A Multistatic Radar Array for Detecting Wild Animals During Pasture Mowing

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***Abstract*— During pasture mowing in spring time, every year countless animals such as fawns are killed or severely injured. In addition to animal protection laws, this is a big problem for farmers due to botulism of the livestock. Many different strategies have been developed to either scar the fawns away or to detect them, for example by searching with a hunting dog. These methods are either ineffective or very time-consuming and therefore less applicable. In this paper, we present a detecting method which is based on microwave signals. This incoherent radar system uses antennas arranged as a matrix and a signal superposition principle. It detects the reflection signature of covered targets of a certain shape - e.g. metals or objects with high water content. The low computing power needed allows a large area to be scanned within a short time. Since this radar system is almost completely insensitive to vertical movement of the extension arm, it can be mounted on a fast driving vehicle.**

I. Introduction

Every year, several 100 thousands of wild animals such as fawns, hares or ground breeders are killed or severely injured during pasture mowing in spring time; and this only in Germany. Due to new animal protection laws, this issue is gaining more and more importance. Another important point is that livestock fed with grass that is contaminated with decomposed animal parts gets ill due to botulism. And, not least, fawns killed this way are a loss of venison.

Many different strategies have been developed to either scare the wild animals away or to detect them and bring them at safe places. Scaring is carried out using loud noises, scarecrows or dogs but is quite inefficient. Other mechanical solutions such as extension arms at the mowing machine with combs hanging down are not successful, either, because fawns cower down when they are scared. Mowing outwards from the centre to scare the animals out of the meadow is another option applied, but the success is rather low. Searching the animal directly is more reliable, for instance with hunting dogs or by systematic searching with many people.

The methods mentioned are very time-consuming and, furthermore, in a time with the speed and capacity of mowing machines increasing more and more, these solutions are becoming less applicable. One viable method practiced operationally is based on the infrared radiation measurement which evaluates the temperature contrast between the animal's body and the surrounding meadow (e.g. [2], [3]). A hand-carried device is commercially available. The disadvantage of this method is the decreasing detection reliability with increasing ambient temperature, i.e. for typical weather conditions, when pasture is mowed, especially around noon.

In contrast to this, the detection with microwave signals is resistant to high ambient temperatures. In a previous work, a coherent radar sensor was developed (e.g. [1]). The disadvantage of this radar is the sensitivity to vertical movements especially if the sensors are carried by an extension arm mounted at the mowing machine. Another disadvantage is the high computing power required for the transformation in frequency domain leading to a small detection capacity.

This paper describes a detection method with high performance in scanning large areas and low system costs. A reliable detection of fawns covered with grass is achieved.

II. Detection Based on Microwave Signals

The basic principle of the detection is to illuminate the area on the ground with a directive microwave beam at a certain incident angle φ and to measure the reflected signal power at a certain angle during a continuous movement of the sensor as shown in fig. 1. Depending on the water content and ground conditions, the soil reflects one part of the microwave beam away; the other part is scattered in all directions. The convex shape of the animal's body and the highly reflective tissue due to the high water content lead to a back reflection that is more or less stronger than from the ground. The aperture of the antenna significantly affects the measurement result. On the

