APPLICATION OF DOPPLER RADAR FOR WILDLIFE DETECTION IN VEGETATION*

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The objective of this paper was to test the suitability of Doppler microwave radar for the detection of wild animals hidden in grassland in front of the harvester. The ability of Doppler radar HB100 sensor to detect a dog or a human person hidden behind different types of crops was tested in laboratory conditions. Relative movement between the radar and the observed object was secured by the assembly acting as mathematical pendulum. The radar always moved in front of different crop samples (arranged in two or one line). The dog or human person was situated behind the crop. In five out of seven cases, the sensor was able to detect the human person. Only in two out of seven cases, the sensor was able to detect the dog. Nevertheless, it can be concluded that microwave radar sensor can be a useful device for detection of wild animals in the crop. Next research is needed in order to better explain the influence of disturbing factors on the measurements.

forage harvest, animals' detection, radar, sensor

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doi: 10.2478/sab-2018-0019
Received for publication on May 17, 2017
Accepted for publication on September 26, 2017

INTRODUCTION

Protection of animals and their welfare is increasingly inflected in relation to intensive economic human activities, not only in agriculture but in all sectors related to outdoor activities. Welfare is generally regarded as a consequence of the development of society and its economic condition (McInerey, 2004).

However, unlike livestock, where measures concerning the protection of animals in western countries are very specific, for wild specimens the issue is addressed in more general terms with little actual impact (Dubois, Fraser, 2013). Linell et al. (1998) highlighted that one such example of violation and disregard for the rules of proper farming and the welfare of wild animals is killing roe deer during first spring haymaking (May–June). Only in western part of Germany, more than 400 000 wild animals are killed or injured every year during spring time pasture mowing (Boostra, 1995). Everything is related to the natural course of the first days of born animals. The doe, like most deer, defers its young and returns to them only for breastfeeding. Little roe deer thus react to any kind of danger by minimizing their motion and in many cases do not run even in direct contact (Linell et al., 1998). This plays an important role in neonatal mortality caused by harvesting machines during haymaking. Death of the young is in many cases very severe, with frequent cases of cut feet and subsequent bleeding. Although great importance of

* Supported by the Internal Grant Agency of the Czech University of Life Sciences Prague (CIGA), Project No. 20163002.

mortality caused by harvesting devices has been highlighted by several authors since the 1970s (Kittler, 1979), it has started to receive more attention only recently (Gaillard et al., 1998; Jarnemo, 2004; Jarnemo, Liberg, 2005; Panzachi et al., 2009).

The possibility of game injury or death is growing with an increasing working width and speed of grass harvesting machines. It is especially the young who are endangered as their natural instinct commands them to stay in grassland (Jarnemo, 2002). That is why the current trend is to develop a system that could locate the position of the animal in front of the harvester. Besides, wildlife may be located for example by a thermal camera or microwave radar. The thermal camera works on the principle of receiving infrared radiation from surroundings (Kaplan, 2007). Unfortunately the ability of thermal cameras can be reduced for use of wild animal's detection. As published by Boostra (1995) it may be difficult or impossible to detect animals because of their feathers that have high insulate properties, which minimize the thermal differential between them and the environment. Thermal cameras can also be placed on a flying drone. Managed by the software, it can automatically scan the marked out land. The problem is to maintain a constant altitude of the drone over the ground in hilly terrain and low resolution of the camera at higher temperatures. Scanning 1 ha takes about 4 min at the altitude of 50 m above ground (Israel, 2011). Thermal cameras can also be mounted onto a tractor. With suitable temperature range setting of the thermal camera an animal is more clearly visible in the picture compared with the surrounding. Experiments have been made on the chicken in a cage and on the game. The system was able to detect a hidden animal even at speeds of 15 km h^1. The camera had the width of shot 2 m and detected the animal 5 m ahead (Steen et al., 2012).

It was also demonstrated that the Doppler radar can perform complex scanning (Biebl, 1999). The microwave Doppler radar with a frequency of 24 GHz can detect the reflection of waves from an animal thanks to the differences in water content in the animal's body and its surroundings. When passing over the animal, its reflection appears using a relatively clean signal with lower noise. As drawbacks remain too many errors in high moisture content and problems of maintaining a constant distance of the sensor from the ground (Patrovsky, Biebl, 2005).

As follows from the above literature review, early detection of the presence of an animal in front of the harvesting machine would undoubtedly be of great benefit for saving its life, especially among the young. However, this is not easy to solve. That is why the main aim of this paper is to test the suitability of Doppler radar for the detection of wild animals hidden in grassland in front of the harvester.

MATERIAL AND METHODS

The main part of the tested device was a Doppler radar HB100 from ST Electronics (transmission frequency 10.525 GHz). The radar output raw signal was amplified and received by Acer Aspire One 721 notebook sound card (through microphone input). Computer sound card enabled to record the sensor output signal (voltage) with a sampling rate of 44.1 kHz. Received data was decoded and stored in text format by computer programme written in Python (ver. 2.7).

