Development and Current State of the Milking Robot in Japan and Europe

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Key words: Automatic milking system, Milking Robot, Cow traffic

The milking robot is spreading across European countries, mainly in The Netherlands. A recent report stated that about 1,000 dairy farmers worldwide were using milking robots. In Japan, the milking robots were in testing at four public agricultural experimental stations and were in use at over 20 private dairy farms by May 2000. The milking robot is a technology that is shifting from the research stage to the implementation stage, though the number of implementations is limited in Japan. However, it has become clear that some farmers in The Netherlands have stopped using milking robots. The advertising catchphrase “Every farmer can easily use the milking robot at any time and in any place” is not true. We should avail ourselves of much more information about milking robots in use under various practical conditions.

In this review, I intend to describe the articles, reports, and documents concerning the milking robot that have been published in Japan, Europe, the USA, and Canada. I will also introduce the researches involved in the development of milking robots worldwide.

1. Development and progress of milking robots in Japan and Europe

A system for automatic milking was patented in 1971 in the former East Germany. However, I believe that the Japanese milking robot was the world’s first robot to attach teat cups to cows successfully without human help. A project called “Development of a new technology for labor saving in milking” was conducted at the Livestock Experimental Station of the Japanese Ministry of Agriculture, Forestry and Fisheries from 1972 to 1977. The project members consisted of engineers and animal scientists selected by the Livestock Experimental Station in Tsukuba, the Institute of Agricultural Machinery, the Shizuoka Livestock Experimental Station, and the Orion Machinery Co. The developed milking robot attached the teat cups to cows successfully, but the robot did not come into practical use because the necessary computer technology had not been developed yet. The robot couldn’t follow the teats’ movements in real time. Unfortunately, further development of the robot was suspended. Notsuki recollected three points at that time: a) cows should not be restricted too tightly, b) teat cup sensors should detect movement in real time, and c) the teat cups held by the robot’s arm should follow the movement of the cow. All these points are achieved in the present milking robots. It seems regrettable that the development of the milking robot has been delayed in Japan.

The movement toward automation in dairy farming was started in Western Europe in conjunction with the remarkable development of the microcomputer in the
KASHIWAMURA

1980s. Especially in The Netherlands, NEDAP Co. developed an electronic individual identification system and used it for automatic concentrate feeders in free-stall barns. The idea of automatic milking was associated with voluntary visits to an automatic concentrate feeder several times a day. Higher milking yields were also expected to be a result of frequent milking. Research into milking robots was started in several countries in Europe. The research stations involved were IMAG-DLO (Netherlands), FAL (West Germany), AFRC Silsoe (UK), and CEMAGREF (France)\(^{63}\).

IMAG-DLO at Wageningen in The Netherlands organized the second symposium, entitled “Automation in Dairying,” in April 1983. The presentations were concerned with automatic concentrate feeders, mastitis detection by electric milk conductivity, and activity meters to detect cows in estrus; only one presentation concerned the automatic teat cup attachments from West Germany\(^{56}\). The third symposium, on “Automation in Dairying,” was held at the same place in The Netherlands in 1987. Of a total of 47 presentations, seven concerned the automation of milking, including three from the UK, two from West Germany, one from France, and one from Denmark. A symposium entitled “Prospects for Automatic Milking” was held at IMAG-DLO in November 1992. The state of development of the milking robot of each country and each company in Europe was shown, and it was evident at this symposium that the milking robot was becoming a reality. The symposium consisted of five sessions: a) techniques of the milking process, b) milk quality, c) milking frequency, d) herd management, and e) general assessments. Some Japanese attendees of this symposium, Fukumori\(^{16}\), Shinde\(^{67,68}\), and others, went on to play an advanced role in developing or extending the milking robot in Japan. I am convinced that this symposium might well have opened the door to the milking robot age.