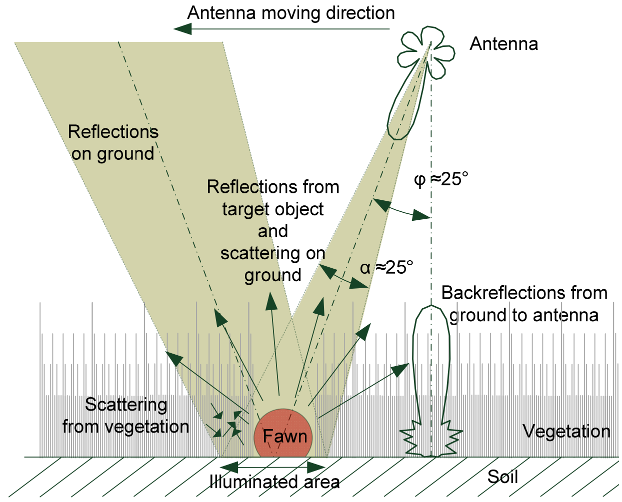

Fig. 1 Arrangement of the microwave sensor in the fawn detection scenario

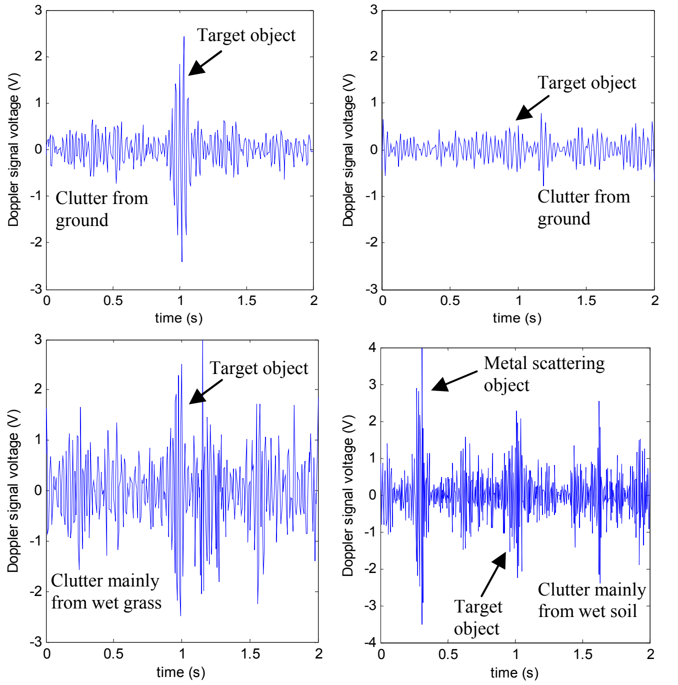

Fig. 2 Doppler signal during object passing; top left: fawn model in dry grass, top right: dry grass but totally misaligned fawn model, down left: fawn model in wet grass, down right: fawn model in dry grass and wet soil

one hand, a large aperture angle decreases the signal ratio between ground with target and ground without target, on the other hand, small angles result in a high amount of antennas needed for a several meter long extension arm. Good results are obtained with an antenna aperture angle that illuminates an area at the ground of about the same size than the target object.

The frequency used for detection depends on the size of the object to be detected. In praxis, outdoor measurements are limited to license free ISM frequency bands. Here we use 5.8 GHz. At higher frequencies (e.g. 24 GHz), interference due to grass covering the target object are higher, especially if the grass is moist or if there are big leaves. With Fresnel near field calculation, the optimal antenna pattern on the flat surface regarding the incident angle is determined. The side lobes of the antenna pointing at right angles to the ground are minimised in order to reduce disturbing reflections from the specular point of the ground. Measurements have shown that the decreased sensitivity caused by wet blades of grass can be slightly increased by an orthogonal antenna polarisation.

Direct measurement of the reflected power is disadvantageous due to coupling between the transmitter and receiver antennas and disturbing reflections at any static objects near the antennas such as the extension arm with the sensors. Therefore the Doppler signal is generated. This is possible thanks to the inclined incident angle which provides a relative movement of the ground to the sensor as shown in fig. 2. Now, only objects that move in reference to the sensor - i.e. the target and the ground - generate a Doppler signal.

Fig. 2 shows some detection measurements of a water filled fawn model (hot-water bottle made of rubber) covered by 50 cm high grass. The radar cross section of the target object - and the real fawn as well - depends on the incidence angle of the microwave to the object and the target object orientation as shown in fig. 3. At particular incident angles, almost no back reflection occurs. In the upper left picture of fig. 2, the target object has an orientation with good back reflection which results in a clear detection signal of the target at the time point around 1 second. In the upper right one, the target orientation is unfavourable leading to low back reflection and therefore detection is impossible. The measurement in the lower left picture is carried out like the first one but in wet grass resulting in strong clutter due to reflections from the grass. In the lower right measurement, the grass is comparatively dry but the soil is wet and additionally there is a metal plate aligned in a specular way producing a strong scattering signal at time point around 0.3 seconds. This fluctuating detectability leads to the assumption that if the smooth shaped target is scanned from different directions and the single signals are superposed, the detection reliability increases significantly.

