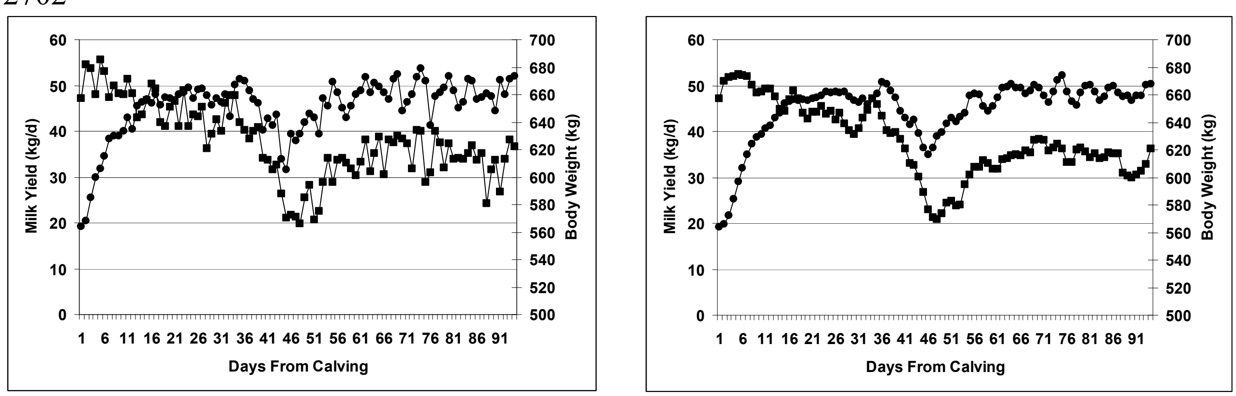

Fig. 1. Milk yield () and body weight () daily values (left) and 3 day running average (right) of 3 cows. Cow 5520 – moderate BW post calving decline (nadir - 91% of post calving weight), cow 333 – steep post calving decline (nadir – 86% of post calving weight) and cow 2702 – very moderate BW post calving decline followed by a clinical event on day 38 after calving

Body Weight and Dry Mater Intake and Nutrition

Individual dry matter intake is a desired parameter for feeding decisions especially when applying individual concentrates supplementation that is a must under robot milking conditions. Daily individual DMI also provides the information about the economical contribution of any cow in the herd at any given time. Halachmi et al. (1997, 2004) showed that DMI can be modeled out of daily MY and BW data. In the NRC (2001) an individual DMI formula was published which also calculates DMI out of performance (MY, milk fat, BW) and time after calving. In addition, Spahr et al. (1993) showed that using cow potential (the ratio of MY to BW at peak production) to group cows has a nutritional advantage. On-line BW data may have a significant contribution PDF in both, individual concentrates supplementation and group feeding.

Body Weight and Reproduction

Van Straten et al. (2008, 2009) found correlations between BW changes cycling in early lactation and reproductive performance. In addition a preliminary attempt was performed to use BW changes at estrous as an indication of emerging from negative energy balance to improve first insemination performance in order to get earlier pregnancies (Kaim et al. 2009). The criteria that were selected were that MY is decreasing or increasing by 0.5 kg/d or less (an indication of past or reaching peak production) and BW is increasing by 0.1% or more of post calving weight. The process of converting row data into an insemination decision is illustrated in Fig. 2. The results of this preliminary study were that 42% of the heifers that showed estrous between 57-85 days after calving and 37% of the cows that showed estrous between 47-65 days after calving (out of 55 and 54 inseminations for heifers and cows respectively) conceived after first insemination that was carried out after BW and MY performance analysis compared to 35% (out of 84 inseminations) and 20% (out of 137 inseminations) for heifers and cows respectively that showed estrous after 85 and 65 days after calving heifers and cows respectively. The later insemination strategy (after 85 days for heifers and 65 days for cows) was the one that was practically performed in that dairy. Incorporating the results obtained by van Straten et al. (2008, 2009) assessing ovarian activity by BW changes cycling from calving with on-line decision making at estrous may improve reproduction decision making.

