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Comparative performance analysis between two different generations of an automatic milking system

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ABSTRACT
The adoption of Automatic Milking Systems (AMS) in Europe and Italy has been increasing gradually in recent years, driven by the advantages they offer over traditional milking methods. AMS reduces the need for manual labor, increases milk production, standardizes teat cleaning and disinfection, and promotes animal welfare. The adoption of milking robots also allows for continuous monitoring of milk parameters, animal health status, and production performance. In a recent study, the authors analyzed the improvements achieved by a buffalo farm in Southern Italy that switched from an older model (Classic) to a newer generation model (VMS 300) of milking robot, showing an increase in production quantity and quality.

Section: RESEARCH PAPER

Keywords: AMS; vision systems; Time-of-Flight (TOF); 3D camera

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1. INTRODUCTION

In recent years in Europe, as well as in Italy, there has been a gradual increase in the number of barns in which milking is carried out by Automatic Milking System (AMS). It is highlighted how the increase in the adoption of these systems, which requires an initial significant investment, is due not only to a simple generational change of dairy barn manager (i.e., young business owners more accustomed to the technology), but also and above all to the advantages they can offer, compared to traditional milking methods [1].

The adoption of robotic milking makes it possible to reduce the number of workers needed to carry out milking operations, thus overcoming a growing difficulty for farms, i.e. finding skilled and motivated labor [2]. Moreover, the milking robot makes it possible to cope with the need to perform more than one milking over a 24-hour period, a factor that leads to increased production, and to standardize teat cleaning, attachment/removal and disinfection operations, thus ensuring greater animal welfare and automatically and continuously keeping a large number of milk parameters under control [3]. Improving animal welfare is not a secondary aspect of the decision to adopt the milking robot [4]. In fact, it is well known that in recent years many intensive farms, in some cases, have been considered as real lagers. Therefore, the activities of farmers and companies have also focused on how to improve animal welfare. To pursue this important goal, adopting robotic milking devices has proven to be a valuable tool [5]. Using the milking robot, in fact, reduces the handling of animals by milkers and promotes the natural inclination of the animals to be milked (inclination understood as the interval between two milkings and the number of milkings in 24 h) [6]. Better welfare results in less stress in the animals, and this also leads to a significant increase in production (up to 10 % more). Finally, the adoption of milking robots makes it possible to check production performance, the health status of the animal, and the presence of any chemical/physical alterations in the milk, allowing timely intervention in herd management, and thus achieving an overall improvement in quantity, production quality, and animal welfare. Milking robots are now highly advanced, constantly evolving tools that take advantage of the latest technological innovations in electronics and connectivity to continuously improve their performance [7].

In this regard, in the present work, the authors have analyzed the improvements achieved by a buffalo farm, located in Southern Italy, which has switched from using a milking robot model Classic from DeLaval, to a newer and latest generation model, the VMS 300. Specifically, the paper discusses the differences and technological improvements introduced in the newer version (VMS300) compared to the older one (Classic), and how these have allowed for an increase in the quantity and quality of production on the farm [8]. The study compares data on milk production and quality collected between June and December 2020, a period when there were four milking robots on the farm, including two of the Classic model used on the first group of buffaloes and two of the VMS300 model, used on the second group of buffaloes, under the same barn and environmental conditions.