The greatest difficulties in developing an automatic milking system are to find four teats separately by sensors and to develop a device that attaches teat cups to those teats at unstable positions. Each country and each company developed several different procedures\(^{5}\). The Prolion milking robot, named the Automatic Milking System (AMS), used two types of ultrasonic sensors: a rough sensor located the front right teat, while a fine sensor found the other three teats. The milking robot of Gascoigne-Melotte used a database that stored the positions of teats in computers, and sensors to sense the position of the pinbone were used as a reference to locate the udder if the animal moved. The automatic milking system developed by CEMAGREF in France was tested for a short period; it used a charge-coupled-device (CCD) camera and laser. A British system developed by Silsoe Research Institute used sensors that pressed gently against the animal’s flanks and back. A matrix of eight infrared light beams was arranged across the top of the end effector to detect the teat. Alfa Laval in Sweden recently commercialized this system as the Voluntary Milking System (VMS). The milking robot developed by Düvelsdorf in West Germany used a computer database of the positions of the teats, and an ultrasonic sensor and light barriers established the exact position. This system was taken over by Westfalia in Germany in 1996 and named Leonardo. The Federal Research Institute for Agriculture at Kiel in Germany has developed an automatic milking system using ultrasonic sensors, a CCD camera, and a laser to locate the teats. No experimental data are available for the Lely system. However, the Lely milking robot named Astronaut, like the Prolion AMS, is working fairly well at practical dairy farms worldwide.

In Japan, research into milking robots has been interrupted since 1977. From 1986 to 1989, Hokkaido Konsen Agricultural Experiment Station and Hokkaido Industry Research Institute had started together developing a milking robot\(^{66}\). The project period was too short to complete the development of a practical milking robot. Afterwards, the plan to develop a Japanese original milking robot was started again, this time by the Bio-oriented Technology Research Advancement Institution (BRAIN) in 1993. The resulting robot is planned to be installed in tie-stall barns. The same year, Orion Machinery, the BRAIN, Advancing Livestock Technology (Chikusan Gijutsu Kyokai), Hokuren Agricultural Cooperative, and others established Milking Automation
Milking Robot in Japan and Europe

Fig. 1. Japanese milking robot “Dairy Dream” on the market on December 1999.

Technology (MAT). A Japanese original milking robot, named “Dairy Dream” (Fig. 1), was on the market by November 1999. This robot is ready for a free-stall barn or a loose barn, not for a tie-stall barn.

2. The practical milking robot in Japan

The Prolion AMS was introduced to Obihiro University of Agriculture and Veterinary Medicine, Hokkaido, Japan, in December 1993. Kubota Co. supported research projects at Obihiro University called “Development of efficient use a milking robot in practical farms in Japan”. Before that introduction, the manager of IMAG-DLO spoke at the First International Symposium on Agricultural Technique for Cold Regions (ISAC) in Obihiro in 1988. He suggested that the milking robot would be practical as a dairy facility in The Netherlands in the near future. The AMS of Obihiro University was continuously used for five years, and a lot of know-how for its practical use was accumulated. During those five years the improvement of teat cup attachments progressed rapidly. The milking routine by the robot has changed from fixed-time milking to free-time milking or 24-h milking.

The three-box type of Prolion AMS was experimentally introduced to a dairy farm in Hokkaido in 1995. The farmer purchased it after the experimental period, and he is still using it. The same type of robot was installed at two national agricultural stations and a local agricultural station, a company dairy farm, and three private dairy farms; two are in Hokkaido and one in Tochigi prefecture. These are one-box to three-box types of the Prolion AMS, and the farms that use these robots keep comparatively large herds, ranging from 80 to 100 cows.

Cornes AG in Japan imported the milking robot Lely Astronaut from The Netherlands, and the first robot was installed at a dairy farm in Hokkaido in December 1997. This milking robot is a one-box type and is comparatively easy to set up in a free-stall barn. The recommended herd size is 60 per robot. This type of milking robot is being tested at the local agricultural center in Iwate prefecture, and 22 Lely robots are in use at private dairy farms at this moment. On some occasions, two or three robots were installed at fairly large-herd dairy farms that keep 100 to 150 cows.

“Dairy Dream” Orion milking robots have been installed at two dairy farms, and I have been informed that those are working fairly well.

3. Investigative reports by Japanese on the milking robot in Europe

The Japanese as a people like investigation very much. Many articles written by Japanese authors have informed audiences in Japan and elsewhere on the overseas situation of milking robots. I will try to show these reports as follows.

