CALIBRATION OF A NON-CONTACT OPTICAL VELOCITY SENSOR FOR A PRECISION FARMING APPLICATION

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KEY WORDS: precision farming, weed control, mechanical hoeing, position-controlled deposition, geodetic multi sensor systems, calibration

ABSTRACT:

This paper shows the possibility of use geodetic multi sensor systems in the area of precision farming, particularly with regard to the position-controlled deposition of seed. The intention of this project is the generation of longitudinal as well as diagonal lines in order to allow a mechanical hoeing between single plants in rectangular. In order to achieve the dynamics of the process under agricultural conditions a combination of sensors, supplemented by the utilisation of the physical inertia of the machine in the form of a movement model (KALMAN-filtering), is being used for solving the problem. By using a multi sensor system for position-controlled deposition a precision range measurement by a distance or velocity sensor is of importance. For verification of the manufacturers' instructions of the implemented Non-Contact Optical Velocity Sensor on agricultural conditions a number of practical examinations have been carried out. Apart from a comparison with measurement data of a Leica Laser-Tracker on laboratory conditions other examinations have been carried out with RTK-GPS for larger distances under conditions of chronological synchronism. The RTK-GPS comparison measurements have taken place above asphalt as well as above prepared farmland. The findings can serve the calibration of the multi sensor system and make the design of the KALMAN filtering for a precise positioning in real-time possible.

1. INTRODUCTION

Recently one priority objective in agricultural research is to develop environmentally friendly weed control techniques. These methods are supposed to reduce the use of pesticides (PSM) in weed control of agricultural cultivation in Western Europe. The reason for this efforts is a very high accumulation of PSM in the soil and groundwater due to the extensive use of herbicides (Gerhards et al., 2002).

In this connection a PSM-free weed control is very often done in terms of mechanical hoeing between the plant lines along the seed direction. But a comprehensive mechanical method of weed control needs also to free the space between the plant inside of a row from weed as well. In the setting of a fairly simple and extensive mechanical weed control lateral as well as longitudinal lines must be created in order to enable agricultural vehicles with a mechanical hoe to drive in a rectangular (Norrenmark, Griepentrog, 2004). The distinctiveness of this method is the use of advanced standard machines that contribute to the ruggedness and efficiency compared to the methods of image processing and the handling of each single plants (Dzinaj et al., 1998), (Gerhards et al., 2002).

The basis of such a comprehensive and environmentally-friendly method of weed control, is the realisation of an area-wide, precise and position controlled deposition of seeds in a rectangular. This allows the needed elimination of weed by mechanical hoeing between the plants within a row with favourable standard methods. Furthermore the distance of the plants can be aligned very easily depending on site, growth of the plants and the requirements of the used machine; another advantage of this approach.

2. PROBLEM AND OBJECTIVES

2.1 APPLICATION

The seeding process of an integral planter, which is used for example with sugar beets, operates in the following principal way (compare Figure 1): Starting from a particular starting position, the deposition of seed takes place with an average speed of 6 km / h along one direction about the hole trace, independent of the use of a single planter or integral planter. At the end of the trace, the machine is being lifted up and the turn-over for a following run along the trace takes place. In the course of this process, the planter is lifted down again and the longitudinal movement of the machine starts again. Thereby the average lay length in Germany are more than 300 m.

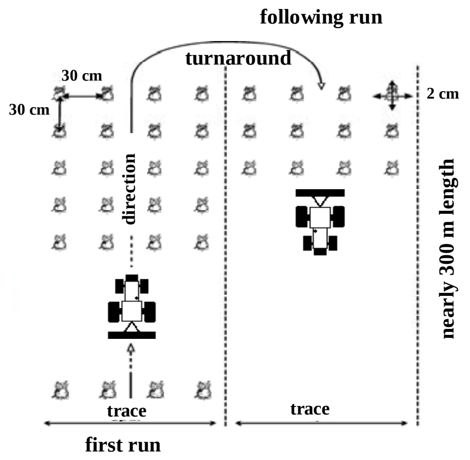

Figure 1. principle drawing (Kuhlmann, Siemes, 2007)

As shown in figure 1, the main problem can be divided into two sub areas: the exact positioning at the longitudinal movement and the dynamic problem of the turnaround.
The longitudinal movement is ideally consistent along the traces. It needs a very exact relative information of positioning in the driving direction to guarantee a very exact reference input to deposit the seeds. In this connection, the accuracy potential of the sensors and the inertia of the whole machine play an important role.