Body Weight and Health

The effect of health problems over BW changes was described in several works (Maltz et al. 1997, Ostergaard and Grohn 1999, Moallem et al. 2002). The loss of appetite due to health problem or discomfort is immediately reflected by a body weight loss (see above) some times preceding that of MY decline or even that of milk conductivity response when measured in whole milk (personal knowledge). Figure 3 demonstrates a case were the BW decline precedes that of MY but ignored because decision were taken according MY and MY drop in day 52 was considered on day 53 as normal fluctuation. The decline in MY on day 54 convinced the farmer to present the cow to the vet.

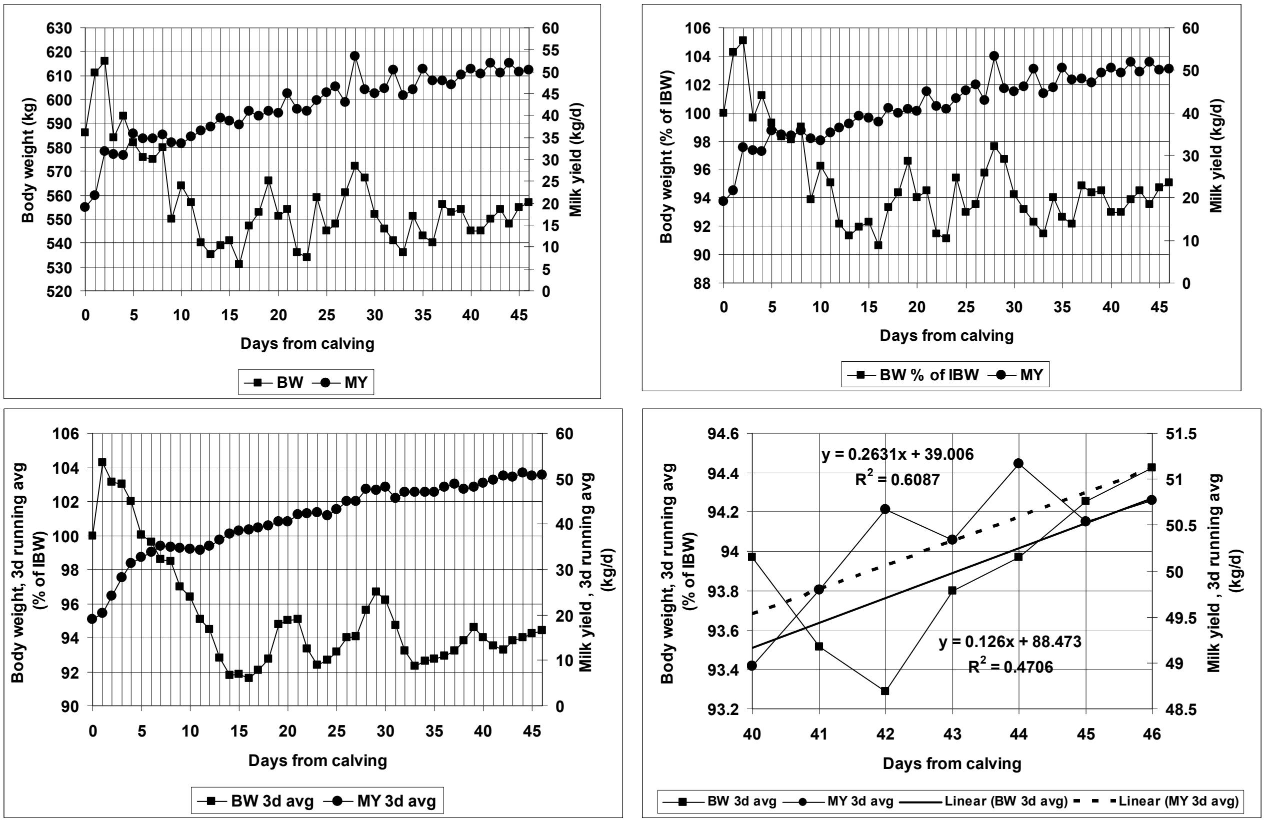

Figure 2. Data collection and insemination decision for one cow shoed estrous 46 days after calving. Row data (upper left panel), standardization to post calving weight (upper right panel), BW data smoothed by 3 day running average (left bottom panel) and linear trendline fitting (right bottom panel) indicating that MY is increasing by less then 0.5 kg/d and BW is increasing by over 0.1% of post calving weight.

