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Research Paper

A novel method for testing automatic systems for controlling the spray boom height

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Automatic boom height control (BHC) systems for sprayers have become more common in recent years. The accuracy of the BHC is dependent on the quality of the height measurement as well as on the control algorithm that should be tailored to the dynamic behaviour of the spray boom and its suspension. There is a need for evaluating BHC performance but there is no objective test method available. A protocol was developed for assessing the control accuracy of BHC systems based on a stationary test bench consisting of target area units placed below the height sensors of the sprayer simulating a ground or canopy surface profile. This study should prove the suitability of this test method, of the target area profiles used and of different statistical parameters describing the test results. The test bench and the protocol developed have proved appropriate for evaluating the performance of BHC systems in a stationary test under defined conditions. Test replications gave consistent results. Several statistical parameters were found suitable to characterise the BHC performance but the standard deviation from set point provided the best selectivity. A smooth and a rough field profile were used for the test in comparison to a synthetic profile consisting of different low frequency harmonics. The rough field and the synthetic profile gave similar results. Opposite to the smooth field, tests using these profiles appear sufficiently selective. It turned out that in some cases the profiles could alter comparative test results. This needs further examination.

The test bench developed for this study can be considered a potential basis of a standardised protocol for BHC assessment as well as for the definition of performance limits.

1. Introduction

Automatic boom height control (BHC) systems are optionally offered by many manufacturers of boom sprayers. These systems are designed for maintaining a constant distance of the spray nozzle tips from the target area (soil or canopy) independent from long-wave variations of terrain surface, crop canopy height or roll angle of the sprayer. It is known that an

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Symbols and abbreviations

a	Number of variants (number of BHC systems to be compared), –
d_l	Boom height deviation at left side, mm
d_r	Boom height deviation at right side, mm
f_{xx}	Percentage of measuring values with a deviation of $\leq$xx cm from set value, %
h_i	Boom height at instant i, mm
h_l	Height of the boom above the surface at left side, mm
h_r	Height of the boom above the surface at right side, mm
h_s	Set value of boom height, mm
HI	Hockley-Index, %
k	Sample size (number of replications for each BHC test), –
LSD	Least significant difference, various
LSD_n	Least significant difference, normalised with the average, %
LSD_t	Least significant difference of multiple t-test, various
MQ_R	Mean square of residues, various
n	Number of measuring values, –
s	Standard deviation, various
SD	Standard deviation from set value, mm
$t_{\alpha;g}$	Quantile of the t distribution for a significance level α and g° of freedom, –
BHC	Boom height control
FFT	Fast Fourier Transformation
US	Ultrasonic

optimum boom height is essential for achieving an even spray distribution (Jeon, Womac, & Gunn, 2004; Wolf, 2002) as well as for sufficient spray drift control (Miller, Lane, O'Sullivan, Tuck, & Ellis, 2008; Nuyttens et al., 2007;). BHC also helps to disburden the operator especially when spraying at high forward speeds as manual boom height control would require a considerable part of the operator's attention. Figure 1 shows the principle of a basic BHC system with one height sensor at each side of the boom.

All known control systems work with ultrasonic (US) sensors for detecting the distance of the boom either from the soil or the canopy. Those sensors may be directed vertically downwards or angled slightly forward in order to avoid disturbances by the spray fan. It can be assumed that US sensors are sensitive to reflections from a cone-shaped region with an angle of approximately 20°–30°. Hence, the shape of the contact area with the target is a circle or an oval.

The measuring values obtained from the height sensors at both sides of the boom are compared to a set value by a computer. This nominal height is chosen by the operator according to the characteristics of the nozzles mounted on the boom, i.e. spray angle and nozzle spacing. For the most common nozzles, flat-fan nozzles with a spray angle of 110° and a nozzle spacing of 0.5 m, the nominal boom height is 0.5 m. It is also possible to select a maximum deviation value tolerated by the control algorithm without any intervention. In case of exceeding this value on either side of the boom, hydraulic or electrical actuators for lifting or tilting the boom are activated in order to minimise the deviation of boom height from the set value.