2. DIFFERENT GENERATIONS OF AUTOMATIC MILKING SYSTEMS

The first studies and research on the full automation of the dairy barn date back to the late 1970s and were activated thanks to the gamble of Dutch researchers at the IMAG Institute in Wageningen; in 1992, the first AMSs began to be commercialized. An estimated 50,000 milking robots operate worldwide, with more than 1,200 of them in Italy (i.e., 4-5 % of the operating farms) [9]. From a technological point of view, the AMS is a complex system, consisting of several parts including the milking box, the electronic identification system and the teat localization system, the robotic arm and a series of sensors, with associated data management software [10]-[23]. The most innovative aspect is definitely single-quarter milking; this is an important innovation made available by automated teat-catcher handling systems and is beginning to be introduced in conventional facilities as well [24]-[28]. The different production quantities and times between quarters lead to a favourable view of individual quarter milking methods, which in this way should avoid any possibility of overmilking. Another innovation specific to robotic systems is the separation of first sprays and abnormal milk, which is conveyed to a separate collection tank, also to meet current legislation [29]. Numerous sensors are included in the milking robots, and they can be used for making measurements and analysis regarding production, milk quality, and health status of the buffalo [30]-[32]. Regarding production, in addition to the quantity produced per each buffalo, it is also possible to measure the flow of milk per quarter, as well as the frequency of visits that the head makes to the robot, with the corresponding duration. Regarding quality, the installed sensors can return the fat, protein, and lactose content of the milk. With regard to health, there may be a device that performs somatic cell counting (the so-called “cell counter”), using optical or viscosity measurements of the milked product [33]-[41]. Such a sensor is useful for rapidly assessing the possible presence of clinical and sub-clinical mastitis per individual breast quarter [42]. The presence of blood in the milk, an indicator of both an inflammatory state of the udder and trauma suffered by the animal, can be detected using a colorimetric sensor [43]-[46]. Progesterone assay, from a minimal volume of milk taken during milking, can show the presence of heat and/or pregnancy in the buffalo. From these considerations, it is evident the amount of important data that the robot is able to collect. Data are subsequently recorded, processed, and stored by special management software, equipped with increasingly intuitive interfaces that can provide the farmer with both detailed information about the individual animal and summary reports. In this way, farmers can have at his disposal an evolved information system, which, appropriately adapted to the herd’s characteristics, allows them to focus attention on any critical issues, providing useful support for barn management choices. The milking cluster or individual teat cups are applied to the buffalo by means of a robotic arm, also known as an end-effector, which is available in two different types: the milking cluster is located at the end of the end-effector and the teat cups are applied to the buffalo in close succession; the end-effector picks up the teat cups one by one from a special storage unit (rack) and applies them individually to the buffalo’s udder. The movements of the robotic arm must be quick, precise and quiet; therefore, they are performed by electric motors and/or pneumatic or hydraulic actuators. In the case of hydraulic actuators, the AMS is equipped with a hydraulic pump built into the unit, while in the case of pneumatically actuated ones, an external (usually spiral) air compressor is provided. At the end of milking and before the next buffalo enters, the liners are washed with hot water, and in some cases sanitized by insufflation of pressurized steam at over 120°.

The most sophisticated, and probably the most important subsystem, is the vision system for teat detection: in fact, the speed, the accuracy, and the reliability of the robot during the preliminary phase of approaching the animal and attaching the milking cluster largely depend on the guidance provided by the vision systems. Such systems must be able to detect the position of the udder relative to the robot’s reference system, locate the position of individual teats, and follow the animal’s movements and the resulting teat movements, taking into account that teat position varies, in fact, not only from one animal to another, but also between successive milkings of the same animal. In most AMSs, this has led to the subdivision of the teat position detection operation into two stages: an initial coarse localization required to allow for rapid approach of the manipulator to the working area, followed by a fine localization aimed at detecting the position of individual teats with sufficient accuracy to ensure correct insertion of the sheath on the teat.

The use of an innovative, higher-performance vision system is precisely what most characterizes the evolution between the older robot model (the DeLaval Classic) and the newer one (the DeLaval VMS 300), whose performance is compared in this paper. The DeLaval Classic, shown in Figure 1 a), uses a vision system based on image processing generated by a digital camera and lasers sensors. When a buffalo enters the AMS for the first time, the coordinates of its teats must be detected and stored by the control system. This procedure is semi-automatic, meaning that it must be performed with the assistance of an operator. Initially, the robot arm moves to an initial position under the buffalo; using the supplied joystick, the operator gently moves the robot arm to bring the actuator closer to the nipple until the red laser beam is visible near the tip of the nipple. Once the

a)

b)