After the first run the problem of turnaround provides a basis for the guarantee of a precise positioning at the beginning for the following run. Thereby an parallel-offset of the traces among each other can be avoided so that lateral traces will be generated. During the turnaround the movement of the whole machine is more dynamic, so that an independent problem begins.

To provide a preferably lossless mechanical hoeing, a requirement concerning the accuracy of about 2 cm for each plant position is necessary. Therefore the standard deviation of the machine positions has been defined with $\sigma = 1$ cm for the 2D-positions. For the achievement of the given accuracy guidelines there is besides the mathematical-physical modelling of the system a high requirement concerning high-frequency measurement of the motion. In this connection the relative sensors (especially the velocity sensor) are of importance. Compared to the absolute sensors, like the GPS-sensor, these sensors have a high accuracy in the close-up area. One disadvantage of these type of sensors exists concerning the drift and the offset.

The intention of the project described here is to create no autonomically driven agricultural vehicle but a manually driven position controlled machine that can easily adapted to each conventional tractor.

2.2 MULTI-SENSOR-SYSTEM

Because of the high accuracy requirements in connection with the real-time positioning and the sowing machines dynamics, it is necessary to mention that only a suitable combination of individual sensors as precise multi sensor system and a filtering approach can lead to an adequate solution to the problem given before (Eichhorn, 2005).

This leads to the sensor system as shown in figure 2, which has been build for position controlled deposition of seed by the mechanical weed control along traces (especially with sugar beets).

The following components comes into operation:

A geodetic double channel receiver in combination with a local reference station in R*eal*T*ime*K*inematik*-mode is used to position the machine in the sub-decimetre area (Stempfhuber, 2004), (Seeber, 1989). To provide a time synchronisation of the different measurement sensors, the receiver additionally have a high-precision, system-based clock-signal (P*ulse*P*er*S*econd*-signal*)*. According to the required accuracy of $\sigma = 1$ cm and the given velocity range, a temporal classification of better than 5 ms should be achieved. This can be easily done by using the PPS-signal.

Furthermore two additional sensors used in the automobile industry have been integrated. Because of their high relative accuracy, they support the enhancement and stabilisation of the GPS-positioning itself for the short-term range. On the one hand a non-contact correlation velocity sensor which controls the velocity over the surface is used. On the other hand a low-cost-micro machined yaw rate sensor which controls the rotating speed by the Coriolis force perpendicular to two oscillating seismic masses has been integrated. In addition to this, the sensor contains a one-dimensional acceleration sensor, which geodetic use is not adequate concerning the accuracy (Ramm, Schwieger, 2004).

The communication, the triggered logging and the processing of the data in real-time is provided by using an industrial computer with different integrated interfaces and data acquisition modules.

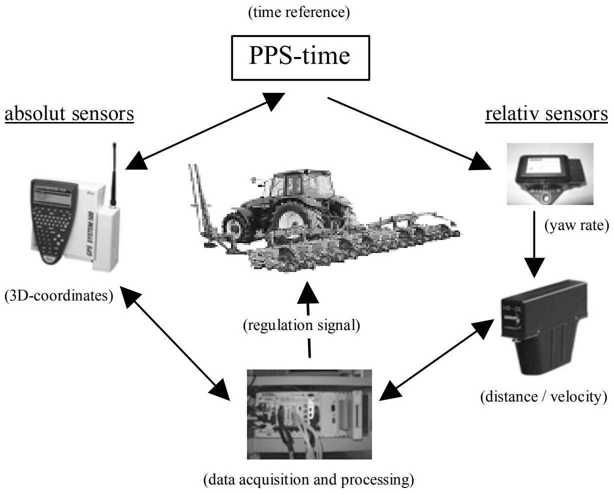

Figure 2. multi sensor system (Kuhlmann, Siemes, 2007)

2.3 FILTER APPROACH

Apart from the technical solution which can be expanded by using more sensors if required, the inertia of the moving machine can be used to achieve the accuracy of positioning. Here only a rough outline of the data analysis approach is given. For a more detailed description see (Kuhlmann, Siemes, 2007).