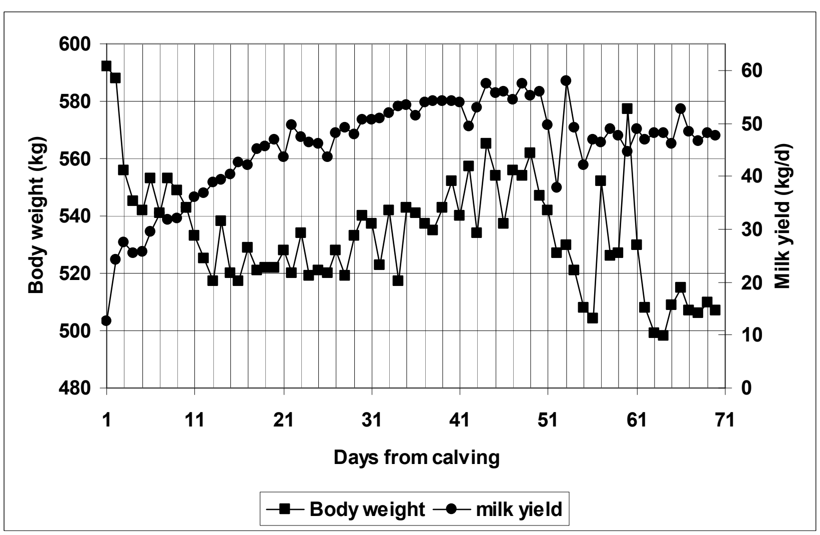

Figure 3. Daily BW change as a result of a health problem. The cow was presented to the vet and treated on day 54.

Milk Composition Analyzer

This novel sensor (Afilab®) was recently introduced into the industry (Katz et al. 2009) and not a moment to early. Milk fluctuates along milking, between milkings between days and changes remarkably along lactation. The periodical milk test analysis has only a limited benefit to PDF on daily or even weekly basis decision making because routinely the periodical milk test is performed once a month. Beside the obvious benefit that this analyzer has for feeding and health (see below), it turns up the possibility for diverting the milk from every cow or even during milking of a single cow to different tanks according to the milk processing needs. Under conditions of robot milking where cows may be sampled in non regular hours and it is possible that not the entire daily MY was sampled, a milk composition analyzer is even more significant for PDF then in the case of conventional milking parlors.

Milk Composition Analyzer and Feeding

For frequent feeding decisions, for example, a monthly milk composition value has a limited contribution especially at early lactation (Maltz et al. 2009). Figure 4 demonstrates the difference between a daily and a monthly value of milk composition for concentrates supplementation decisions during the first 100 days after calving. The daily milk composition data improved decision making regarding computer controlled individual concentrates supplementation by encouraging cows with a desired milk composition and depressing MY of those that their milk had a low economical value (Maltz et al. 2009). In any feeding system that supplements concentrates individually like in robot milking, the milk composition analyzer is a significant contribution.

Milk Composition Analyzer and Diagnostic Indications

Among the health problems those of after calving can affect the entire lactation and Heuer et al. (1999) described the association between milk composition of first milk test and a variety of health problems. An on line milk composition analyzer can be a useful tool in this respect being able to monitor on-line both the fat content and fat protein ratio (Tomaszewski and Cannon, 1993, Heuer et al. 1999). Milk lactose elevation was associated with mastitis (Schlinsen and Bauer, 1992). Together with the milk conductivity sensor, on line lactose measured by the analyzer can improve mastitis detection. The economical benefits of this sensor are so obvious that it is likely it penetrates into practical use before scientific trials show it.

Behaviour sensor

An animal manifests its feeling by its behaviour. Therefore, any environmental or physiological status or discomfort will be expressed by its behaviour and it is our duty to decipher behaviour and behavioural changes into managerial information. This is successfully done for diagnostic purposed in estrus detection where the increasing activity of the cycling cow is detected by increasing number of steps (S.A.E. Afikim, Afiact®) or neck movements (SCR, H-Tag®, Heatime®). Estrus was recently associated also by a remarkable change in lying behaviour (Livshin et al. 2005). Monitoring the behaviour of the dairy cow has potentially several applications. The first can satisfy the public growing concern regarding livestock welfare, and the second for a variety of diagnostic purposes that will improve animal well being, management and profitability.