III. Principle of a Multi Static Radar for Detecting the Signature of the Target

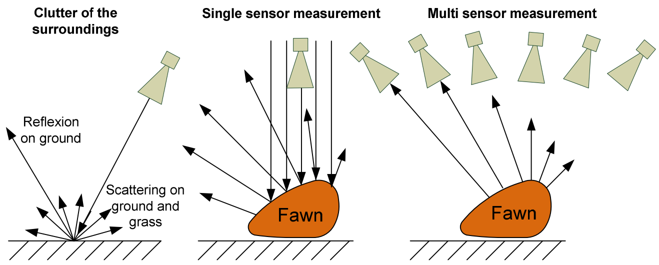

Fig. 3 Microwave signal scattering from the fawn and the ground

As mentioned before, the detection probability depends on the incident angle of the microwave beam to the fawn since the radar cross section varies according to the body posture of the animal (fig. 3). In addition, the reflectivity of the target object is only slightly stronger than earth and grass depending on the humidity. Thus a reliable detection can only be achieved if the back reflection signature of the target object is measured at different perspectives and the signals obtained are combined accordingly (e.g. multiplication). A round target object on even ground reflects the microwave radiation in a wide angular range. Therefore, several sensors are directed from different incident angles to the target. When they are guided across the target object, each sensor measures a more ore less strong maximum superposed by interferences. If all the signals are multiplied, the clutter from grass and ground that is approximately randomly distributed is suppressed. So the signal maximum originating from the target object can be detected more easily than with separate sensors. The covering material or surroundings (also ground) must have a lower back reflection to all the antennas than the target object. For example, the detection of a round object at a surface with reflection coefficient of 100 % is possible if the antennas are arranged so that the main part of the incident beam is not reflected back from the surface to the receiving antennas. The difficulty is that, for this detection method, a high number of sensors is necessary which cannot be implemented. A 3 m long extension arm requires about 100 patch antennas with a size of 25 cm by 25 cm each using an operation frequency of 5.8 GHz. This cannot be realized due to limitations in space and the high costs of the antennas' substrate material. In the next chapter, a technical solution is given which reduces the antenna area to about 3%.

IV. System implementation

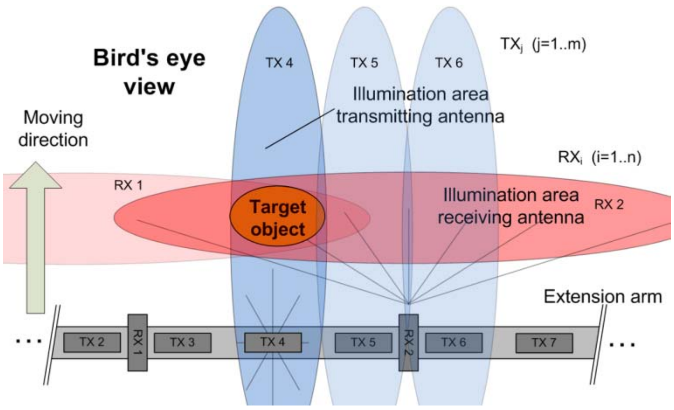

Fig. 4 Antenna arrangement of the multistatic radar

A high directivity in two directions can also be achieved by combining two line array antennas that have an orthogonal orientation to each other using one as transmitting antenna and the other one as receiving antenna (fig. 4). The intersection of the illuminated areas from both antennas has about the size of the target object. As these line array antennas feature a long and narrow radiation pattern, one antenna can be used with several other orthogonal antennas that are arranged side by side at the extension arm. If these antennas are switched through sequentially, one antenna can be used with all others with time slot method. For the detection measurement the transmitting antennas are arranged closely side by side featuring a strong directivity in parallel to the extension arm which results in small patterns in moving direction (fig. 4). These patterns can overlap more or less und cover the entire extension arm. The signal path is switched sequentially from one transmitting antenna to all receiving antennas. This procedure is repeated for all transmitting antennas. The total number of signal paths equals the product of the number of transmitting antennas and the number of receiving antennas. The advantage of this method is that this big amount of signal paths corresponds to many different incident angles on the ground. All receiving signals per transmitting antenna are multiplied - optionally with a certain weighting. The weighting depends on the shape of the object. A further advantage of this switchable antenna matrix is that only one signal source and one receiver are required. The signal multiplication results in one signal per transmitting antenna which shows a peak when the extension arm is moved over a target object. With this radar system, big areas can be scanned as the extension arm can be enlarged considerably; and with increasing length, the costs per meter even decrease. A high driving speed is possible due to the low signal processing requirements.