In general moving objects can be described as dynamic systems that follow physical rules and where the reasons for changes of the output parameters in terms of specified forces (transmission) have to be considered (compare Figure 3). Because of the inertia the objects still move even when there are no external forces working. In the systems theory this is called the dynamic memory of the system (Kuhlmann, 2004).

Figure 3. chain of causation from Welsch 1981, in this case for the state space

The demonstration of the transmission is provided by the physical description of the interaction between reason and effect and the mathematical formulation with the help of a suitable modelling. This quantification can be done by using different mathematical descriptions of the dynamic system farm machine. Frequently an approach with ordinary and / or partial differential equation or the universal applicable approach of a convolution integral was used (Pelzer, 1977 / 1988). Under certain conditions, even a crossover between the different descriptions is possible, as shown for example in Pelzer (1977).

The basic idea of modelling the inertia of the sowing in rows is founded basically on the convolution integral and its possible transfer into differential equations. The parameters of the convolution integral will therefore be deduced from the measurements of a default run with the sowing machine. Therefore the mistaken measurements will be freed from the systematic effects and cleaned by suitable functional approaches. This function represents the movement behaviour and results in a kind of reference values, mentioned by Kuhlmann, Siemes (2007).

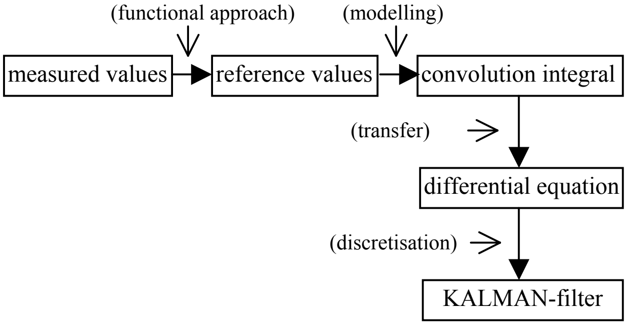

Figure 4. creation of the filter approach by ideal informations

Afterwards the modelling of the inertia, besides the measurements, flows as additional information in a special matched KALMAN-filtering. This serves the cleaning of the positioning in real-time and enhanced the accuracy and reliability of the system (Kuhlmann, 2004).

2.4 OBJEKTIVE OF THIS PAPER

In the presented problem the reliable and exact information about the distance or the velocity under farming conditions plays a decisive role. In particular to the longitudinal movement following a trace, the quality of the positioning depends on the determination of the mileage distance. This will be registered in the framework of the presented project by a non-contact optical velocity sensor developed by the automobile-industry (Corrvit L-400). To verify the given manufacturer data and to find out the character of the sensor under different conditions, a calibration of this sensor would be purposeful.

3. CALIBRATION OF THE NON-CONTACT OPTICAL VELOCITY SENSOR CORRVIT L-400

As aforementioned, the exact measurement of the distance sensors under agricultural conditions plays an important role for the exact positioning. On the market there are different kinds of sensors for the practical field use. Besides the use of independent incremental encoders and camera systems, the vehicle intern odometers will be used for distance informations (Rothmund et al., 2006). However the incremental encoders have the disadvantage to require a direct mechanical connection to the ground by a drive wheel. This requirement can, especially by the sowing process on a prepared field surface, lead to slip effects and therefore to falsification of the relative information of the distance or the velocity. In contrast optical systems work with non-contact and are free of this problem. In this case the image processing quality und speedness plays an important role for the quality of the measurement. The basis for this point is a adequate structure of the surface which will be projected through optics towards a light-sensitive sensor.

The non-contact optical distance and velocity sensor Corrvit L-400 made by Corrsys-Datron comes in this project into effect. This one-dimensional automobile sensor, also comes into effect in other areas of research because of its flexibility and the great measurement spectrum (Ramm, Schwieger, 2004).