The performance of the BHC is dependent on the accuracy of the height measurement as well as on the control algorithm that should be tailored to the dynamic behaviour of the spray boom and its suspension.

As BHC systems have been becoming standard equipment for boom sprayers in Europe, testing the performance of those systems should be an inherent part of sprayer examination protocols. This requires a reliable procedure providing reproducible test results obtained under defined conditions.

Currently there is no standard method available worldwide for objective testing the accuracy of these systems. When they are tested, the sprayers are usually operated on real fields and the system's boom height values are recorded. For the evaluation of such data Griffith, Strelioff, and Schnaider (2012) developed a statistical parameter describing the degree of matching the boom height set point, the Hockley-Index.

It is also possible to use artificial obstacles or earthwork for assessing BHC. The German Agricultural Society (DLG) have been using this approach for sprayer demonstrations on the DLG-Feldtage, a biennial agricultural exhibition and show (DLG, 2014). Sprayers have to pass a track with an artificial earth bank on one side of the boom that represents a short slope of the terrain. This is used for visual evaluation of the system performance only.

At Julius-Kühn-Institut (JKI), the German authority for testing of plant protection equipment, a test protocol for boom height control systems was developed on the basis of a test bench in co-operation with CheckTec, a manufacturer of testing equipment. This paper describes the test method and some preliminary studies necessary for its development. One part of the study should prove the suitability of the test equipment and of different statistical parameters describing the test results. Another part was to examine different profiles applied to the test bench and their potential influence on the test results.

2. Method

2.1. Test bench

As a basic principle, the official testing of sprayers shall be as reliable and reproducible as possible. Field tests seem to be inappropriate as they are difficult to reproduce. A controlled laboratory based test system was therefore developed.

The concept of the test protocol for evaluating the performance of BHC was based on a stationary test bench consisting of two target area units (Fig. 2) placed below the height sensors of the sprayer. Each of them consists of an artificial spray target area that can be moved in vertical direction with the help of linear guide units driven by an electric stepper motor. The master target area unit is equipped with a terminal which allows basic inputs as well as the transfer of the desired target area positions with a time increment of 0.02 s from a flash drive to the programmable controller activating the stepper

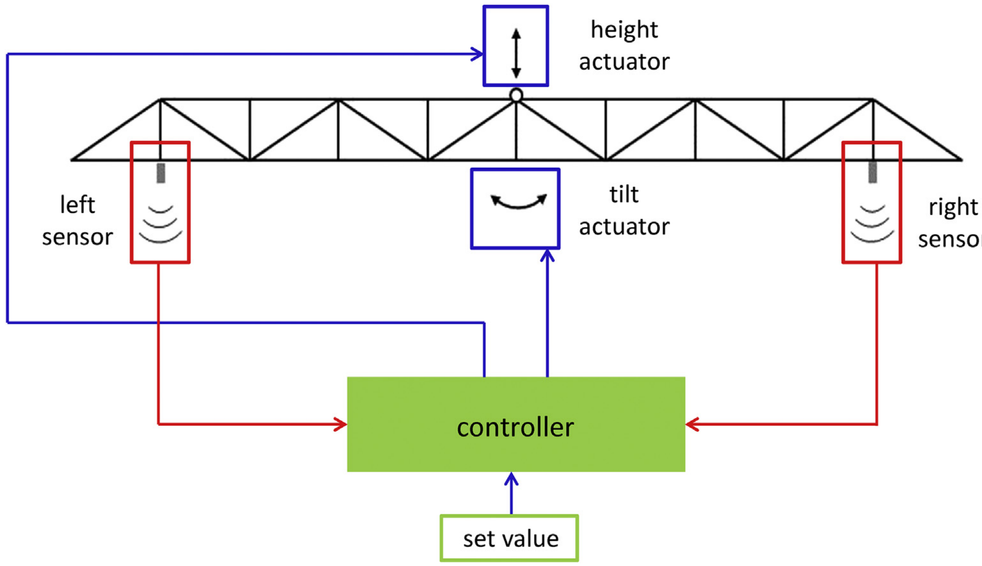

Fig. 1 – Principle of a BHC system.