The Doppler radar (Fig. 1a) was chosen because it continuously transmits and receives microwave radiation. That is why this type of radar can be easily used to determine the strength of the reflected signal. Nevertheless, for radar proper function it is necessary to ensure relative movement between the radar and the observed object. Sensor was hanged by two thin strings to laboratory roof beam. This assembly acted as mathematical pendulum. It was possible to provide a defined movement of the sensor, which could be used for the measurements. The length of the pendulum hanger was 4.8 m.

A dog (of Bavarian Mountain Hound breed) and/or a Ph.D. student simulated wild animal hidden in undergrowth for the aim of our experiments. The

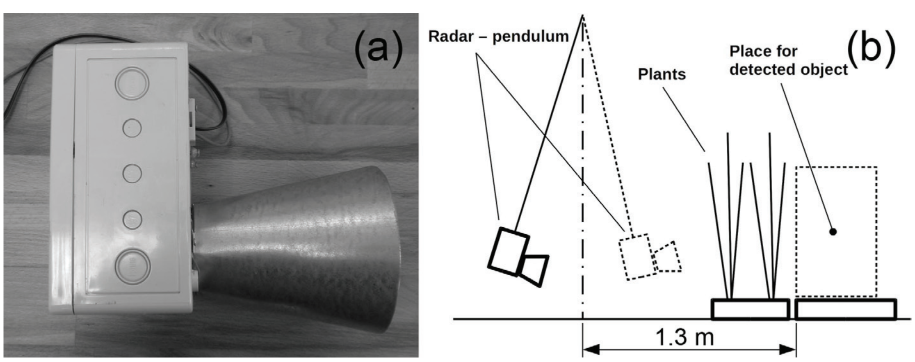

Fig. 1. Detailed view of Doppler radar sensor used for our measurements (**a**); arrangement of measuring station for our experiments (**b**)

Table 1. Combination of the crops in gardener boxes used as a simulation of different crops

Label of combination	Crop	Material moisture content, w.b. (%)
A	grass one line	40.9
B	grass two lines	40.9; 41.2
C	first line nettle, second line grass	65.4; 41.2
D	prickly lettuce one line	41.3
E	moistened prickly lettuce one line	41.3 + 200 g water
F	moistened nettle two lines	65.4; 66.8 + 400 g water
G	moistened grass two lines	40.9; 41.2 + 400 g water

dog/human was in seated position, down and behind samples of the crop. Gardener boxes with dimensions 585 mm in length, 200 mm in width, and 180 mm in height with different plants (meadow grass, nettle and prickly lettuce) were used to simulate different types of crops. The view of measuring stand arrangement is in Fig. 2. Material moisture content was determined for each particular crop according to ASABE Standard S358.2 (ASABE Standard, 2006). This standard defines the procedure of moisture measurements for forages, based on the oven drying method. For the measurements, seven types of different crops were simulated. For each simulated crop three measurements were made: without hidden object (1), with dog (2), and with student (3). In total, 21 measurements were made by this way. Six courses of sensor output signal were recorded for each particular measurement. A detailed description of simulated crops can be seen in Table 1. In order to simulate conditions with possible dew, the surface of tested crop was wetted by 200 g of water per one row for last three combinations.

Measurements arrangement was according to Fig. 1b. The pendulum was moved approximately perpendicularly to the wall formed from simulated crops. The simulated crop always formed a 1170 mm wide and at least 1 m high obstacle. The detected object was hidden behind that obstacle always at a distance of 1.3 m from the radar sensor centre position. The initial displacement of the pendulum was always 500 mm. At least six pendulum swings were recorded for each particular measurement.

Data analysis

For the data analysis, short time Fourier transformation (STFT) was used (Sejdic et al., 2009).

Fig. 2. Detailed view of measuring stand during dog detection experiment

Table 2. Compared measured values with dog and with person with the variant without hidden object; resulting P-values from paired t-test statistics

Simulated crop	Dog × without	Human person × without
A	0.355	< 0.01
B	0.151	< 0.01
C	0.955	0.075
D	< 0.01	< 0.01
E	0.148	< 0.01
F	0.959	< 0.01*
G	0.026	< 0.01

*P-value indicates that signal strength was smaller with human person than with the variant without hidden object in this case

A dominant frequency was derived from acquired time-frequency distribution. This frequency corresponded to the radar sensor speed. Local maximums were detected in the next step. Data area, in which a maximum could be assumed, was fitted by fourth degree polynomial for the maximum detection purposes. The point where this polynom reached its peak was designated as search local maximum. Such maxima corresponded to the moments when radar sensor moved at top speed and therefore found in the central position. The data in the neighbourhood of these points (± 0.1 s) was used for next evaluation. Fig. 3 shows the part of dominant frequency course and the corresponding part of the sensor output signal. Ten such defined sections were evaluated for each particular measurement. Root mean square (u_{RMS}) was calculated for each particular measurement according to the formula:

$$u_{RMS} = \sqrt{\frac{1}{n}(u_1^2 + u_2^2 + \ldots + u_n^2)} \quad (1)$$

where:
n = number of values in observed interval
u_i = radar sensor output value (V).

