Radar-based evaluation of lameness detection in ruminants: preliminary results

Francesco Fioranelli(1), Haobo Li(1), Julien Le Kernec(1),
Valentina Busin(2), Nicholas Jonsson(2), George King(2), Martin Tomlinson(2), Lorenzo Viora(2)
(1)*School of Engineering,* (2)*School of Veterinary Medicine*
University of Glasgow
Glasgow, UK
francesco.fioranelli@glasgow.ac.uk

***Abstract*—This paper presents preliminary results on using radar systems and micro-Doppler signatures to evaluate lameness in ruminants. Lameness is regarded as a major welfare and economic problem for animals such as cattle and sheep. As evaluation methods are typically based on time-consuming, subjective scoring by trained veterinary clinicians, there is scope for automatic methods that can improve repeatability and reliability. Our initial results on a relatively large sample of 51 dairy cows and 75 sheep show promising performance, with accuracy above 80% for cows and above 90% for sheep in the most favorable cases.**

Keywords—radar micro-Doppler, spectrograms, supervised learning, lameness sensing, veterinary radar applications

I. INTRODUCTION

Radar micro-Doppler has been proposed for a variety of applications to classify movements, gestures, activities, and gait of humans [1-2], thanks to its capability to capture the pattern of small modulations generated on the received radar signals by the movement of limbs, torso, hands, feet. Micro-Doppler signatures of animals have been analysed in the literature [3-4], but often only as sources of false alarms for potential misclassification of humans in the context of border control and ground-surveillance radar.

In this paper, we present preliminary results on the use of radar micro-Doppler signatures to evaluate lameness in ruminants, specifically dairy cows and sheep. The assumption is that lame animals will move differently from healthy ones, and that the different movement patterns of their limbs can be inferred from the radar signatures. Lameness is a significant problem for farmed animals, both in terms of welfare of the animals involved, and economic cost of the treatment and production loss [5-6]. The most common method to evaluate lameness in veterinary practice is by subjective visual scoring, with clinicians on site at farms observing the animals under test scoring them. between 0 (no lameness) and 3 (severe lameness). Although this approach offers an immediate assessment without the need of specialised equipment deployed on farm, issues of repeatability and reliability exist [7]. Furthermore, this approach is time-consuming, requiring trained veterinary clinicians on site to perform the assessment.

Hence, more objective and automatic methods have been proposed for lameness and gait abnormalities evaluation, such as inertial sensors, force plates, tracking systems using cameras. The interest in radar technology for lameness evaluation in farm environment is related to its contactless sensing capabilities (no sensors need to be attached to the animals under test), as well as insensitivity to light and or weather conditions (day/night, fog, rain) which can be an advantage for deployment in farms. Very preliminary results on lameness evaluation using radar were presented by our group in [8] with a rather limited group of animals. In this paper, we expand that investigation considering a relatively large group of animals (51 dairy cows and 75 sheep) and a larger set of features extracted from the radar data. The results appear promising, with accuracy above 80% for dairy cows and above 90% for sheep in the most favourable cases. It should be noted that automatic evaluation of lameness in ruminants is a challenging task, accounting for the unpredictable behaviour of the animals under assessment (e.g. stop&go behaviour, sudden acceleration or deceleration), as well as the inevitable uncertainties in the labels provided for ground-truth by visual scoring.

II. EXPERIMENTAL SETUP AND DATA COLLECTION

The data analysed in this paper were collected at the Cochno Farm, of the University of Glasgow in summer 2018. The measurements were performed with a commercial off-the-shelf Frequency Modulated Continuous Wave (FMCW) radar sensor, Ancortek SDR 580-B, operating at 5.8 GHz in C-band. The radar transmits linear chirp signals with 400 MHz of instantaneous bandwidth at 1 kHz PRF (Pulse Repetition Frequency), and about 100 mW of power. The radar system had two antennas, one for the transmitter and one for the receiver, placed close to each other at approximately 30-50 cm distance. The antennas were Yagi, with approximately 17 dB of gain. The antennas were placed on tripods and directed towards the areas where the animals were moving one at a time, namely a corridor leading to milk parlour for cows, and a gated running race for the sheep.