motors of both target area units. The target areas can perform arbitrary vertical movements within the following nominal limits:

- maximum displacement: 1000 mm
- maximum velocity: 2 m s^{-1}
- maximum acceleration: 10 m s^{-2}

These parameters should be sufficient to give a dynamic behaviour of the target area appropriate for the low frequencies of a practical relief. A short test was performed to prove this. A sine wave with a frequency of 0.1 Hz and an amplitude of 200 mm was applied to the target area and the movement was measured using a laser sensor mounted on its frame. It can be seen from Fig. 3 that the target area followed exactly, only with a delay of 0.1 s. As only the desired profile was recorded during the BHC tests, the time delay was considered for the evaluation of the results.

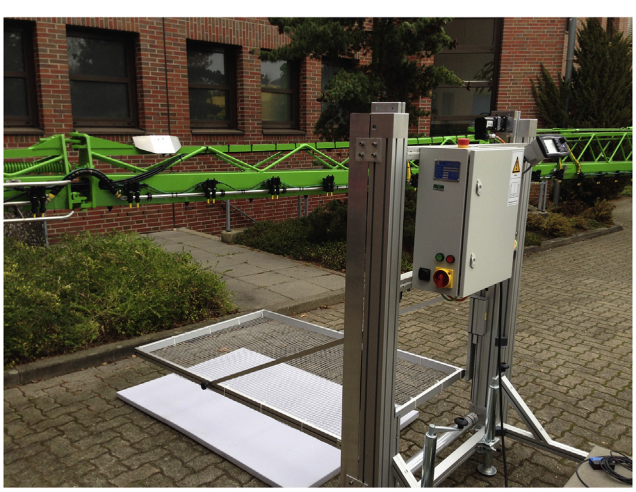

Fig. 2 – Target area unit of the BHC test bench.

The size of the target area was designed according to the characteristics of the height sensors. Assuming a cone angle of 30° and a maximum height of the sensor from the target of 1.5 m, the footprint is a circle of 0.8 m diameter. If the sensor is directed forward by 30°, the longitudinal extension of the footprint would increase. The length of the target area should also accommodate a change of the longitudinal footprint position from an angled sensor with boom height. Figure 4 illustrates the geometric proportions of a sensor's footprint for a maximum height of 1.5 m and a minimum height of 0.5 m above the target area. A minimum length of 1.35 m would be required. So a target area of 1 m width and 1.5 m length was considered to be wide enough to accommodate the footprint dimensions and positions of a common ultrasonic sensor in a wide range of conditions.

The material of the target area should give a similar response to the sensor signals as a crop canopy or a soil surface. At the same time it should be lightweight and porous in order to limit the power necessary to move it. Several materials were tested with a common US sensor, some of them from different heights, in order to evaluate the signal levels. The output of the sensor is a voltage depending on the reflecting material and its distance below the sensor. It gave a maximum voltage of 18 V. As Fig. 5 shows, an increase of the distance between surface and sensor would lower the voltage level.

Hard surfaces at a low distance give signals close to the maximum level. With this material, changes in distance would not have a big influence on the signal. Light and porous material like foam plastics gives low signal levels in general. A wire mesh with a gauge of 0.5 mm and a mesh width of 10 mm was found to give signal levels close to the level obtained from a beet crop canopy. On the other hand, the mesh is sufficiently transmissible so that the sensors are able to detect the surface below, too. So it is possible for some sensors to detect "canopy" and "ground" surface at the same time. These reasons supported the decision to use the metal mesh for the target area in the first instance.