Fukumori reported on agricultural mechanization in Europe in 1987. He participated in the above-mentioned symposia, “Automation in Dairying” in 1987 and “Prospects for Automatic Milking” in 1992. Hachiya investigated the developmental situation of the milking robot in The Netherlands, Germany, and France in 1994, and he reported on the differences among the various machines. Hoshiba et al. investigated The Netherlands and Germany in January 1995, and reported that the milking robot of Lely was exhibited at Landbouw RAI 95. Ichito investigated The Netherlands and Germany in July 1995, and he reported that about 50 milking robots must be in use around the world. Kuwana of BRAIN did investigative travel in Europe in 1996 and introduced more detail about the Lely milking robot.
In addition, detailed information about dairy farms in The Netherlands is available from the reports of the Agriculture and Livestock Industries Corporation\(^4\) and the Hokkaido Konsen Agricultural Experiment Station\(^2\). In these reports, a member of the investigative team described that the dairymen using the robot expected "labor saving for milking" and an "increase of milk production owing to the frequent milking."

4. Articles on milking robots for promotion in Japan

The staff of BRAIN summarized milking robots in the booklet "Investigation concerning automatic milking." The booklet\(^6,7\) contains many translations of the proceedings of the symposium "Prospects for Automatic Milking" from 1992. Matsuki\(^4\) and Okada\(^5\) were mentioned regarding the Japanese milking robot "Dairy Dream" developed by the MAT and Orion Machinery. Advancing Livestock Technology started the project "Promotion of a practical automatic milking system" in 1997. That organization published two booklets that summarized much information about automatic milking systems both in Japan and Europe\(^2,3\). A special edition of the Journal of the Japanese Society of Agricultural Machinery entitled "Current state and development of the milking robot" was published in 1999\(^21,25,31,34,41,54\). Also, the journal Livestock Technology published a special issue on "Development, current state and future direction of the milking robot"\(^26,74\). The articles in these two journals provide many useful suggestions about milking robots, so I can recommend them for information on the situation of dairy automation in Japan.

5. Research aspects for the milking robot in Japan

The detailed results of research on new milking robots have not been fully published, because the technology has been deeply affected by a patent. In Japan, there was limited information about the Lely Astronaut before Japan Corns AG began importing it to Japan in 1997. We could get information about the Prolion AMS comparatively easily, but photographing it was prohibited in the early stage of its introduction to Obihiro University in 1993. The results of the research works conducted at Obihiro University were mainly presented at meetings of the Japanese Society of Animal Science and the Japanese Society of Livestock Management. I will show the shortened titles as follows.

- "Effects of timer-controlled gates for a temporary one-way cow traffic"
- "Comparison of behavior and performance between an automatic milking system and a conventional milking parlor system"
- "Comparison of milk yield and behavior of cows between 2 times and 3 times milking by robot"
- "Trial of freetime milking"
- "Cow training to encourage entering the milking box"
- "Investigation of labor requirement for robotic milking"
- "Factors influencing voluntary visits to an automatic milking system"
- "Experimental trial of temporarily stopping concentrate supply in the milking box"
- "Influence of milking interval to the numbers of voluntary visits and milking frequency"
- "Possibilities in combining pasturing management and automatic milking system"
- "Effects of milking frequency to the quality of teats"

Morita\(^48,49\) who has worked at IMAG-DLO, presented a strategy of foraging to encourage cows to voluntarily visit the robotic milking stalls. He also explained about applications of cow traffic. Basic research into the technology of surveying teat position was done by Hachiya \textit{et al.}\(^19\), one of the BRAIN engineers formally engaged in the development of milking robots in Japan. His results have been tested for a milking robot installed in a tie-stall barn. Investigative surveys of dairy farms using milking robots have been reported by several researchers, but unfortunately all these reports were written in Japanese\(^28\). Kawamura, of the Iwate Prefecture Agricultural Research Center, is now doing practical experiments using the Lely Astronaut. Kida, a researcher at the National Grassland Research Institute, is researching the Prolion AMS to promote to dairy farmers in Japan.