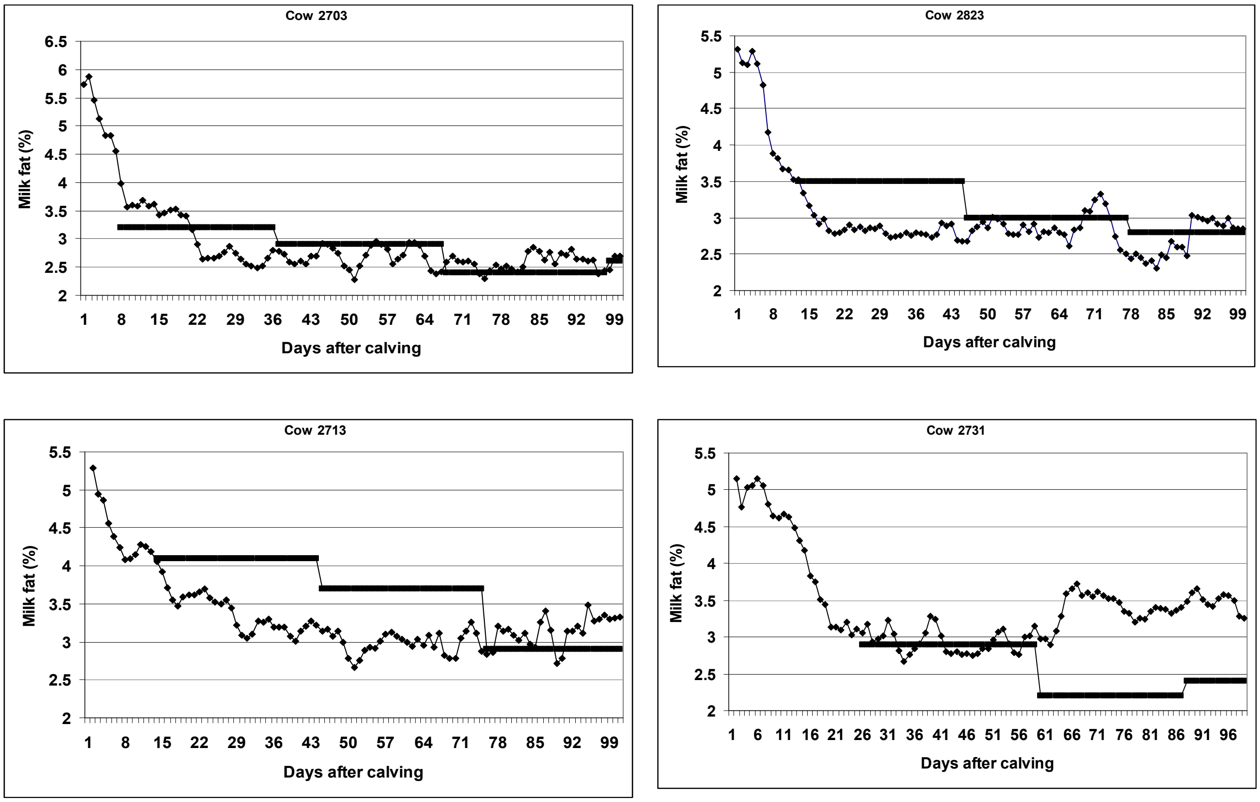

Figure 4. Four cows demonstrating the difference in depending on milk fat values achieved through periodical milk test (■) were one measurement dictates to relay on the same value for about a month until next milk test, and data achieved daily (3 days running average) by the milk composition sensor (▲). (From Maltz et al. 2009, Precision Livestock Farming '09)

Behaviour Sensor and Animal Welfare

"Optimal biological functioning of an organism occurs only when it lives in the most appropriate surrounding. …under such conditions, and only under such conditions, the best overall biological functioning of the organism is assured and the maximum quality of its life is reached" (Hurnik, 1992). Under such condition the animal should be free to carry out its normal behaviour. Rest and activity are fundamental and complementary components of animals' behaviour. In ruminants in general, and dairy cows in particular, lying behaviour reflects the rumination activity as well as resting. It may be effected by daily routine (feeding, milking), individual temper, and is often considered as an indicator of cow comfort when different housing environments are compared (for references see Livshin et al. 2005).

A leg-mounted sensor to monitor and register lying times was developed in The Institute of Agricultural Engineering, the Volcani Center. It had data storage and transmission capabilities. The sensor was tested through parallel visual observations and by comparing data of two sensors fitted to same cows. A trial was conducted using this sensor where diurnal lying behaviour was compared under two different housing systems (Fully roofed barn with no stalls and free stall barn, Livshin et al. 2005) it was found that:

Under stable daily management routine the cows adapt a very constant pattern of lying behaviour (Table 1).
Housing system effects lying behaviour (Table 1).
When cows were moved from on housing system to the other they adapted the behavior typical to that particular housing system.