3.1 Physical Principle

The correlation velocity sensor Corrvit L-400 measured the velocity and distance of unmarked objects (in form of a structure) against a reference without any direct contact. The sensor is equipped by two special halogen spot lights which the structure of the surface vertical illuminates. The reflection of the structure will then be projected into the middle of the sensor in form of a picture. There this picture appears on a 90° prism fence which split up the picture information in two 180° asynchronous subframes. In the following both parts of the original surface picture will be guided through collector lenses on two independent photodiodes (compare Figure 5).

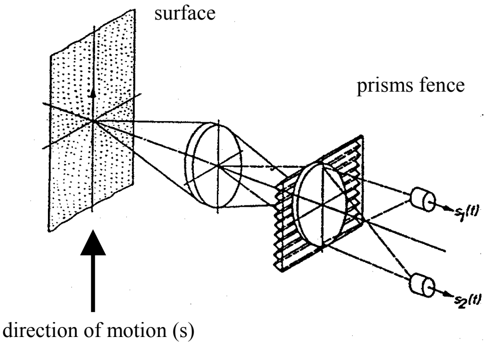

Figure 5. principle drawing (source: Corrsys-Datron)

The image of an object-detail creates a sinusoidal modulated photo signal by the movement across the prism fence. Any period of the signal, which consists of a low-frequency signal (basement intensity) and a modulated upon high-frequency signal (intensity of the single object), in accordance with the average of a certain distance of a illuminated object on the surface (compare Figure 6).

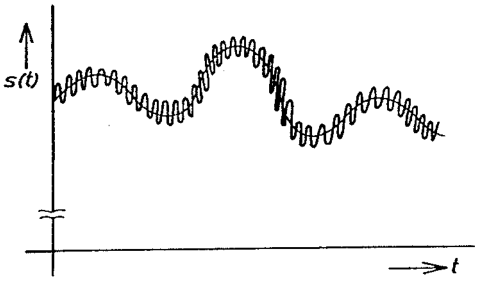

Figure 6. signal over the time (source: Corrsys-Datron)

The required high-frequency signal can be separated mathematical from the total signal by splitting the information of the picture into two parts so that the velocity information is left.
The frequency determined out of this split picture information is proportional to the velocity of the sensor concerning the surface (compare formula (1)).

$$f = (M / g) \cdot v \tag{1}$$

with f = signal frequency,
M = reproduction scale of the optical characteristic,
g = lattice parameter,
v = velocity of the object.

The mentioned principle of the velocity measurement depends on the so-called “Ortsfrequenzfilterverfahren” and is explained by Delingat (1976).

3.2 Specifications

The following information are available in the technical data sheet of the Corrvit L-400:

The possible velocity measuring range is between 0,5 km / h and 400 km / h, in working area of 400 mm ± 130 mm over the surface. Under these conditions the resolution of the distance is 1,9 mm. The accuracy of the sensor is declared with less than ± 0,1 % of covered distance over the calibration surface used by the manufacturer. The Corrvit-sensor offers a digital output as well as an analogues output for the measurement transfer, with 1...1000 pulses / m respectively 0...10 V potential. With an special software tool of the Corrsys-Datron company (CeCal-Win) is it possible to make some modifications of the internal default settings. In this process the value of the pulses per meter, the calibration data and the filtering time for the signal processing can be varied.

These specifications of the manufacturer will be verified concerning the accuracy requirement of $\sigma = 1$ cm and the application possibility under agricultural conditions by calibration measurements as shown in the following chapters.

3.3 Calibration Measurement

First of all the quality of the distance and velocity measurement has been tested with a Laser-Tracker under laboratory conditions followed by field tests with RTK-GPS equipment as reference:

3.3.1 Calibration using Laser-Tracker:

For the calibration by means of Laser-Tracker the Corrvit L-400 was adapted on an experimental vehicle. The adaptation of the sensors occurred in the center of rotation of the experimental vehicle vertical to the surface with a working area of 400 mm (compare Figure 7).

The digital distance informations have constantly been recorded with 250 Hz by the industrial computer mentioned in chapter 3. The preadjustment for the distance information of the sensor was preset for 460 pulses / m and on a non-delaying or unfiltered output of the data, in accordance with the manufacturer calibration protocol. The calibration runs occurred over a structured “norm”-surface of a white woodchip wall paper. This surface is recommended by Corrsys-Datron for special calibration procedures.