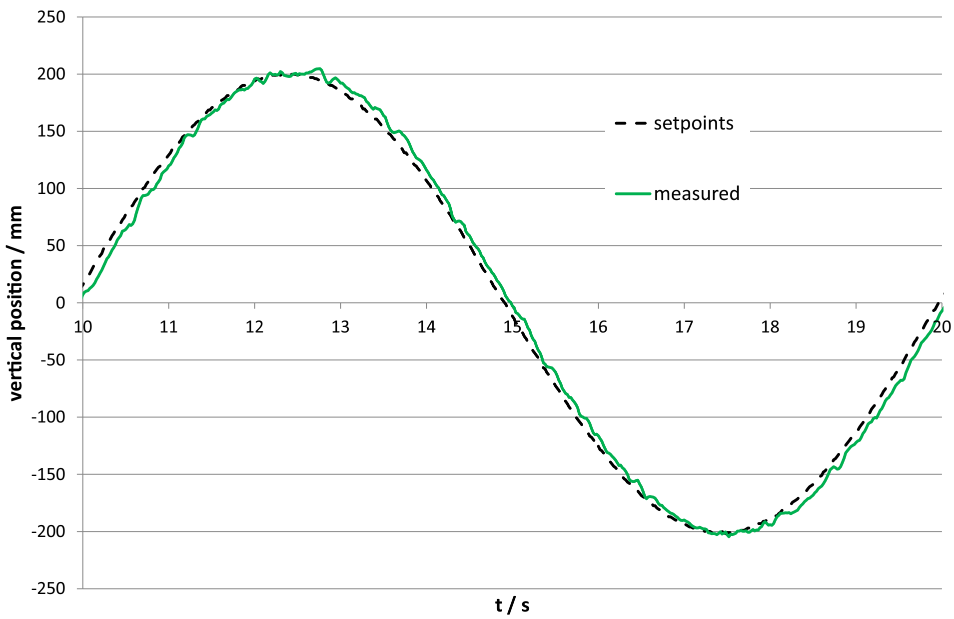

Fig. 3 – Desired and measured position of the target area with a sine wave input of a frequency of 0.1 Hz and an amplitude of 200 mm.

2.2. *Test profiles*

In principle the target area units of the test bench can perform any movements within the above mentioned limits. This allows several test approaches. For instance, it would be possible to determine the frequency response function of a BHC system. This is the reaction of the system on harmonics of different frequencies. This could be interesting for

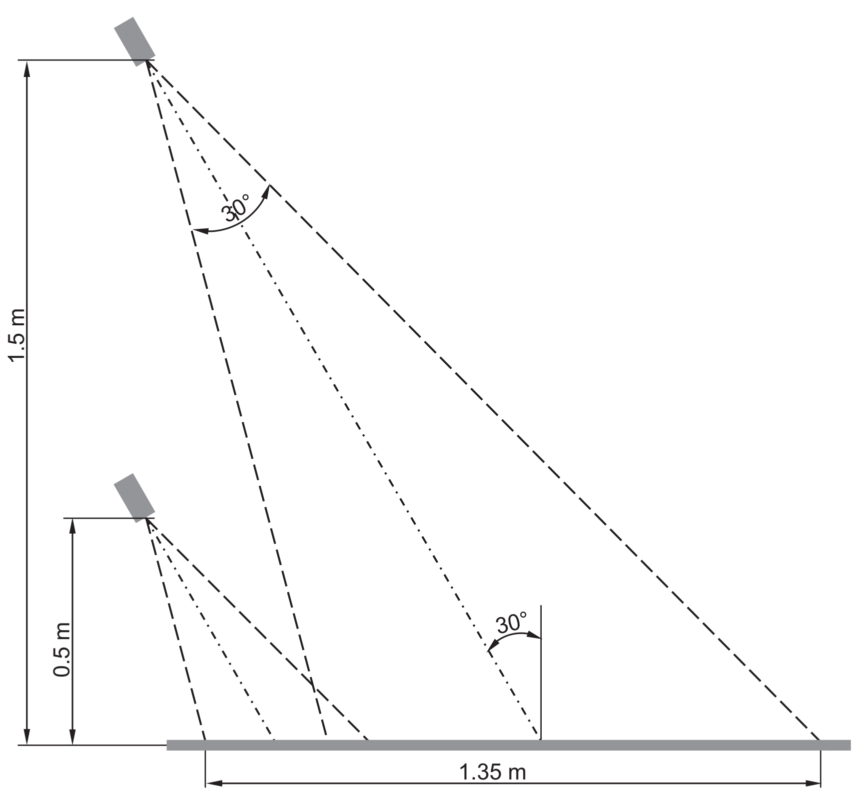

Fig. 4 – Footprint geometry of a common boom height sensor.