Routine management practice may affect the pattern and the time of lying. Allowing sufficient lying time may be particularly significant under hot climate conditions where cows are moved several times a day between milking to the milking parlor waiting area, and/or tied in the feeding alley for forced cooling. This, in addition to the before milking cooling. All these activities are time consuming and may impair lying behaviour of the high yielding dairy cow.

Table 1. Lying time (mean ± SD) in between-milking diurnal intervals of 8 cows in a no-stalls barn and 8 cows in free-stalls barn (from Livshin et al. 2005).

Time interval	Lying time (min)		Lying time in free-stall, % of no-stall	Significance (P<)
	No-stall	Free-stalls		
04:30 - 12:30	157 ± 42	120 ± 43	76.4	0.01
12:30 - 20:30	118 ± 50	108 ± 49	91.5	Ns
20:30 - 04:30	258 ± 51	199 ± 50	77.1	0.001
24h total	533 ± 87	427 ± 90	80.1	0.001

Behaviour Sensor and Diagnostic Aspects

Since resting and activity are complementary components of animals' behaviour then lying behaviour may have a significant contribution to estrus detection especially under condition that activity is limited (free stall) or prevented (tied stalls). Its potential in this respect was indicated by Brehme et al. (2004) and Livshin et al. (2005).

Motivated by the potential benefits that were presented by Livshin et al. (2005) S.A.E. Afikim developed a behaviour sensor that measures number of steps, lying time and lying bouts, which was recently introduced to dairy industry. It is common knowledge that the behaviour of the cow changes prior calving. So, it is but logical to test the capabilities of this sensor for approaching calving by analyzing daily changes in behaviour and detect those that are related to approaching calving. It was found that calving time can be detected 24 hours before happening by analyzing the day to day changes of number of steps, lying time and lying bouts (Maltz and Antler 2007). The performance of this sensor is significantly improved when analyzing, in addition to diurnal data, also separately day time and night time behaviour (Maltz, unpublished data).

In addition to the activity sensor described above, it was suggested to analyze feeding behaviour as an additional indicator for approaching calving. The possibility that feeding behaviour can serve as a management tool was already indicated by Livshin et al. (2003). In a trial where dry cows before calving were capped in a "finishing group" equipped with two computer controlled self feeders and rationed daily 5 kg of concentrate in addition to dry finishing cow ration fed in the common feeding trough. The daily concentrates ration was fed in equal portions in four six hours feeding windows. Feeding behaviour of feeding window consumption and number of visits to the self-feeders were analyzed in addition to the normal behaviour variables of number of steps, lying time and lying bouts that were analyzed in addition to day, night and diurnal analysis. It was found that every animal has her own visiting pattern to the self feeders. Reduced number of visits and missing a normally used feeding window, was often associated with calving within the following few hours. Missing two feeding windows, in most cases indicated that the animal is calving. This trial is still on going. It is presented in this paper to illustrate that technology that was developed for one purpose, concentrates rationing, can serve as a sensor and be incorporated into PDF in a way the producers never thought about.

Rumination Sensor

A sensor that measures rumination time was recently introduced to the industry by SCR. Rumination time can be stored and analyzed 2 hour intervals in 2 minutes resolution. The potential benefit of this sensor lies in the fact that it can serve both in nutrition management, and as a health and cow's welfare sensor. In a trial recently conducted (Adin et al. 2009) difference in rumination time and pattern was recorded on group level for cows fed different TMRs. This trial indicates the significance of this sensor for both nutritional research and management. The potential benefits of this sensor for diagnostic purposes like health and predicting calving time is demonstrated by the producer. The close association of rumination, the variable that is measured by this sensor, to any nutritional aspect or gastrointestinal occurrence may put it into practical use before research is producing proofs to justify its use.