Figure 7. experimental vehicle

As reference sensor a Laser-Tracker SMART 310 produced by Leica was chosen with a distance measurement following interferometer principle. This one recorded the coordinates of a special reflector in three dimensions. The reflector was also adapted in the center of rotation of the experimental vehicle for having no offset in the attitude. With its high accuracy of positioning in the range of sub-millimeter and the recording clock rate of 500 Hz during the calibration run, the Laser-Tracker enables the survey of a reference run of the vehicle.

The Laser-Tracker has been installed in extension of the test track at the end of the laboratory, so that all components are on the line. The driven track length in form of straight included 10 m at a velocity of about 1,5 m / s.

The synchronization of both sensors with a common time-scale was due to the measuring arrangement not possible, so that each measurement system have recorded data concerning the internal clock frequency. For the timing of the Corrvit-data an oven stabilized crystal with a precision better than 1 µs and for the Laser-Tracker the internal clock frequency was used. The necessary synchronization of both data streams followed by post-processing through calculation of the cross-correlation. For that purpose two striking points (jerky braking movements prior to standstill) within the track, at the beginning and the end of the run, have been produced.

3.3.2 Calibration using RTK-GPS:

A calibration measurement about longer distances occurs with the Leica RTK-GPS 500 equipment. The local reference station was built-on up near by the test area. For this purpose the experimental vehicle shown in chapter 4.3.1 was used first for a straight distance of 100 m on asphalt and then sowing machine used in practice was used along a slightly bent trajectory of 200 metres on the surface of farmland (compare Figure 8).

Figure 8. test run above the field surface

As the expected accuracy of velocity of the Corrvit L-400 according to the data sheet is ± 0,1 % of the distance, the accuracy of the RTK-GPS of 2 – 5 cm after being increased for example by a running average proves to be sufficient. Sensor data were captured synchronically by means of the P*ulse*P*er*S*econd signal* of the GPS-receiver through the measuring computer. The recording of both of the sensors was 10 Hz and the velocity was 1,4 m / s. The Corrvit L-400 was adjusted the same way as when used in the laboratory. The GPS antenna was adapted with an extension over the Corrvit sensor in order to avoid a shifting of the measurement and exclude possible systematics at the measuring.

4. RESULTS

4.1 Results of the calibration by means of the Laser-Tracker

Based on the measured coordinates of the laser–tracker distance and velocity data were calculated as reference values. After that these data were synchronized over the two striking points (jerky braking movements prior to standstill) of the run in order to get information about the accuracy of the sensor. Figure 9 shows the course of a 12 m Corrvit-run referring to the time. Because of the brake points at 2 m and 10 m only a run of 7 m can be used for calibration.

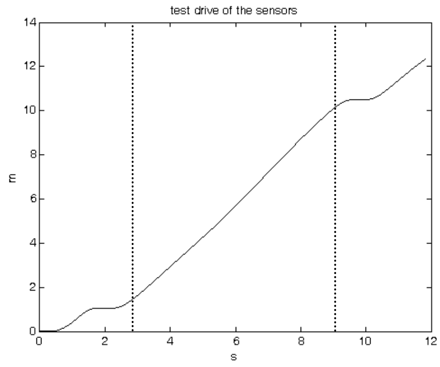

Figure 9. run of the calibration with the Corrvit-sensor

Further we calculated the differences of velocity and of the way to each measuring point (0,04s) referring to the hole measured way. As figure 10 shows the graph of the differences of velocity differs ± 5 cm / s at the coordinate axis in the range between the brake points.

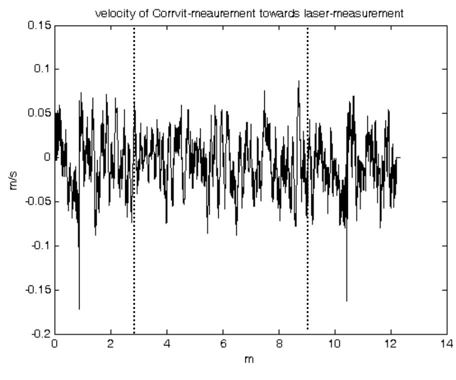

Figure 10. velocity differences

These errors are caused solely by the Corrvit-data because of the given superior accuracy of the laser tracker and can be varied by smoothening the measurements for example by moving average. A statement on the accuracy from the differences of velocity is not possible and you cannot see a drift between the sensors.