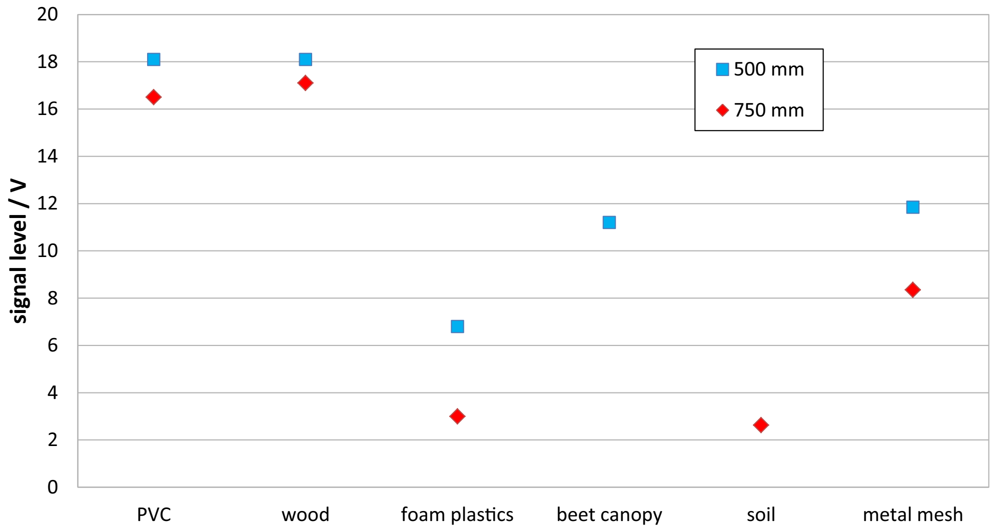

Fig. 5 – Response of a commercial US sensor on several reflector materials from different distances.

companies producing and adopting BHC systems for sprayers in order to optimise their design. However, within sprayer testing schemes the main attention is put on the evaluation of the performance "as it is" using test criteria easy to interpret by the costumers. This is why this study is focussed on assessing BHC systems in the time domain simulating target area profiles.

A synthetic test profile was initially generated for the very first tests with the test bench. It consists of a few ramps with constant speed movements of 0.05 m s^{-1} in the first part. The second part is a superposition of harmonics in a frequency range of 0.01 Hz–0.15 Hz with a random phase.

A number of real field relief data sets with a resolution of 1 m was used to describe practical conditions. From each of these relief data four corresponding profiles were selected representing the soil surface in the wheel tracks and below the boom height sensors. Assuming a hard surface, a wheel gauge of 2 m and an estimated position of height sensors at 13.5 m from the centre of a 30 m boom, the height of the boom above the surface at left side (h_l) and right side (h_r) was calculated for a virtual horizontal position of sprayer and boom (Fig. 6). The deviations from the set value h_s at each relief point below the sensors are considered the profile that should be reproduced by the target area units of the BHC test bench.

A Fast Fourier Transformation (FFT) of the profiles below the height sensors was performed for the different field reliefs. Normally, an FFT is done in the time domain but here it was more useful to stay in the length domain with the frequency expressed in m^{-1} in order to describe the profile.

Afterwards the profiles were transferred into the time domain, applying the maximum recommended travel speed in Germany of 8 km h^{-1}. The two extreme profiles (rough and smooth) were used for BHC tests.

2.3. Tests and sprayers

A first set of tests was conducted with one trailed sprayer with two different control systems (BHC1 and BHC2, Table 1). The aim of this test was to compare the influence of the target area unit drive signals (synthetic, field profiles) on the test results and to identify potential interactions with the statistical parameters describing the BHC performance (see Section 2.4).

Only the synthetic profile was used to study the performance of BHC systems at two different trailed sprayers (BHC3 and BHC4) in a second set of tests (Table 1). The aim of these tests was to identify suitable parameters describing the results of the BHC tests and to find out the consistency of the test results according to the number of repetitions. These tests were replicated 5 times.