During the measurements, individual animals were recorded walking away from the radar, i.e. showing their hind limbs to the radar. A trained veterinary clinician was present during each measurement and provided "ground truth data" by scoring each animal on a lameness scale 0 to 3. Lower scores 0 to 1 are associated to healthy gait or very mild signs of lameness, whereas higher scores 2 to 3 are associated to signs of lameness that the animal showed while walking. For these preliminary results, the classification problem was cast as a binary classification, lame (score 1-2-3) vs non-lame (score 0). This initial level of discrimination, albeit coarse, can be useful in practical scenarios where an automatic system could help veterinary clinicians and farmers to pre-screen their animals and concentrate time and resources on the cases with suspected lameness. In total, we have collected data for 51 dairy cows (of which 31 labelled as lame) and for 75 sheep (of which 25 were labelled as lame). On average longer recordings were collected for cows than for sheep, as cows were slower and walked along a longer straight trajectory (about 20 m of milk parlour and a few meters of sheep race). Furthermore, cows are instinctively animals of habit and are used to walk along the parlour individually when milked during their normal routine. Sheep conversely tend to stay together in the flock; therefore arranging the setup and measurement protocol to have them go through the gate individually is more difficult.

III. Data processing and data analysis results

The data were processed using Short Time Fourier Transform (STFT) to extract micro-Doppler signatures. Examples of range-time plots and spectrograms for a dairy cow and a sheep are shown in Figure 1, with spectrograms generated with a 0.3s Hamming window and 95% overlap. The use of spectrograms for human micro-Doppler applications has been extensively investigated [1-2], but its applications to the domain of animal welfare for detection and diagnostic of lameness in farmed animals is to the best of our knowledge novel, with only our previous works in literature with very preliminary results on a small sample of dairy cows, sheep, and horses [8].

Each spectrogram was divided into segments of different duration, namely 1.5s, 3s, and 5s to extract feature samples to be used in supervised learning classification. The different durations were considered to investigate how long it takes to identify features in the radar signature that may be related to lameness, a practical constraint for deployment in real farms. To summarise, for each cow 5 segments of 5s duration, 7 segments of 3s duration and 14 segments of 1.5s duration were considered. For each sheep, we had 2 segments of 5s duration, 3 segments of 3s duration, and 6 segments of 1.5s duration. Fewer segments are available for sheep compared to cows, as sheep were quicker and their race area shorter, hence less time to capture the radar signature.

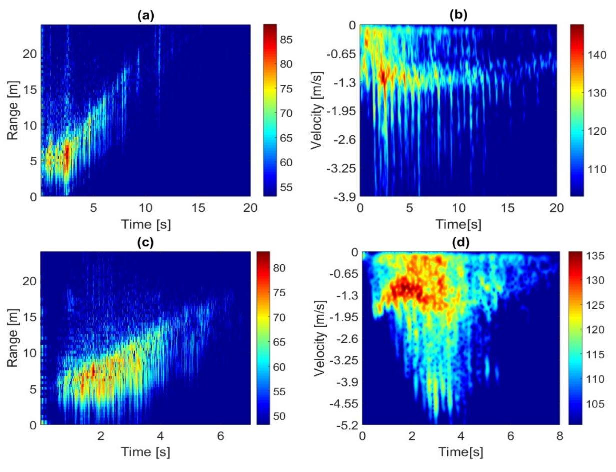

Fig. 1. Radar Range-Time-Intensity plots for a cow (a) and a sheep (c), and related spectrograms showing the micro-Doppler signature for the cow (b) and the sheep (d)

A. Features extraction and classification approach

Many features have been proposed to analyse and classify human gait and activities using radar [9]. Here we considered only 20 simple features related to the statistical moments of the centroid and bandwidth of the micro-Doppler signature, and to its Singular Value Decomposition (SVD). Both approaches have provided in the past good results for classification of human micro-Doppler signatures. These features included mean, standard deviation, skewness, and kurtosis of the centroid and bandwidth of the signature; two-dimensional mean, standard deviation, skewness, and kurtosis of the whole segment of spectrogram interpreted as a matrix of pixels; mean and standard deviation of the first right and the first left eigenvector of the SVD of the segment of spectrogram; the sum of pixels of the entire left and right SVD matrices, U and V, and the mean of their diagonal.