Figure 1. a) DeLaval Classic, b) DeLaval VMS 300.

position is confirmed, if the determination is positive, the robot arm moves away. The procedure should then be repeated for all other nipples. When the position of all nipples has been determined, the robot arm moves to the parking position and the nipple positions are saved in the DeLaval Classic database. Buffaloes that go into new lactation after calving often have changed udder shapes. The position of each teat must be determined again before the buffaloes are successfully milked again; the effort for the operator is therefore considerable in training. In addition, the system is sensitive to the presence of dirt and moisture [47].

As for the vision system in the DeLaval VMS 300 (Figure 1 b)), it consists of a 3-D time-of-flight (Time-of-Flight-TOF) camera for teat detection. The time-of-flight camera is an instrument that enables real-time estimation of the distance between the camera and the framed objects or scene by measuring the time it takes for a light pulse in the infrared spectrum to travel the camera-object-camera path (time-of-flight). The scene is then fully captured in the same way as for a photo, but the distance measurement is taken independently on each pixel, thus enabling 3D reconstruction of the measured object or scene. In this context the synchronization among the signals triggering the equipment hardware components is key factor [48]-[49]. It should be remembered, however, that infrared light does not contain any of the colours visible to our eye, so the image that the vision sensors detect, will only be black/white.

Each pixel that reflects the image forms a grey scale and thus determines the distance of the object. The image that is produced by the camera is a 3D point cloud-like creation. This technique thus stands as an alternative to 3D laser scanners, which instead scan the scene one line at a time. The main advantage of this technique is that no teaching of the udder is required, but the

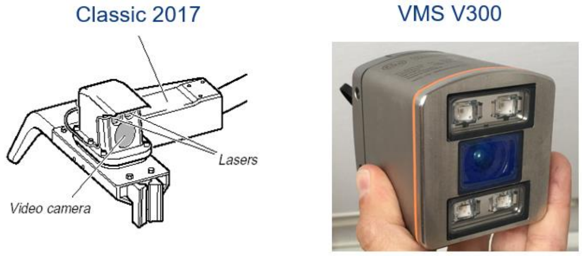

Figure 2. Vision systems in the DeLaval Classic model (*left*) and VMS 300 model (*right*).

coordinates are learned directly from the camera at the entrance of the buffalo.

This allows for increased attachment rate, reduced animal stress, reduced management time and cost by increasing the performance of the VMS300 model compared to the Classic model (Figure 2). In this regard, the newer model no longer has a joystick for the operator.

3. COMPARATIVE PERFORMANCE ANALISYS

The comparative performance analysis involved two different generations of AMSs, namely Classic and VMS300. The trial lasted between June and December 2020. A total of 315 lactating buffaloes were assigned to two groups homogenous for days in milk (157.72 ± 2.90 and 158.94 ±.2.95 DIM respectively for VMS and classic) and parity (2.43 ± 0.08 and 2.47 ± 0.08, respectively for VMS and classic), and they were milked by either the classic or the VMS 300 system.

The quality and quantity parameters of individual milk were recorded monthly in line with the official samplings, the operating parameters of the two robots were recorded daily from June to December 2020. Statistical analyses were carried out using SPSS (28.0) for Windows 10 [50].

The groups were compared in terms of quality and quantity of milk and operating parameters of milking systems by analysis of variance (ANOVA, generalized linear mixed model). The month and the day were the repeated measures, the generation of the automatic milking system and the animals were the fixed and random effects respectively.

Data are presented as mean ± deviation error. A statistical significance was accepted at $p < 0.05$. As reported in Table 1, the buffaloes milked by the VMS 300 showed higher milk yield (kg) per day (8.75 ± 0.12 vs 7.11 ± 0.12) and per lactation (1683.49 ± 29.11 vs 1544.86 ± 29.53). Similarly, buffaloes milked by the VMS produced higher ($P < 0.01$) effective fat (115.76 ± 2.22 kg) and protein (76.51 ± 1.35 kg) content than the classic group (106.07 ± 2.25 and 70.38 ± 1.37, respectively, for fat and protein content).