V. Radar Detection Measurement

The continuous Doppler signals $u_{c\_ij}(t)$ and velocity $v_c(t)$ in moving direction of the extension arm are recorded with an ADC, and the time-discrete signals $u_{ij}(k)=u_{c\_ij}(kT)$ and $v(k)=v_c(kT)$ with $k=1,2,3,..,N$ are obtained. The index j corresponds to the index of the transmitting antenna and i to the receiving antenna. Fig. 6 shows six of this Doppler signals with different incident angles. The detection signal $u_{Det\_ij}(k)$ is obtained by filtering the rectified Doppler signal with an adaptive band pass filter: $u_{Det\_ij}(k)=BP\_filter(|u_{ij}(k)|)$. The lower cut-off frequency has to be adjusted to the velocity v(k) and is defined by the shape of the signal amplitude of the target object. The upper cut-off frequency removes the DC component of the signal and eliminates all disturbing signals with higher frequency as well as the Doppler signal frequency. The signals from one transmitting antenna TX_j and all receiving antennas RX_i are multiplied with a certain weighting factor a_i as follows:

$$u_{Det\_j}(k) = \left(\prod_{i=1}^{n} a_i \cdot u_{Det\_ij}(k) \right)^{\frac{1}{n}} \qquad (5.1)$$

There are many degrees of freedom how the antenna matrix can be arranged relative to the ground. So, before equipping an extension arm completely with the antennas, measurements with two single antenna elements are carried out which allows following adjustments: the antenna height over ground, the inclination angle of the receiving antenna, the misalignment between transmitting antenna and target (important for determining the distance between the transmitting antennas). The measurement is carried out with an extension arm mounted on a tripod. This allows the superposition of different measurements with different antenna positions emulating an entire multistatic system. A rotary encoder enables an accurate superposition of the individual signals (fig 5).

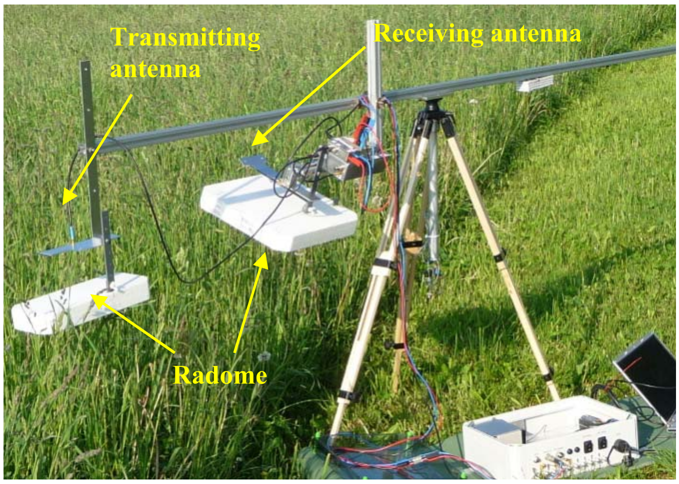

Fig. 5 Multistatic radar measurements with a tripod

The signals in fig. 6 are normalised to the maximum amplitude. They show different ratios between the amplitude maxima resulting from the target object and its superposed