Heart Rate

A major part of the metabolized energy consumed by the dairy cow is dissipated as heat. This fraction is referred to as energy expenditure and reflects the natural, environmental and social conditions of the free ranging animal. No wonder that this is a desired parameter for both science and practice. In a study in Australia Brosh et al. (1998) found that "heart rate can be useful and accurate in estimating energy expenditure". Since then many studies were performed in which the validity of heart rate as an estimate for the energetic status of cows under variety of environmental (heat stress), managerial (feeding time), nutritional (different rations) conditions in ruminants was confirmed (for references see Brosh, 2007). Brosh concludes that "Soon when devices for automatic heart rate monitoring of domestic ruminants become available at a reasonable price, continuous monitoring of heart rate might provide producers with a sensitive tool for identifying changes in the energy status of their animals. This will also significantly help to shorten the time needed to identify health problems of individual animals" (Brosh, 2007). The materialization of this estimation is behind the corner. It could be added, that a heart rate sensor being a device measuring directly a physiological response of the animal to its environment and managements routines may become a useful tool for animals' short time detection of sickness and welfare status as well.

References

Adin, G., R. Solomon, M. Nikbachat, A. Zenou, E. Yosef, A. Brosh, A. Shabtay, S. J. Mabjeesh, I. Halachmi, and J. Miron. 2009. Effect of feeding cows in early lactation with diets differing in roughage-neutral detergent fiber content on intake behavior, rumination, and milk production. J. Dairy Sci. 92:3364.

Bar Peled, U., A.R. Lehrer, Y. Folman, I. Bruckental, J. Kali, H. Gacitua, E. Maltz, H. Tagari, B. Robinzon, and C.H. Knight. 1995. Relationship between frequent milking or suckling in early lactation and milk production of high producing dairy cows. J. Dairy Sci. 78:2726-2736.

Bewley, J. M., A. M. Peacock, O. Lewis, R. E. Boyce, D. J. Roberts, M. P. Coffey, S. J. Kenyon, and M. M. Schutz. Potential for Estimation of Body Condition Scores in Dairy Cattle from Digital Images. J Dairy Sci 2008 91: 3439-3453.

Bossen, D., M.R. Weisbjerg, L. Munksgaard, S. Hojsgaard. 2009. Allocation of feed based on individual dairy live weight changes I: Feed intake and live weight changes during lactation. Livst. Scie. 126:252-272

Bossen, D., M.R. Weisbjerg. 2009. Allocation of feed based on individual dairy live weight changes II: Effect on milk production. Livst. Scie. 126:273-285

Brosh, A., Y. Aharoni, A.A. Degen, D. Wright, and B.A. Young. 1998. Estimation of energy expenditure from heart rate measurements in cattle maintained under different conditions. J. Anim. Sci.76: 3054-3064.

Breheme, E., U. Stollberg, R. Holtz, T., Scleusener. 2004. Safer oestrus detection with sensor aided ALT-pedometer. In: Proceedings of Third International Workshop on Smart Sensors in Livestock Monitoring, 10-11 September 2004, Leuven, Belgium. Pp. 43-46.

Brosh, A. 2007. Heart rate measurements as an index of energy expenditure and energy balance in ruminants: A review. Journal of Animal Science, 85:1213-1227.

Dyer, R.M., N.K. Neerchal, U. Tasch, Y. Wu, P. Dyer, and P.G. Rajkondawar. 2007. Objective determination of claw pain and its relationship to limb locomotion score in dairy cattle. J Dairy Sci. 90: 4592-4602.

Filby, D. E., M. J. B. Turner, and M. J. Street. 1979. A walk-through weigher for dairy cows. J. Agric. Engng. Res. 24: 67-78

Frik, R., E. Stamer, W. Junge, J. Kreieter. 2002, Automation of oestrous detection in dairy cows: a review. Livestock Production Science, 75:219-232.

Halachmi, I., P. Polak, D.J. Roberts, and M. Klopcic. 2008. Cow body shape and automation of condition scoring. J. Dairy. Sci. 91:4444-4451.

Halachmi, I., Y. Edan, U. Moallem, E. Maltz (2004). Predicting feed intake of the individual airy cow. J. of Dairy Sci. 87:2254-2267

Heuer, C., Schukken, H. and P. Dobbelaar, 1999. Postpartum body condition score and results from the first test day milk as predictors of disease, fertility, yield, and culling in commercial dairy herds. J. Dairy Sci. 82, 295-304.

Hojman, D., M. Gips, and E. Ezra. 2005. Association between live body weight and milk urea concentration in Holstein cows. J. Dairy Sci. 88:580-584.