If you consider the differences of the distances concerning the run, there is a drift of nearly 2 cm visible (compare Figure 11). At a useable run of 7 m this value corresponds approximately to a driftage of 0,2 – 0,3 %, which is a little bit inferior to the specifications of the sensor (± 0,1 %).

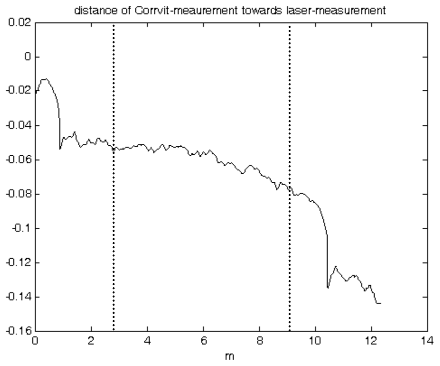

Figure 11. track differences

Figure 12 shows the differences of ways after the split off of a drift of 0,25 %. It turns out that the errors left over cannot be modelled and the random noise of Corrvit-Sensor is about 5-7 mm.

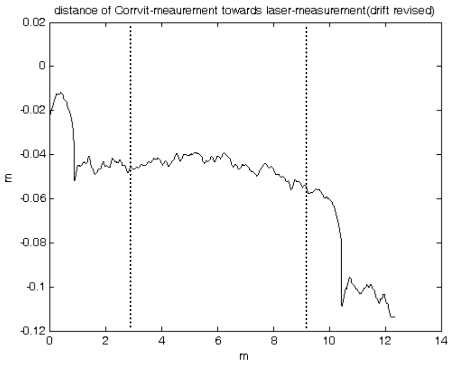

Figure 12. track differences after drift separation

4.2 Results of the calibration using RTK-GPS

In connection with the calibration by means of RTK-GPS you receive 3D-coordinates in the geocentric system which include a noise factor because of the rest systematics and random errors. These coordinates must be improved in accuracy for calibration. For this reason there must be a transformation of the geocentric 3D-coordinates into the plain by revolving around two axis. After that the two-dimensional trajectory was smoothed out by a balanced function (polynomial approach). This is plausible because of the inertness of the vehicles. Finally the differences of the velocities and the way concerning the Corrvit-Sensor were calculated by the perpendicular projections on the balanced function. Because of the hardware synchronisation we did not need to have any striking points along the run for mathematical synchronisation.

If you look at first the calibration drive on asphalt along a straight line of about 100m the differences of velocity do not show a significant offset or an increase of the draft in form of a drift in the velocity (compare Figure 13). The values move with a range of up to ± 0.2 m / s around the zero axis. This fact is of no significance because of the smooth out of the GPS measurements.

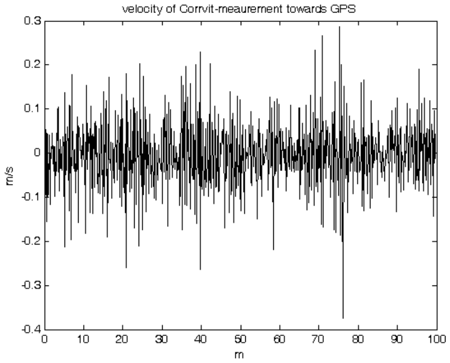

Figure 13. velocity differences above asphalt

The differences of the distances along the way on asphalt show a slightly weaker drift of about 20 cm over a distance of 100m (0,2%) compared to the Laser-Tracker calibration an a woodchip wall paper (0,25%). The general course of the curve is considerably more noisy than in laboratory (compare Figure 14).