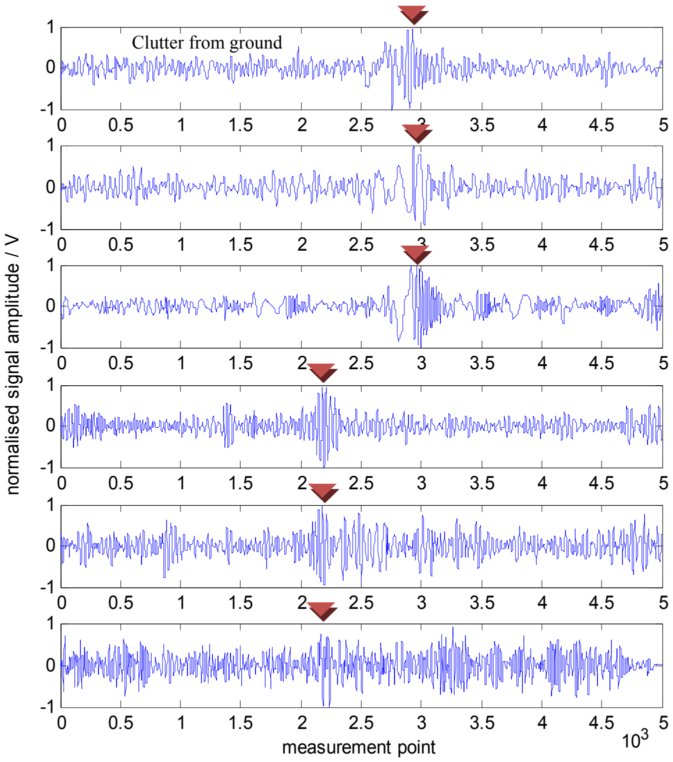

Fig. 6 Doppler signal measurement with six receiving antennas and one transmitting antenna (three transmitting antennas pointing in moving direction, the other three backwards, : target object, TX and RX antenna height = 80 cm, TX-RXantenna distances = 20 cm, 60 cm, 120 cm)

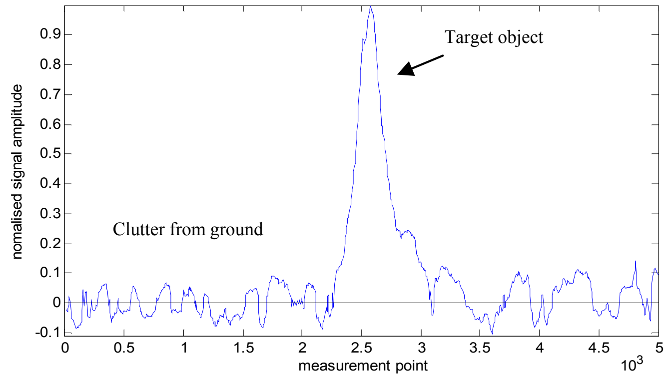

Fig. 7 Multistatic superposition of the signals of fig. 6

clutter from grass and ground. In the upper three measurements, the target can be identified quite easily at the measurement point 3000. In the lower three signals, the target is located at the measurement point 2200. Especially in the last two signals, the target cannot be identified at all. The reason is that here, the orientation of the target is very disadvantageous concerning to the incident angle of the antennas resulting in a weak back reflection.

The signals of the upper three measurements of fig. 6 are measured with receiving antennas pointing in moving direction with an incident angle of 25° as shown in fig. 1. The lower three signals are measured with receiving antennas pointing with the same angle to the opposite direction. So, the signals are time shifted relatively to the target. The advantage of this so-called Janus arrangement is the time shifted object detection. If there is a disturbance e.g. due to shocks or vertical movement of the extension arm, the resulting disturbing signals occur at the same time. To superpose both these signals, one is shifted by a certain time depending on the velocity of the movement and the antenna height over ground so that the amplitude maxima from the target object are synchronous. Now the disturbing peaks are at different points in time. By multiplying the signals, the disturbing signals are suppressed.

The result of the superposition of all signals of fig. 6 is shown in fig. 7. The strong peak around the measurement point 2500 represents the target object. Finally, the decision whether an amplitude peak corresponds actually to a target object (e.g. fawn) is made by comparing this signal with a moving average value.

VI. Conclusion

A non coherent radar type based on the multistatic principle has been presented. It works at 5.8 GHz and uses the advantages of a continuous wave (CW) Doppler radar. The measurement method has been described, and a detection measurement has been shown. Generally, a detection of covered microwave reflecting objects such as metal objects or objects with high water content like fawns or other animals is possible. The detection works if the covering material or surroundings and the ground have a lower back reflection to all antennas than the target object. This method suits ideally for the detection of covered objects where it is only important to get information about the presence of the target but not to obtain other characteristics such as its distance or velocity. One of the main advantages of this radar is the high performance in scanning large areas. This is achieved by the low signal processing effort combined with a long extension arm. The relatively low sensor costs per meter even decrease for an increasing arm length. A further advantage compared to other detection methods is the insensitivity against movements of the extension arm. This is achieved by a particular superposition of signals from antennas pointing with different angles to or against the moving direction. So the extension arm can be mounted on a fast driving vehicle. This detection method may also be used for searching metal objects such as mines (weapons).

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