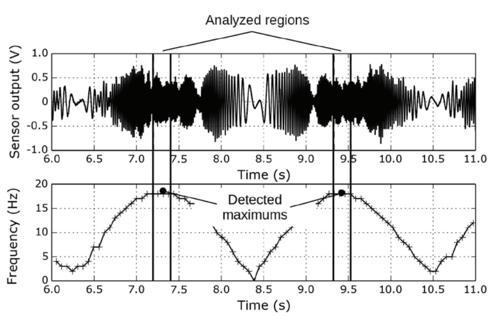

Fig. 3. Graphical view of the procedure for local maximum determination from the course of observed signal

Computer programme Python (ver. 2.7) and supporting libraries Numpy 1.8 and Scipy 0.13 were used for the data analysis.

RESULTS

The results from all our 21 measurements can be seen in Fig. 4. Various measurement combinations according to Table 1 (A, B, C, D, E, F, G) without hidden object (1), with dog (2), and with student (3) are displayed in x axis, and y axis displays the processed values of the radar sensor output signal. Calculated averages and standard deviations are plotted in this graph for each combination.

The results from the measurements with dog and with person were then statistically compared with the variant without hidden object. P-values resulting from paired t-test are provided in Table 2. These values represent the probability that compared data files are the same.

DISCUSSION

It is clear from Fig. 4 and Table 2 that in most cases it was possible to detect human person hidden behind simulated crop (P-value < 0.01). Weaker result was obtained in the variant C3. In this case, the combination of nettle crop in the first line and grass crop in the second one was tested. The resulting simulated crop was dense with a relatively high material moisture content. This caused that only small amount of signal penetrated the simulated crop and hidden person was not detected reliably. The worst result in human person detection was achieved in the

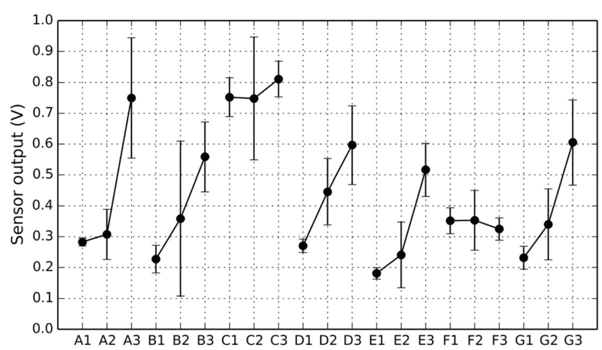

Fig. 4. Calculated averages and standard deviations of observed values from various measurement combinations: **A** – grass one line, **B** – grass two lines, **C** – first line nettle, second line grass, **D** – prickly lettuce one line, **E** – moistened prickly lettuce one line, **F** – moistened nettle two lines, **G** – moistened grass two lines without hidden object (1), with dog (2), and with student (3)

variant F3 as it is also clear from Fig. 3 and Table 2. In this case, the measured radar sensor output values were even smaller than those for the situation without hidden object (F1). The crop was simulated by two lines of moistened nettle for this measurement. It is clear that a relatively high amount of water in plants and plant surface prevented completely the successful detection in this case.

The results showed that the surface moisture does not significantly affect the signal permeability. In the case when all measurements were made under the same conditions (B and G) no significant difference between results with and without moisture on grass surface was observed.

The results obtained also showed the failure in detecting dog hidden behind simulated crop in almost all cases. Only two cases of detection (D2, G2) can be evaluated as successful (P-value < 0.05). In this case, the main problem was that it was hard to keep the dog in the desired position without moving during the measuring interval (about 21 s). This subsequently caused a great dispersion of measured values. Unfortunately, the consequences of this fact were not clear until the evaluation of measured values.

Patrovsky, Biebl (2005) reported that in the laboratory conditions and in spring-time pasture, very high reliability of detection was achieved by a 24 GHz Doppler radar. Nevertheless, the authors used fabric-covered hot-water bottle instead of live animal under both laboratory and field conditions. They reported 50% detection reliability in the case when the target was covered by plants. When comparing our results with those published, it can be concluded that our system worked with similar precision under laboratory conditions with live objects.

Fackelmeier, Biebl (2009) found that a Doppler radar sensor worked at 5.8 GHz suits ideally for the detection of a covered object where it was only important to get information about the presence of the target but not to obtain other characteristics (distance, velocity etc.). It also agrees with our results. To detect the dog was a problem due to its slight movement during the measuring interval.

It is obvious that for a more reliable detection, probably the combination of Doppler radar with other sensors is needed.

CONCLUSION

First results obtained during the tests of the Doppler radar sensor as a device for possible detection of wild animal hidden in crop are presented in this paper. The radar sensor was able to detect human person hidden behind the crop. In five of the seven cases the P-value was < 0.01. Weaker results were obtained in the case of detection of the dog. Only in two of the seven cases, the P-value resulted less than 0.05. On the base of our results it can be concluded, that microwave radar sensor can be a useful device for detection of wild animals in the crop, with certain limitations (crop moisture content, movement of the animal). Further research is planned in order to better understand the influence of those limitations.

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