APPLICATION OF FAST FOURIER TRANSFORMATION IN PLANT DETECTION

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Abstract. The detection of the position of an individual plant in a row of sugar beet is discussed. Precise detection of the position is necessary for efficient mechanical weed control in the row in the growing of sugar beet. It is shown that with a simple sensor consisting of a combination of infrared light sources and photoelectric cells, together with signal processing by means of Fast Fourier Transformation (FFT), it is possible to reconstruct the individual positions of the sugar beet plants from the measured data, even despite the presence of weed in the row.

Keywords. Mechanical weed control; signal processing; fast fourier transformation.

INTRODUCTION

At present weed control in the growing of sugar beet is mainly done by the use of herbicides, although between the rows also weeders are used. Recently the Dutch government has decided that a considerable reduction of the use of pesticides in agriculture is necessary in future. In order to achieve this reduction there is among others a need to introduce more mechanical weed control, where in our research in first instance we will focus on the weed control in growing of sugar beet. (see f.i. Kouwenhoven, Wevers and Post, 1990 and Terpstra and Kouwenhoven, 1986).

Since on a field rows can easily be tracked, mechanical weed control between rows is very well possible. However for a human being on a moving vehicle it is impossible to locate individual plants in a row. So in order to perform mechanical weed control in the row as well, a fully automated detection system to locate the plants in the row is required. (Pleijjsier, 1990, Lohuis, 1991, Bontsema, Grift and Pleijjsier, 1991).

This paper is organized as follows:
- a simple model of a row of sugar beet is proposed together with a model for the weed.
- as a method for the reconstruction of the individual position of a plant from a measured signal, the use of the Fourier transform will be considered.
- field experiments will be discussed and the FFT technique will be applied on real data of this experiments.
- some conclusions and remarks for further research are given.
A MODEL OF A ROW OF SUGAR BEET WITH WEED

In practice sugar beet is sowed with a precision drill, so the distance between the plants will be approximately constant. For the model we assume that the distance is approximately 20 cm. In order to model the variations in the in-between distances we assume that this distances have a Gaussian distribution with mean 20 cm and a certain standard deviation. This matches reasonable the practical situation (Gego, 1968). We assume that the width of a plant is 2 cm. The weed is assumed to cover a certain percentage of the space between the plants. Furthermore we assume that the place where weed appears is random according to the uniform distribution. For the model it is assumed that the row is sampled with a frequency of 3 cm⁻¹.

The actual measured data from such a model is a sequence of zeros and ones, where a one means that there was a (part of) plant or weed. A typical data sequence is given in Fig. 1.

Fig. 1. The data from a model of a row of sugar beet, distance 20 cm, 16% weed, '•' actual position of a beet.

FOURIER TRANSFORMATION

A useful tool to study time series is the Discrete Fourier Transformation (DFT), which is usually implemented by the Fast Fourier Transformation (FFT). If the time series \( \{x_n\} \) has length \( N \) then the DFT is defined as:

\[
X_k = \frac{1}{N} \sum_{n=0}^{N-1} x_n e^{-j2\pi kn/N}
\]  

Once we have the transformed series \( \{X_k\} \) we can do the inverse transformation (IDFT) to determine the series \( \{x_n\} \):

\[
x_n = \frac{1}{N} \sum_{k=0}^{N-1} X_k e^{j2\pi kn/N}
\]  

The absolute values \( |X_k| \) of the complex numbers \( X_k \) give a measure for the importance of the frequency \( f_k = kf_s/N \) in the measured data \( \{x_n\} \). Here \( f_s \) is the frequency by which the series is sampled. The absolute values of the \( |X_k| \) considered as a function of the
frequencies is called the spectrum of the series \( \{x_i\} \).
DFT has some useful properties for our purposes:
1. for a purely random signal all the \( X_k \)'s will be equal.
2. for a periodic pulse shaped signal a fundamental frequency
will occur together with harmonics. The fundamental and
adjacent harmonics will contribute much more to the spectrum
than higher frequency harmonics.

Intuitively it is then clear for our data that the contribution
of beet plants to the spectrum of the measured data will only be
in a restricted frequency band, whereas the contribution of the
weed will approximately be the same for all frequencies and it
is clear that this last contribution will in general be much
smaller than the specific contribution of the beets. Since the
frequencies of the beets will be in the lower frequency range
(for the above mentioned models around 0.05 cm\(^{-1}\)), it is
reasonable to assume that \( X_k \) is almost zero for the high
frequency range. Setting \( X_k = 0 \), for \( k > k_0 \), in equation (2) will give
a filtered version of the original sequence \( \{x_i\} \).
In Fig. 2 and Fig. 3, the spectra are given of a model of the
row of sugar beet with in-between distance of 20 cm and standard
deviation of 2 cm and a model with in-between distance of 20 cm
and 16% weed.