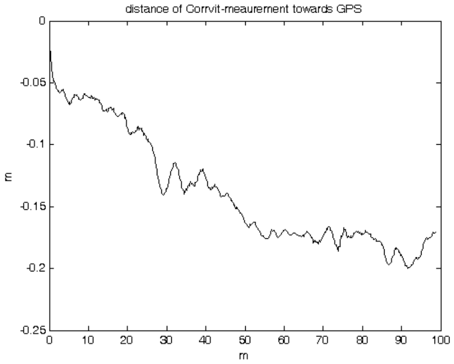

Figure 14. track differences above asphalt

If all Corrvit-data are corrected about a drift of 0,15 % the course of the differences of the distances shows a noise area of ± 4 cm as shown in figure 15. The course of the curve does not make possible a further split of a systematic through a functional attempt. Therefore this calibration drive shows also a strong colourful noise based on the Corrvit-sensor which must be taken into consideration during later filtration, other scale factors seem to be reasonable too.

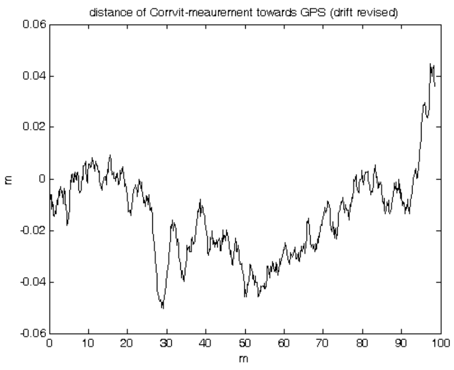

Figure 15. track differences after drift separation above asphalt

The second calibration by means of RTK-GPS was done on a length of 200m along a slightly bent trajectory over arable ground (compare Figure 16). The surface consisted of a claylike soil which had been prepared for the sowing of sugar beets. All the other circumstances and the improvements of the GPS-measures were equal to those on asphalt.

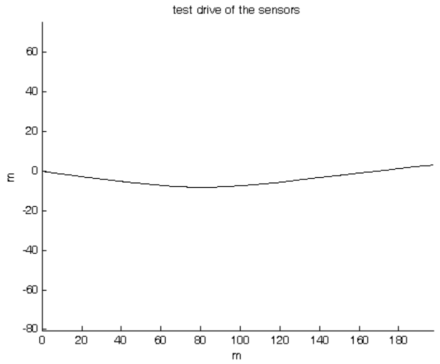

Figure 16. run of the calibration with the Corrvit-sensor above farmland

The differences of the velocities on farmland pictured in figure 17 show a slightly rougher course compared to that on asphalt but further significant statements concerning the velocity cannot be made at this point.

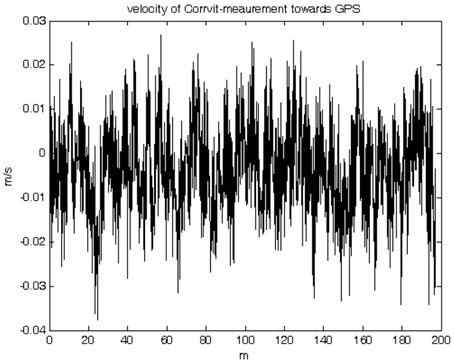

Figure 17. velocity differences above farmland

The drift of the distance measurements of the Corrvit-sensor on arable soil is nearly 0,5 m on a 200 m distance as can be seen in figure 18. This corresponds to a value of 0.25% and is slightly worse than the calibration drive on asphalt. The results of the calibration in the laboratory showed on the other hand a similar drift behaviour.

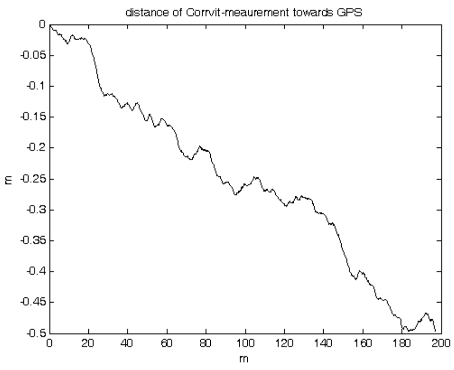

Figure 18. track differences above farmland

A correction of the Corrvit-data by a factor of 1.0025 shows again a strong colourful noise in the resulting differences of distances (compare Figure 19). Again a further modelling of systematic parts through a functional attempt does not seem to be reasonable considering the course of the curve so that the colourful noise must be taken into account in the stochastic model at the filtering design for longer distances.