Samples from these 20 features were extracted for every segment of spectrogram, followed by feature ranking and selection based on the T-test criterion [9]. The 8 highest-ranked features were then selected and all their possible combinations (255 in total) were tested with a wrapper approach as input to the classification algorithms. The best result, i.e. the one providing highest accuracy, out of all the 255 combinations was considered and used for the results' section in this paper. Labels of "lame" or "non-lame" were given to each sample based on the lameness score as mentioned in section II. Two classifiers were considered in this work for their simplicity, the Nearest Neighbour with 3 neighbours (KNN) and Naïve Bayes (NB) classifier. They were trained and tested with a "leave-out approach", whereby data from each individual animal were used for testing, separated from the rest of the dataset used for training. This aims to imitate scenarios in which the classifier is presented with unknown animals, whose samples were not included in the training dataset, for example when a pre-trained classifier is deployed for the first time in a new farm.

B. Results and discussion

Table I shows a compact summary of these initial results for the case of NB classifier with 3s spectrograms segments for feature extraction, for dairy cows and sheep. The results are in the form of confusion matrix, comparing the prediction from the radar-based system with the score assigned by veterinary clinicians. The average accuracy is approximately 82% for dairy cows and 93% for sheep; in the former case there is a relatively high rate of missed detection (about 20% of cases scored as lame were classified as not-lame by the radar). This is a concern for the effectiveness of the method, and further work is being carried out to assess the causes of these missed detections. Cases of mild lameness scored with 1 by veterinary clinicians are difficult to distinguish from non-lame cases, given the short observation time available especially when assessing sheep. So validating the proposed automatic radar-based classification is challenging, as the current ground-truth methods based on scores assigned by human personnel can be also biased and inaccurate. Further results are shown in table II for dairy cows and sheep. The average true positives (actual lame animals predicted as lame) and average true negatives (actual non-lame animals predicted as non-lame) are shown as a function of the two classifiers and the duration of the spectrogram segments used for feature extraction. The average is calculated across all the segments for all animals considered as testing samples with the leave-out approach described in the previous section. Performance appears to change significantly across classifiers and duration of segments, but are promising accounting for the uncertainties in labelling of the ground-truth data and inherent challenges of this particular application. An interesting trend is the increased accuracy for shorter duration of segments for the NB classifier for sheep. In general, NB appears to provide better results than KNN (with the limit case of very low accuracy, 43%, for the KNN with 5s segments for dairy cows).

A final set of results considers the effect on the classification performance of different duration of the STFT windows. As mentioned in section II, the results presented so far originated from STFT with 300 ms Hamming windows. In Figure 2 we summarise results considering also shorter (150 ms) and longer (450, 600, and 750 ms) windows. The average classification accuracy is reported, i.e. the average of true positives and true negatives for lameness for all animals' data used at testing stage. The duration of the STFT window affects the time and Doppler resolution of the spectrograms, and in turn the quality and suitability of the feature extracted. For dairy cows, longer windows (600-700ms) with short dwell time (1.5s) provide the best results, with accuracy of approximately 87%. For sheep, shorter STFT windows (150-300ms) are the most suitable choice, with accuracy above 95% in the most favourable cases. This may be related to the different kinematics of the two animals, with sheep walking (on average) faster and with shorter steps than cows, hence requiring matched, shorter windows to capture their time-velocity patterns. On average, for dairy cows better results are obtained with shorter dwell time given a certain STFT window duration, whereas for sheep this is only true for the short STFT windows of 150ms and 300ms. Further analysis will help optimise these two parameters. Dwell time may be constrained in practice by the size and shape of the specific farm environment (e.g. length of the milk parlour), so optimal STFT parameters may be chosen and adapted to each specific scenario.

TABLE I. SUMMARY CLASSIFICATION RESULTS FOR NB CLASSIFIER, 3S SPECTROGRAM SEGMENTS DURATION

		Radar Non-lame	*Radar Lame*
Dairy Cows	*Veterinary Non-lame*	86.4	13.6
	Veterinary Lame	20.7	79.3
Sheep	*Veterinary Non-lame*	92	8
	Veterinary Lame	5.3	94.7

TABLE II. TRUE POSITIVES AND TRUE NEGATIVES FOR LAMENESS AS A FUNCTION OF DURATION OF SPECTROGRAMS FOR FEATURE EXTRACTION AND 2 CLASSIFIERS NB AND KNN

		Radar Predicted Lameness Accuracy [%] - NB			**Radar Predicted Lameness Accuracy [%] - KNN**		
		5s	**3s**	**1.5s**	**5s**	**3s**	**1.5s**
Dairy Cows	**Average True Pos**	71.6	79.3	82.5	73.6	70.9	69.6
	Average True Neg	72	86.4	73.9	43	72.9	72.1
Sheep	**Average True Pos**	84	94.7	94	84	81.3	79.3
	Average True Neg	74	92	96.3	86	83.3	79