In Table 2 are showed the operating parameters of the two milking systems. The total conductivity of milk was calculated from conductivity of foremilk of individual udder quarters and differed between the two groups (6.51 ± 0.02 vs 9.62 ± 0.02 mS/cm respectively for VMS 300 and classic system). Finally, the buffaloes milked by VMS 300 had higher total flow peaks than those milked by the classic system (1.51 ± 0.00 vs 1.33 ± 0.00 respectively).

Table 1. Comparison in terms of quality and quantity of milk and operating parameters of milking systems by analysis of variance (ANOVA, generalized linear mixed model).

Parameters	Milking System	Mean	Error Deviation	P
Milk yield (kg/die)	VMS300	8.75	0.12	0.000
	Classic	7.11	0.12	
Fat content (%/die)	VMS300	7.98	0.10	0.404
	Classic	8.09	0.10	
Protein content (%/die)	VMS300	4.88	0.03	0.354
	Classic	4.91	0.03	
Somatic cell count (die)t	VMS300	89.27	7.60	0.669
	Classic	93.89	7.71	
Milk yield (kg/milking)	VMS300	1683.49	29.11	0.001
	Classic	1544.86	29.53	
Fat content (effective production, kg)	VMS300	115.76	2.22	0.002
	Classic	106.07	2.25	
Protein content (effective production, kg)	VMS300	76.51	1.35	0.001
	Classic	70.38	1.37	
Effective milk yield (kg/die)	VMS300	10.90	0.09	0.000
	Classic	9.91	0.09	
Mature equivalent milk yield (kg)	VMS300	2642.94	17.24	0.000
	Classic	2423.66	17.48	
Mature equivalent fat content (kg)	VMS300	199.05	1.20	0.000
	Classic	183.62	1.22	
Mature equivalent protein content (kg) Equations	VMS300	119.66	0.77	0.000
	Classic	110.22	0.78	

Pairwise comparison between VMS 300 (n = 428) and Classic (n = 416) robots
The mature equivalent yields are adjusted to that of a mature buffalo

Table 2. Operating parameters of the two milking systems.

Parameters	Milking System	Mean	Error Deviation	P
Udder milk flow	VMS300	1.508	0.003	0.000
	Classic	1.330	0.003	
Conductivity	VMS300	6.515	0.022	0.000
	Classic	9.622	0.021	
Flow peaks	VMS300	2.911	0.005	0.000
	Classic	2.679	0.005	
Milk yield	VMS300	4.204	0.011	0.000
	Classic	3.925	0.011	

Pairwise comparison between VMS 300 (n = 19331) and Classic (n = 21304) robots
The udder parameters have been calculated as sum of the individual quarters' values

4. CONCLUSIONS AND FUTURE PERSPECTIVES

Based on the comparative performance analysis between the VMS 300 and Classic Automatic Milking Systems, it can be concluded that the buffaloes milked by the VMS 300 system produced significantly higher milk yields per day and per lactation, as well as higher effective fat and protein content than those milked by the Classic system. In addition, the VMS 300 system also showed a lower total conductivity of milk and higher total flow peaks. These results suggest that the VMS 300 system could be a more efficient and effective option for milking buffaloes than the Classic system. However, further research is needed to confirm these findings, as well as to evaluate the economic feasibility of implementing the VMS 300 system in a commercial buffalo farm. Future developments could focus on comparing the performance of the VMS 300 system with other automatic milking systems, as well as investigating the effects of different management practices and environmental conditions on the milking efficiency and milk quality of buffaloes. This could help to optimize the milking process and improve the overall productivity and profitability of buffalo farming.