For all tests, both target area units were applying the profiles with the same sign (height control mode) as well as with opposite sign (tilt control mode).

2.4. Statistical analysis

The results of all tests were described by different statistical parameters characterising the accuracy of the BHC systems. First parameter was the standard deviation SD calculated from the deviations from the set value as:

$$SD = \sqrt{\frac{\sum_{i=1}^{n}(h_i - h_s)^2}{n-1}} \quad (1)$$

where h_i is boom height at instant i, h_s is set value of boom height and n number of measuring values.

The second parameter was the percentage f_{10} of measured values within a maximum deviation of 10 cm from the set value.

The third parameter was a modified Hockley-Index HI, defined as:

$$HI = f_{10} + 0.75 f_{25} + 0.25 f_{40} - f_{>40} \quad (2)$$

where f_{10} is percentage of measuring values with a deviation of $\leq$10 cm from set value; f_{25} is percentage of measuring values with a deviation of >10 cm and $\leq$25 cm; f_{40} percentage of measuring values with a deviation of >25 cm and $\leq$40 cm and $f_{>40}$ is percentage of measuring values with a deviation of >40 cm.

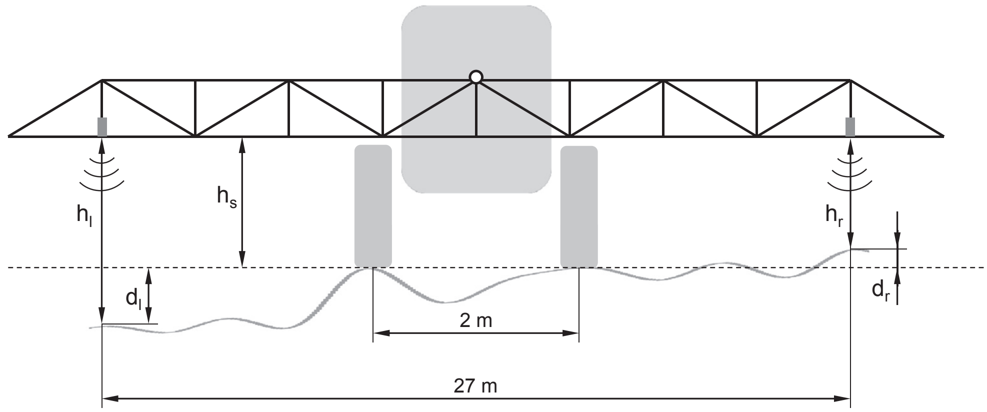

Fig. 6 – The boom height deviation *d* at virtual horizontal position of sprayer and boom for each longitudinal relief position is considered as the disturbance profile at each side of the boom.

The consistency of the BHC tests should be characterised by repeating the measurements for test set 2 (BHC3 and BHC4) in height and tilt control mode. Each of these four systems was tested five times using the synthetic profile. For each of the parameters *SD*, f_{10} and *HI* obtained as the average values, several statistical analyses were conducted using only the first three replications versus using all five. The aim was to calculate least significant differences (*LSD*) that can be obtained from the BHC tests and to verify if they could be improved by increasing the samples. The hypotheses for the statistical evaluations were:

- null hypothesis: no statistical differences between tested BHC systems or between any of the systems and a limit value
- alternative hypothesis: statistical difference between tested BHC systems or between any of the systems and a limit value

The initial investigation checked to which extent the BHC test was able to discriminate between different systems in a comparative test. A variance analysis for each parameter was conducted to identify whether there were differences in control quality. *LSD* values for each parameter were calculated using the multiple *t*-test. The LSD_t for this test is defined as:

$$LSD_t = t_{0.975;a(k-1)}\sqrt{\frac{2MQ_R}{k}} \quad (3)$$

where *a* is the number of variants, *k* is sample size (number of replications for each BHC test), $t_{0.975;a(k-1)}$ is the quantile of the *t* distribution for a significance level of 95% (two-sided) with $a(k-1)$ degrees of freedom and MQ_R is mean square of residues (result of the variance analysis).