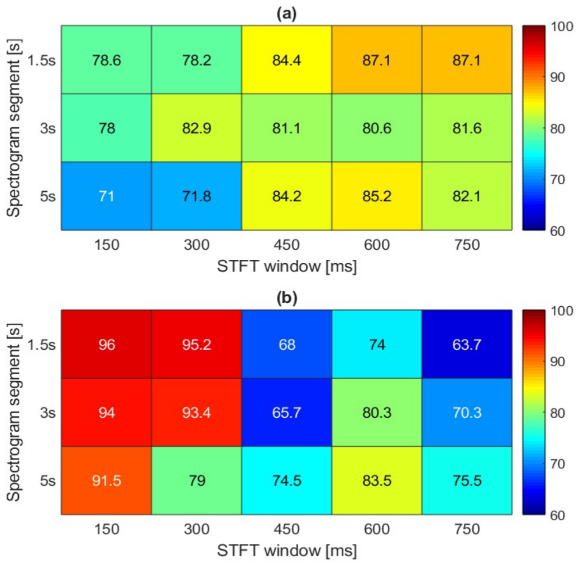

Fig. 2. Accuracy (average of true positives and true negative for lameness detection) for dairy cows (a) and sheep (b) as a function of STFT window duration and dwell time for feature extraction – NB classifier

IV. CONCLUSIONS

In this paper, we presented initial results for lameness evaluation in ruminants using radar micro-Doppler signatures. Simple features and classifiers were considered at this initial stage, using a relatively large sample of 51 dairy cows and 75 sheep at the Cochno Farm of the University of Glasgow. Promising results were obtained, with over 80% accuracy achieved for dairy cows and over 90% for sheep in the most favourable cases. Further work will validate this approach for a wider range of animals and operational parameters, including the radar location (distance, height, aspect angle, anterior/posterior view of the animals, presence of clutter from structures in the farm), the carrier frequency, spatial resolution, and polarisation of the radar. Furthermore, additional features and classification algorithms can be explored, to capture the intricate patterns of front and hind limbs movements and distinguish between different levels of lameness and identification of the affected limbs.

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REFERENCES

[1] M. G. Amin, Y. D. Zhang, F. Ahmad, and K. C. D. Ho, “Radar signal processing for elderly fall detection: The future for in-home monitoring,” *IEEE Signal Process. Mag.*, vol. 33(2), pp. 71–80, 2016.

[2] E. Cippitelli, F. Fioranelli, E. Gambi, and S. Spinsante, “Radar and RGB-depth sensors for fall detection: a review,” IEEE Sens. J., vol. 17, no. 12, pp. 3585–3604, 2017.

[3] D. Tahmoush, "Review of micro-Doppler signatures," in IET Radar, Sonar & Navigation, vol. 9, no. 9, pp. 1140-1146, 12 2015.

[4] K. Youngwook, H. Sungjae, K. Jihoon, ‘Human detection using Doppler radar based on physical characteristics of targets’, IEEE Geoscience and Remote Sensing Letters, vol. 12, pp. 289-293, 2015.

[5] Bruijnis, M. R. N., H. Hogeveen, et al. (2010). "Assessing economic consequences of foot disorders in dairy cattle using a dynamic stochastic simulation model.", *Journal of Dairy Science,* 93(6): 2419.

[6] Nieuwhof G. J. and S. C. Bishop (2005). Costs of the major endemic diseases of sheep in Great Britain and the potential benefits of reduction in disease impact. Animal Science, 81, pp 23-29.

[7] K. G. Keegan, "Objective Measures of Lameness Evaluation," in American College of Veterinary Surgeons Symposium, 2012.

[8] A. Shrestha et al., "Animal Lameness Detection With Radar Sensing," in IEEE Geoscience and Remote Sensing Letters, vol. 15, no. 8, pp. 1189-1193, Aug. 2018.

[9] S. Z. Gürbüz, B. Erol, B. Çağlıyan, B. Tekeli, 'Operational assessment and adaptive selection of micro-Doppler features', *IET Radar, Sonar & Navigation*, vol. 9 (9), p. 1196-1204, December 2015.