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REFERENCES

[1] J. A. Hogenboom, L. Pellegrino, A. Sandrucci, V. Rosi, P. D'Incecco, Invited review: Hygienic quality, composition, and technological performance of raw milk obtained by robotic milking of cows, Journal of Dairy Science 102(9) 2019, pp. 7640-7654.
DOI: 10.3168/jds.2018-16013S

[2] C. Tse, H. W. Barkema, T. J. DeVries, J. Rushen, E. A. Pajor, Effect of transitioning to automatic milking systems on producers' perceptions of farm management and cow health in the Canadian dairy industry, Journal of Dairy Science 100(3) 2017, pp. 2404-2414.
DOI: 10.3168/jds.2016-11521

[3] M. Sannino, S. Faugno, M. Crimaldi, A. Di Francia, L. Ardito, F. Serrapica, F. Masucci, Effects of an automatic milking system on milk yield and quality of Mediterranean buffaloes, Journal of Dairy Science 101(9) 2018, pp. 8308-8312.
DOI: 10.3168/jds.2017-14157

[4] M. Caria, F. M. Tangorra, S. Leonardi, V. Bronzo, L. Murgia, A. Pazzona, Evaluation of the performance of the first automatic milking system for buffaloes, Journal of Dairy Science 97(3) 2014, pp. 1491-1498
DOI: 10.3168/jds.2013-7385

[5] H. D. A. Cordova, D. R. M. Alessio, L. L. Cardozo, A. Thaler Ne to, Impact of the factors of animal production and welfare on robotic milking frequency, Pesq. agropec. bras. 53(2) 2018, pp. 238-246.
DOI: 10.1590/s0100-204x2018000200013

[6] H. W. Barkema, M. A. G. von Keyserlingk, J. P. Kastelic, T. J. G. M. Lam, C. Luby, J. P. Roy, S. J. LeBlanc, G. P. Keefe, (+1 more author), Invited review: Changes in the dairy industry affecting dairy cattle health and welfare, Journal of Dairy Science 98(11) 2015, pp. 7426-7445
DOI: 10.3168/jds.2015-9377

[7] J. M. Siewert, J. A. Salfer, M. I. Endres, Milk yield and milking station visits of primiparous versus multiparous cows on automatic milking system farms in the Upper Midwest United States, Journal of Dairy Science 102 (2019), pp. 3523-3530.
DOI: 10.3168/jds.2018-15382

[8] DeLaval Solutions. Online [Accessed 25 November 2023].
https://www.delaval.com/it

[9] C. Kamphuis, B. Dela Rue, S. A. Turner, S. F. Petch, Devices used by automated milking systems are similarly accurate in estimating milk yield and in collecting a representative milk sample compared with devices used by farms with conventional milk recording, Journal of Dairy Science 98(5) 2015, pp. 3541-3557.
DOI: 10.3168/jds.2014-8714

[10] A. Bria, G. Cerro, M. Ferdinandi, C. Marrocco, M. Molinara, An IoT-ready solution for automated recognition of water contaminants, Pattern Recognition Letters 135 (2020), pp. 188-195.
DOI: 10.1016/j.patrec.2020.04.019

[11] E. Garone, et. al., Clock synchronization for wireless sensor network with communication delay, Proc. of the American Control Conf., art. no. 6579929, pp. 771-776.
DOI: 10.1109/acc.2013.6579929

[12] P. Daponte, F. Lamonaca, F. Picariello, L. De Vito, G. Mazzilli, I. Tudosa, A Survey of Measurement Applications Based on IoT, Proc. of IEEE Int. Workshop on Metrology for Industry 4.0 and IoT, Brescia, Italy, 16-18 April 2018, pp. 1-6.
DOI: 10.1109/METROI4.2018.8428335

[13] G. Cerro, L. Ferrigno, M. Laracca, F. Milano, P. Carbone, A. Comuniello, A. De Angelis, A. Moschitta, An accurate localization system for Nondestructive testing based on magnetic measurements in quasi-planar domain, Measurement, vol. 139, June 2019, pp. 467-474.
DOI: 10.1016/j.measurement.2019.03.022