6. Research on milking robots in European and North American countries

a) Netherlands: Most researchers working with milking robots in The Netherlands belong to IMAG-DLO. Rossing\(^62-65\) is a well-known researcher who has written many articles explaining the development of milking robots in Europe from an engineering standpoint. Ipema\(^32,33\) is also a well-known...
researcher of milking robots. He especially reported on milking frequency and teat quality in the early stage of development. Ketelaar-de Lauwere\textsuperscript{36-40} and Stefanowska\textsuperscript{46,73-76} are interested in the behavioral aspects of cows in a robotic milking barn. Their research includes one-way cow traffic and a selection unit, concentrate and forage feeding strategies and pasturing management. Devir\textsuperscript{9-13} showed the idea of a total dairy control and management system which includes a decision making system, an automatic milking system, on-line sensor data that cover activity, body weight and body temperature, and off-line information. Hogeveen \textit{et al.}\textsuperscript{23} of the Research Station for Cattle, Sheep and Horse Husbandry (PR) also reported on the importance of cow traffic. Kuipers\textsuperscript{43} has written comprehensively about robotic milking.

b) Germany: Ordolff\textsuperscript{56,57}, an authority on milking robots in Germany, sends not only information from Germany but from other European countries as well. Kremer\textsuperscript{42} and Artman\textsuperscript{5} described the milking robot in Germany. Pirkelmann\textsuperscript{58}, of the Technical University of Munich, has pointed out the importance of feeding strategies in the automatic milking system at an early stage of development.

c) UK: Mottram\textsuperscript{50-53}, Street \textit{et al.}\textsuperscript{77} and Frost \textit{et al.}\textsuperscript{15}, engineers at the AFRC Silsoe Research Institute, deeply affected the initial development of milking systems in Britain. Research on the relationship between feeding and voluntary visits was tested by Winter\textsuperscript{81,82} and Prescott \textit{et al.}\textsuperscript{59-61} in Britain.

d) France: The further development of a milking robot at CEMAGREF in France has not been reported. I have read only information from France by Marcal \textit{et al.}\textsuperscript{44}, who discussed a voluntary visit.

e) Canada: Hurnik\textsuperscript{29} of the University of Guelph in Canada discussed the ethological aspects of the milking robot and suggested the importance of minimizing the development of negative conditioning to the milking unit. Uetake \textit{et al.}\textsuperscript{79,80}, a Japanese researcher who also researched at Guelph, described that visual and aural signals to cows also affected voluntary visits.

f) USA: Spahr\textsuperscript{72} of the University of Illinois at Urbana-Champaign is a researcher who is trying to apply electronic technology to dairy management; he doubts the advantage of using a milking robot in the US. He has pointed out that the economical merit is not clarified yet, because the labor cost is not so high in the US. Miller \textit{et al.}\textsuperscript{47} of the University of Maryland introduced the milking robot of Gascoigne Melotte at the early development stage and described four teat locations. Albright \textit{et al.}\textsuperscript{1}, known as a behavioral scientist on cattle, cited voluntary visits to milking parlors.

In conjunction with the development of automatic milking systems, automatic mastitis detection became much more important. The electric conductivity of milk is normally used as a detective parameter. The imaging of the color of the udder\textsuperscript{31} and light reflection from milk were also tested\textsuperscript{17} as new technologies. Harsh \textit{et al.}\textsuperscript{20} has compared the economic consequence of the milking robot and the conventional milking parlor in the US and The Netherlands. Sonck\textsuperscript{69-71} emphasizes the domination of milking robots as an aspect of labor reduction.

At the early stage of development of milking robots, most studies were from the engineering fields. The recent research field has shifted to cow behavior regarding voluntary visits and the hygiene of milking for bacteria and mastitis control.

Conclusion

Harvesting milk from cows should make farmers happy anytime. However, it is also true that having to milk cows at least twice a day, at inconvenient hours, becomes stressful for some farmers who run large dairy herds. It is thought that the milking robot will bring about a major revolution for those farmers. Such robots have now entered the implementation stage from the experimental stage. Since the reliability of the milking robot is improved, it seems that the voluntary visits of cows to milking stalls has become the most important factor for the success of these systems. In Japan about 90\% of the cowshed is a conventional tethered-type barn. Free-stall barns account for only 5\% of the total, although this has increased in the past 10 years. Many farmers are considering which is better a conventional milking parlor or a milking robot for their future. It is worrisome, however, that Japanese dairymen are not
familiar with the management of unrestricted animals in the barn. Most cows in Japan also are unfamiliar with social behavior associated with free movement. Though the milking robot is a technology on the way, it is becoming popular very quickly in Japan. Drastic changes in dairy practices will be expected not only for the farmers but also for the animals in the near future.

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Milking Robot in Japan and Europe


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Milking Robot in Japan and Europe