Hurnik, J.F. 1992. Ethology and technology: the role of ethology in automation of animal production process. In: Prospects for Automatic Milking. Ipema, A.H., A.C. Lipus, J.H.M. Metz, and W. Rossing (Eds.). PUDOC Scientific Publishers, Wageningen, the Netherlands EAAP Publ. No. 65, pp. 322-330

Kaim, M., A. Native, A. Zukerman, A. Antler, E. Maltz. 2009. Use of on-line body weight and milk yield data to improve earlier first insemination performance. Proc. The 21th Conference of Cattle Sciences, Jerusalem, Israel, 30 June-2 July, 2009, pp 106-108 (in Hebrew).

Katz, G., A. Arazi, N. Pinski, I. Halachmi, Z. Schmilovitz, E. Aizinbud, E. Maltz. 2007. Current and Near Term Technologies for Automated Recording of Animal Data for Precision Dairy Farming. ADSA, San Antonio, TX, USA, 8-12 July 2007. J. Dairy Sci. Vol. 90, Suppl. 1, pp. 377.

Livshin, N., E. Aizinbud, M. Tinsky, U. Bargai, E. Maltz. 2003. Automated monitoring of dairy cows' behavioral patterns as a tool for management. In: Proceedings, itafe ' 03, International Congress on Information Technology in Agriculture, Food and Environment, 7 to 10 October 2003, Izmir, Turkey

Livshin, N., A. Antler, B. Zion, G. Stojanovski, G. Bunevski, and E. Maltz. 2005. Lying behaviour of dairy cows under different housing systems and physiological conditions. In: Proc. 2nd ECPLF, 9-12 June 2005 in Uppsala, Sweden, pp. 305-311.

Maltz E., O. Kroll, S.L. Spahr. 1987. Parameters required for individual concentrates supplementation of the dairy cow: their recording, analysis and use. Proc. Third Sym. in Automation in Dairying, Wageningen, the Netherlands, pp. 86-101

Maltz E., O. Kroll, R. Sagi, S. Devir, S.L. Spahr, A. Genizi. 1991. Milk yield, parity and cow potential as variables for computerized concentrates supplementation strategy. J. Dairy Sci. 74:2277-2289

Maltz, E., S. Devir, O. Kroll, B. Zur, S.L. Spahr, R.D. Shanks. 1992. Comparative responses of lactating cows to total mixed ration or computerized individual concentrates feeding. J. Dairy Sci. 75:1588-1603

Maltz, E., Devir, S., J.H.M. Metz, and H. Hogeveen. 1997. The body weight of the dairy cow: I. Introductory study into body weight changes in dairy cows as a management aid. Livestock Production Sci. 48:175-186

Maltz E., 1997. The body weight of the dairy cow: III. Use for on-line management purposes of individual cows. Livestock Production Sci. 48:187-200

Maltz, E., A. Mizrach, U. Flitsanov, Z. Schmilovitch, S.L. Spahr, M.R. Murphy and J. Novakofski. 2001. Body weight and milk yield changes along lactation to evaluate and model body condition. Proc.52nd Annual Meeting of the E.A.A.P. (Budapest, Hungary). pp. 190.

Maltz, E., A. Mizrach Z. Schmilovitch, H. Lherer, M. R. Murphy, J. E. Novakofski 2002. Body condition modeling of dairy cows by online body weight and milk yield data. Proc. AgEng2002, Budapest, Hungary, 02-AP-004, 1:60.

Maltz, E., N. Livshin, A. Antler, I. Brukental, A. Arieli (2004). Technologies and Modeling, for Precision Protein Feeding of Dairy Cows during Transition Time. CIGR Int. Conf. 11-14 October, 2004, Beijing, China. CD, Session III, Sub Session 4 KIS/DSS, paper 6.

Maltz, E., N. Livshin, E. Aizinbud, and M. Tinsky. 2004. Real-time sensors in the milking parlor as a tool to monitor cows' milk let down and parlor performance to improve milking routines and operation efficiency. AgEng 2004, International Conference on Agricultural Engineering, 12-16 September 2004, Luven, Belgium, CD Session 18, No. 543. book of abstracts pp. 580-581.