[14] C. Scuro, F. Lamonaca, S. Porzio, G. Milani, R. S. Olivito, Internet of Things (IoT) for masonry structural health monitoring (SHM): Overview and examples of innovative systems, Construction and Building Materials 290 (2021), pp. 1-17.
DOI: 10.1016/j.conbuildmat.2021.123092

[15] C. Scuro, R. S. Olivito, F. Lamonaca, D. L. Carnì, C. Angotti, Seismic analysis of an ancient masonry palace through two simplified numerical methods, International Journal of Masonry Research and Innovation 8(1), January 2023, pp. 1-29.
DOI: 10.1504/IJMRI.2023.127492

[16] I. Tudosa, F. Picariello, E. Balestrieri, L. De Vito, F. Lamonaca, Hardware Security in IoT era: the Role of Measurements and Instrumentation, Proc. of the IEEE Int. Workshop on Metrology for Industry 4.0 and IoT, Naples, Italy, 4-6 June 2019, pp. 285-290.
DOI: 10.1109/METROI4.2019.8792895

[17] L. Angrisani, A. Amodio, P. Arpaia, M. Asciolla, A. Bellizzi, F. Bonavolontà, R. Carbone, E. Caputo, (+ 9 more authors), An innovative air quality monitoring system based on drone and IoT enabling technologies, Proc. of the IEEE Int. Workshop on Metrology for Agriculture and Forestry (MetroAgriFor), Portici, Italy, 24-26 October 2019, pp. 207-211.
DOI: 10.1109/MetroAgriFor.2019.8909245

[18] V. Nastro, D. L. Carnì, A. Vitale, F. Lamonaca, M. Vasile, Passive and active methods for Radon pollution measurements in historical heritage buildings, Measurement, vol. 114, January 2018, pp. 526-533.
DOI: 10.1016/j.measurement.2016.09.002

[19] L. Angrisani, F. Bonavolontà, A. Tocchi, R. Schiano Lo Moriello, Frequency domain measurement node based on compressive sampling for sensors networks, IEEE Int. Workshop on Measurements Networking (MN), Coimbra, Portugal, 12-13 October 2015, pp. 1-5.
DOI: 10.1109/IWMN.2015.7322972

[20] G. Iadarola, S. Spinsante, L. De Vito, F. Lamonaca, A support for signal compression in living environments: the Analog-to-Information Converter, Proc. of IEEE Int. Workshop on Metrology for Living Environment, MetroLivEn 2022, Cosenza, Italy, 25-27 May 2022, pp.292-297.
DOI: 10.1109/MetroLivEnv54405.2022.9826923

[21] L. De Vito, G. Iadarola, F. Lamonaca, F. Picariello, S. Rapuano, I. Tudosa, Non-uniform wavelet bandpass sampling Analog-to-Information Converter: a hardware implementation and its experimental assessment, Measurement 134 (2019), pp. 739-749.
DOI: 10.1016/j.measurement.2018.11.015

[22] M. Carratù, V. Gallo, V. Paciello, IEEE 1451: Communication among smart sensors using MQTT protocol, 2022 IEEE International Symposium on Measurements Networking (MN), Padua, Italy, 18-20 July 2022, pp.1-6.
DOI: 10.1109/MN55117.2022.9887708

[23] G. Patrizi, A. Bartolini, L. Ciani, V. Gallo, P. Sommella, M.Carratù, A virtual soil moisture sensor for smart farming using deep learning, IEEE Transactions on Instrumentation and Measurement 71 (2022), art no. 2515411.
DOI: 10.1109/TIM.2022.3196446

[24] J. F. Penry, Mastitis control in automatic milking systems, veterinary clinics of North America: food animal practice 34(3) (2018), pp. 439-456.
DOI: 10.1016/j.cvfa.2018.06.004