![Fig. 2. The spectrum of a model of a row of sugar beet, distance
20 cm, sd=2 cm, sample frequency 3 cm\(^{-1}\).](image1)

![Fig. 3. The spectrum of a model of a row of sugar beet, distance
20 cm, 16% weed, sample frequency 3 cm\(^{-1}\).](image2)

In both spectra the first peak appears for the frequency 0.05
cm¹, which corresponds to the in-between distance of 20 cm. For the cut-off frequency needed in the inverse transformation we choose 0.37 cm¹, since for the higher frequencies the contribution in the spectra is negligible. The transformed data are shown in Figs. 4 and 5.

Fig. 4. The transformed data of a model of a row of sugar beet, distance 20 cm, sd=2 cm, ‘*’ actual position of individual beet.

Fig. 5. The transformed data of a model of a row of sugar beet, distance 20 cm, 16% weed, ‘*’ actual position of individual beet.

From these figures it is clear that the highest peaks in the transformed data agree well with the actual position of the individual plants. If we compare Figs. 1 and 5 we can conclude that the influence of the weed is sufficiently reduced by the transformation.

EXPERIMENTS

The measurements on a real row of sugar beets were carried out in the spring and summer of 1990. The beets were sowed with a precision drill on a parcel of arable land with sandy soil near Wolfheze, the Netherlands. When we started the experiments there was a lot of weed on the land, mainly pigweed and goosefoot. The sensors were placed on a measuring frame which was mounted in front of a tractor (Grift, 1991). The sensor consists of 3 pairs of infrared light sources and photoelectric cells, which enables us to measure the row at three different heights, all at the same time (see Fig. 6). The reason to do this is that we expect that in this way a sugar beet plant
will give more signal than weed. The velocity of the tractor was kept constant during the measurements. The strategy behind the detection method is to transform repeatedly a certain part (f.i. 100 to 150 cm) of the whole row and use this information for actuating the weed control system. For this reason in this paper we only study small parts of the rows.

Fig. 6. The measurement system.

As an example we study a part of a row, with length 140 cm. As can be seen from this figure the individual sugar beet plants give quite different signals and also can be seen that the distances between the plants are not very constant. Applying the Fourier transform and setting the high frequency components to zero and then performing the inverse transformation results in the transformed data (see Fig. 7).

Fig. 7. Measured data and transformed signal (using FFT) from a row of sugar beet, no weed, '*' actual position of a beet.
As can be seen the peaks in the filtered signal give a quite good approximation of the actual position of the beets.

The spectrum is shown in Fig. 8 and we see that the frequency 0.0111 cm\(^{-1}\) gives the largest contribution to the spectrum. This contribution is mainly due to the width of every beet. Furthermore we see from the spectrum that the contributions for frequencies greater than 0.3 cm\(^{-1}\) can be neglected.

![Spectrum of the measured data of Fig. 7.](image)

Fig. 8. Spectrum of the measured data of Fig. 7.

As a second example we study a part of a row of 140 cm with a lot of weed. We only consider the lower and the upper part of the three signals. The measured data and the transformed data are given in Fig. 9. The amount of weed is a little unrealistic but we see that still the actual positions match reasonably well with the peaks. The weed however is not sufficiently suppressed in the transformation.

![Measured data and transformed signal of a row of sugar beet, with weed, '*' actual position of individual beet.](image)

Fig. 9. Measured data and transformed signal of a row of sugar beet, with weed, '*' actual position of individual beet.

CONCLUSIONS AND REMARKS

In this paper we showed that the combination of a simple sensor and Fourier transformation gives a promising method to detect the individual position of a sugar beet plant in a row, even if there is also weed between the plants. The Fast Fourier Transformation seems to be powerful and this method has the advantage that it is numerically very fast and it can be implemented both in software as in hardware.
For further research we make the following remarks. In the first place we need more information about the shape of a sugar beet plant especially in comparison with that of the weeds. Also the sensivity of the sensor needs further study. In the Fourier transformation method we truncated the higher frequency components in an ad hoc way, this should be replaced by a more systematic method. Also we have to consider if windowing the signals will improve the results. Although Fourier transformation is the most widely used tool in signal processing it should be considered whether the basic functions sine and cosine are the most suitable to express a binary signal. A set of base-functions with a binary nature is found in the so called Walsh functions. A transformation based on these Walsh functions may give better results, especially in case of severe weed disturbance.

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REFERENCES