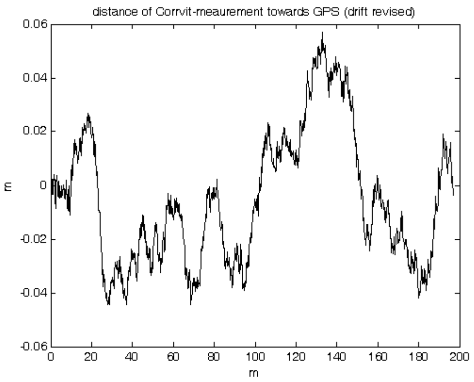

Figure 19. track differences after drift separation above farmland

As mentioned in chapter 2.3 the calculation of positions will be carried out in a Kalman-filter in a recursive manner. Here a time step of one second is reasonable. Based on the data in Figure 19 new differences for each second (1,5 m) were computed for the 200 m trajectory in order to find an additional conclusion concerning the distance differences in the close-up range. After that procedure the results contain nearly white noise, as you can see in figure 20. So it is possible to calculate a standard deviation about these values.

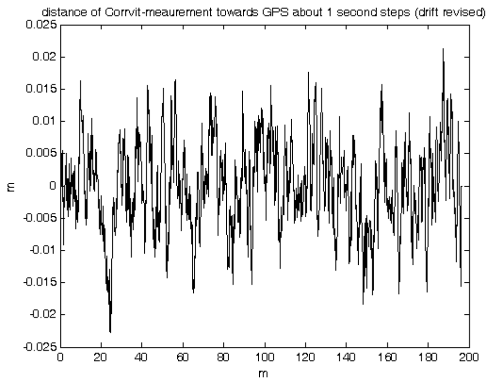

Figure 20. differences over 1 second of the track differences (Figure 19)

The calculation of the standard deviation of the distance differences over 1 second results σ = 7 mm. This standard deviation can introduce in the covariance matrix of the observations, when using a KALMAN-filtering.

A further calibration drive on a field under slightly different basic conditions brought a similar result. This drive took place on a rougher soil with a velocity of only 1 m / s.

5. CONCLUSION AND OUTLOOK

The examinations shown here deal with the calibration of the distance or velocity sensor Corrvit L-400 from the company Corrsys-Datron. The calibration measurements were made both in the laboratory, and on the asphalt and above farmland. The calibration of the sensors of a multi-sensor system are an important aspect for the filtering design and the covariance matrix of the observation vector at the KALMAN-filtering. In case of a not white noise that effect must be designed in terms of additional equations in a shaping filter (Kuhlmann, 2003).

During the examinations the following conclusions resulted:

- A drift in the distance measurements of the Corrvit L-400 sensor can be seen at all drives therefore it can be modelled and corrected.
- In this case it seems reasonable to correct the drift by a factor differing between 0,15 % and 0,25 % dependant on the surface. This factor is slightly higher than the accuracy of ± 0.1% recommended by the producer.
- In spite of the improvements of the distance measurements the remaining range of noise with ± 4 cm on longer distances does not conform to the standards of accuracy needed for mechanical hoeing.
- In addition to the separation of the drift no further splitting of a systematic by modelling is reasonable so that the colourful noise at the KALMAN-filtering by a shaping filter approach has to be taken into account.
- For relative distance measurements nearby one second and a velocity of 1,5 m / s the Corrvit-sensor offers quasi white noise. At the realisation with a clock rate of one second for the multi sensor system there is no shaping filter approach necessary. The determined standard deviation of about σ = 7 mm can introduce in the covariance matrix of the observations

The newly won information about the sensor will have to be verified in the future by further calibration measurements. Different velocities and various surfaces of the fields should be accounted for. No internal filtering of the sensor signals was chosen in the results shown here because of the prevention of a delay in the signals. That is why further tests under consideration of the internal temporal filtering of the sensor signals should be carried out. Finally if necessary the remaining colourful noise must be modelled by a corresponding shaping filter approach.

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