[25] M. Khatun, P. C. Thomson, K. L. Kerrisk, N. A. Lyons, C. E. F. Clark, J. Molfino, S. C. García, Development of a new clinical mastitis detection method for automatic milking systems, Journal of Dairy Science 101(10) 2018, pp. 9385-9395.
DOI: 10.3168/jds.2017-14310

[26] I. Lusis, V. Antane, A. Laurs, Effectiveness of mastitis detection index for cow monitoring and abnormal milk detection in milking robots, 2017.
DOI: 10.22616/ERDev2017.16.N314

[27] M. Hovinen, S. Pyörälä, Invited review: Udder health of dairy cows in automatic milking, Journal of Dairy Science 94(2) 2011, pp. 547-562.
DOI: 10.3168/jds.2010-3556

[28] C. Kamphuis, R. Sherlock, J. Jago, G. Mein, H. Hogeveen, Automatic detection of clinical mastitis is improved by in-line monitoring of somatic cell count, Journal of Dairy Science 91(12) 2008, pp. 4560-4570.
DOI: 10.3168/jds.2008-1160

[29] J. Rodenburg, Robotic milking: Technology, farm design, and effects on work flow, Journal of Dairy Science 100(9) 2017, pp. 7729-7738,
DOI: 10.3168/jds.2016-11715

[30] M. Kuczaj, A. Mucha, A. Kowalczyk, R. Mordak, E. Czerniawska-Piatkowska, Relationships between selected physiological factors and milking parameters for cows using a milking robot, Animals 10(11) 2020, art. No. 2063.
DOI: 10.3390/ani10112063

[31] B. G. Hansen, H. O. Herje, e J. H ̈ova, Profitability on dairy farms with automatic milking systems compared to farms with conventional milking systems, International Food and Agribusiness Management Review 22(2) 2019, pp. 215-228.
DOI: 10.22434/IFAMR2018.0028

[32] U. Drach, I. Halachmi, T. Pnini, I. Izhaki, A. Degani, Automatic herding reduces labour and increases milking frequency in robotic milking, Biosystems Engineering 155 (2017), pp. 134-141.
DOI: 10.1016/j.biosystemseng.2016.12.010

[33] G. de Alteriis, A. T. Silvestri, C. Conte, V. Bottino, E. Caputo, A. Squillace, D. Accardo, R. Schiano Lo Moriello, Innovative Fusion Strategy for MEMS Redundant-IMU Exploiting Custom 3D Components, Sensors 23(5) 2023, art. no. 2508.
DOI: 10.3390/s23052508

[34] F. Gargiulo, A. Liccardo, R. Schiano Lo Moriello, A Non-Invasive Method Based on AI and Current Measurements for the Detection of Faults in Three-Phase Motors, Energies 15(12) 2022, art. no. 4407
DOI: 10.3390/en15124407

[35] D. L. Carnì, F.Lamonaca, Toward an automatic power quality measurement system: an effective classifier of power signal alterations, IEEE Transactions on Instrumentation and Measurement 71 (2022), pp. 1-8.
DOI: 10.1109/TIM.2022.3192258

[36] G. De Alteriis, C. Conte, E. Caputo, P. Chiariotti, D. Accardo, A. Cigada, R. Schiano Lo Moriello, Low-cost and high-performance solution for positioning and monitoring of large structures, Sensors 22(5) (2022), art. no. 1788,
DOI: 10.3390/s22051788

[37] F. Lamonaca, A. Carrozzini, D. Grimaldi, R. S. Olivito, Improved monitoring of acoustic emissions in concrete structures by multi-triggering and adaptive acquisition time interval, Measurement 59 (2015), pp. 227-236.
DOI: 10.1016/j.measurement.2014.09.053

[38] G. Siracusano, F. Garescì, G. Finocchio, R. Tomasello, F. Lamonaca, (+ 5 more authors), Automatic crack classification by exploiting statistical event descriptors for deep learning, Applied Sciences 11(24) 2021, art. no. 12059.
DOI: 10.3390/app112412059