Maltz, E., A. Antler. 2007. A practical way to detect approaching calving of the dairy cow by a behaviour sensor. Proc. Precision livestock farming ’07, Edited by: S. Cox, Academic Publishers, pp. 141-146

Maltz, E., A. Antler, I. Halachmi, Z. Schmilovitch (2009). Precision concentrate rationing to the dairy cow using on-line daily milk composition sensor, milk yield and body weight. Precision Livestock Farming ‘09, Proc. Of The 4th ECPLF, 6-11 June 2009 in Wageningen, the Netherlands, pp. 17-23.

Mizrach, A., U. Flitsanov, E. Maltz, S. L. Spahr, J. E. Novakofski. (1998). Ultrasonic assessment of body condition changes of the dairy cow during lactation. Transactions of the ASAE. 42(3):805-812.

Moallem, U., P. Gur, N. Shpigel, E. Maltz, N. Livshin, S.Yacoby, A. Antman and E.Aizinbud 2002. Graphic monitoring of the course of some clinical conditions in dairy cows using a computerized dairy management system. Israel Journal for Veterinary Medicine 57(2):57-64

National Research Council (NRC), 2001. National Academy Press, Washingtom D.C.

Peiper, U. M., E. Maltz, Y. Edan, M. Babazada, H. Schon, R. Artman. 1987. Routine automatic dairy cow’s weight measurements for the use of husbandry decision. Proc. 3rd Symp. utomation in Dairying. Wageningen, the Netherlands, pp. 116-128

Peiper, U. M., Y. Edan, S. Devir, M. Barak, E. Maltz. 1993. Automatic weighing of dairy cows. J. Agric. Engng. Res. 56:13-24

Rajkondawar, P.G., M. Liu, R.M. Dyer, N.K. Neerchal, U. Tasch, A. M. Lefcourt, B. Erez, and M. A. Varner. Comparison of models to identify lame cows based on gait and lesion scores, and limb movement variables. J Dairy Sci 2006 89: 4267-4275.

Roche, J.R., N.C. Friggens, J.K. Kay, M.W. Fisher, K.J. Stafford, and D.P. Berry. 2009. Invited review: Body condition score and its association with dairy cow production, health, and welfare. J. Dairy Sci. 92:5769-5801.

Schlunsen, D., and R. Bauer. 1992. Investigation on the suitability of different milk parameters for early detection of mastitis, and implication for automated monitoring. In: Prospects for Automatic Milking. Ipema, A.H., A.C. Lipus, J.H.M. Metz, and W. Rossing (Eds.). PUDOC Scientific Publishers, Wageningen, the Netherlands EAAP Publ. No. 65, pp. 322-330

Silanikove, N., E. Maltz, A. Halevi, D. Shinder. (1997). Metabolism of water, sodium, potassium, and chlorine by high yielding dairy cows at onset of lactation. J. Dairy Sci. 80:949-956.

Spahr, S.L., R.D. Shanks, G.C. McCoy, E. Maltz, and O. Kroll. 1993. Lactation potential as a criterion for total mixed ration feeding strategy for dairy cows. J. Dairy Sci. 76:2723-2735

Tomaszewski M.A. and T.J. Cannon, 1993 Using records for large herd management. Western Large Herd Management Conference, Las Vegas Nevada, USA. pp 137-140.

Toshniwal, J.K., C.D. Dechow, B.G. Cassell, J.A.D.R.N. Appuhamy, and G.A. Verga. 2008. Heritability of electronically recorded daily body weight and correlations with yield, dry matter intake, and body condition score. J. Dairy Sci. 91:3201-3210.

van Straten, M., N. Shpigel, and M. Friger. 2008. Analysis of daily body weight of high-yielding dairy cows in the first one hundred twenty days of lactation and associations with ovarian inactivity. J. Dairy Sci. 91:3353-3362.

van Straten, M., N. Shpigel, and M. Friger. 2009. Association among patterns in daily body weight, body condition scoring, and reproductive performance in high-producing dairy cows. J. Dairy Sci. 92:4375-4385.

van Straten, M., M. Friger, and N. Shpigel. 2009. Events of elevated somatic cell counts in high-producing dairy cows are associated with daily body weight loss in early lactation. J. Dairy Sci. 92:436-4394.

Walsh, S., F. Buckley, K. Pierce, N. Byrne, J. Patton, and P. Dillon. 2008. Effect of breed and feeding system on milk production, body weight, body condition score, reproductive performance, and postpartum ovarian function. J. Dairy Sci. 91:4401-4413.