[39] A. Aubry, V. Carotenuto, A. De Maio, A. Farina, A. Izzo, R. Schiano Lo Moriello, Assessing power amplifier impairments and digital predistortion on radar waveforms for spectral coexistence, IEEE Transactions on Aerospace and Electronic Systems 58(1) 2022, pp. 635-650.
DOI: 10.1109/TAES.2021.3103712

[40] C. Conte, G. de Alteriis, R. Schiano Lo Moriello, D. Accardo, G. Rufino, Drone trajectory segmentation for real-time and adaptive time-of-flight prediction, Drones 5(3) 2021, art. no. 62.
DOI: 10.3390/drones5030062

[41] G. de Alteriis, D. Accardo, C. Conte, R. Schiano Lo Moriello, Performance enhancement of consumer-grade mems sensors through geometrical redundancy, Sensors 21(14) 2021, art. no. 4851.
DOI: 10.3390/10.3390/s21144851

[42] P. Daponte, C. De Capua, A. Liccardo, A technique for remote management of instrumentation based on Web Service, 13th IMEKO TC4 Symposium on Measurements for Research and Industrial Applications 2014, Held Together with the 9th Workshop on ADC Modeling and Testing, pp. 657-662. Online [Accessed 25 November 2023]
https://www.imeko.org/publications/tc4-2004/IMEKO-TC4-2004-122.pdf

[43] A. Baccigalupi, M. D'Arco, A. Liccardo, M. Vadursi, Test equipment for DAC's performance assessment: Design and characterization, IEEE Transactions on Instrumentation and Measurement 59(5) 2010, art. no. 5433055, pp. 1027-1034.
DOI: 10.1109/TIM.2010.2041019

[44] A. Liccardo, F. Bonavolontà, R. Schiano Lo Moriello, F. Lamonaca, (+ 4 more authors), Digital twins based on augmented reality of measurement instruments for the implementation of a cyber-physical system, Acta IMEKO 11(4) 2022, pp. 1-8.
DOI: 10.21014/actaimeko.v11i4.1397

[45] A. Baccigalupi, C. De Capua, A. Liccardo, Overview on development of remote teaching laboratories: From lab VIEW to Web Services, Proc. of the IEEE Instrumentation and Measurement Technology Conf., 24-27 April 2006, art. no. 1700321, pp. 992-997.
DOI: 10.1109/IMTC.2006.236946

[46] C. De Capua, A. Liccardo, R. Morello, On the Web service-based remote didactical laboratory: Further developments and improvements, proc. of IEEE Instrumentation and Measurement Technology Conference, 2005, art. no. 1604458, pp. 1692-1696,
DOI: 10.1109/IMTC.2005.1604458

[47] D.L. Carnì, D.Grimaldi, F.Lamonaca, Preprocessing correction for micronucleus image detection affected by contemporaneous alterations, IEEE Transactions on Instrumentation and Measurement 56(4) (2007), pp. 1202-1211.
DOI: 10.1109/TIM.2007.900160

[48] F. Lamonaca, D. Grimaldi, R. Morello, A. Nastro, Sub-µs synchronization accuracy in distributed measurement system by PDA and PC triggers realignement, Proc. of the IEEE Instrumentation and Measurement Technology Conf., Minneapolis, MN, USA, 6-9 May 2013, pp.801-806.
DOI: 10.1109/I2MTC.2013.6555525

[49] F. Lamonaca, D. Grimaldi, Trigger realignment by networking synchronized embedded hardware, IEEE Transactions on Instrumentation and Measurement 62(1) (2013), pp. 38-49.
DOI: 10.1109/TIM.2012.2218058

[50] IBM, Downloading IBM SPSS Statistics 28.0.1.0. Online [Accessed 25 November 2023]
https://www.ibm.com/support/pages/downloading-ibm-spss-statistics-28010