Ultimately, the BHC test should show whether the system under test would meet a limit value with certain reliability. So another statistical analysis was conducted to show whether the BHC test procedure was appropriate and which of the statistical parameters were suitable to assess whether a BHC system would comply with a certain performance limit. Therefore, the confidence interval was calculated for each parameter. The half of this interval equals the *LSD* of the average test result to a limit value calculated using the one-sample *t*-test:

$$LSD = t_{0.95;(k-1)}\frac{s}{\sqrt{k}} \quad (4)$$

where $t_{0.95;(k-1)}$ is the quantile of the *t* distribution for a significance level of 95% and a sample size of *k* and *s* is the standard deviation of the statistical parameters within *k* replications of the test.

3. Results

Figure 7 gives an example for the differences in the characteristics of the profiles used for the tests. The amplitudes of the field profiles are obviously bigger than those from the synthetic profile and would exceed the ±500 mm range of the test bench considerably. This is why the field profiles were reduced by a factor of 0.6 prior to the tests.

Differences in the frequency characteristics can be seen in Fig. 8 showing the results of the FFT. The amplitudes were normalised. So it is possible to identify the frequency ranges with higher amplitudes compared to those with lower amplitudes in the different profiles. It is obvious that in all cases the highest amplitudes have a frequency below 0.01 m^{-1} or in

Table 1 – Summary of the tests.

Test set	System	Sprayer working width/m	Distance of height sensors from boom centre/m	Profiles used
1	BHC1	36	13.50	field (rough, smooth), synthetic
	BHC2	36	13.50	
2	BHC3	30	12.30	synthetic
	BHC4	27	10.75	

other words, the wavelength of the biggest profile roughness is above 100 m. The synthetic profile spectrum shows higher amplitudes at higher frequencies compared to the rough field profile whereas there is almost no roughness with frequencies above 0.02 m^{-1} in the smooth field profile.

When the different profiles were used for testing different BHC systems, the results shown in Table 2 were obtained. In general all tests using the different profiles gave a better performance of BHC2 compared to BHC1. Comparing the parameters between height and tilt control for each profile and BHC system, the height control works more accurate than tilt control in general. But in two cases the result was opposite (bold numbers). This is an indication of interactions between the test profile and the control systems or in other words, the relative performance of a control system can depend on the test profile. For BHC2 which performs very well the smooth field profile only shows very low differences between height and tilt control.

Figures 9 and 10 show examples of the measured boom movements at the left height sensor position following the target area performing the synthetic profile. The curves represent the displacement from the initial position ($t = 0$ s) of the target area (profile) and the boom. So each curve starts at zero, although the boom height was set to 0.5 m above the target area. As the boom curves do not follow the profile exactly, there are deviations from the set value. In height mode control the worst system was BHC3 ($SD = 131$ mm) whereas in tilt control mode the worst was BHC4 ($SD = 160$ mm). In both cases BHC2 performed best, with $SD = 43$ mm in height and $SD = 82$ mm in tilt control mode. As expected, the boom cannot follow the target areas exactly due to the dynamic characteristics of the control system. Usually the settings of the system allow a certain deviation from the set value. This and the use of a simple two-way valve for controlling the boom lift can lead to the stepwise adjustment of the boom height (Fig. 9). The system shows a different behaviour when only the boom tilt is controlled (Fig. 10) as due to the integral characteristics of the actuator and the boom inertia, it is more difficult to control the rotational boom movement.

The statistical parameters derived from the test set 2 measurements are listed in Table 3. The results of the replications are consistent, and this is true for all statistical parameters.

Further processing of the data should show what statistical accuracy can be obtained from the tests for the different statistical parameters considering the sample size, e.g. number of replications.

Table 4 shows the *LSD* values calculated for a multiple comparison of the test results for the different BHC systems and control modes, if only the first 3 or all 5 replications were considered. Such a comparison would be made for instance in case of a comparative test.

Comparing the average and standard deviation values resulting from 3 or 5 replications, the differences appear very low. Accordingly, the increase of the LSD_t values caused by the reduction of the sample size is only very moderate. It would not have any influence on the ranking of the systems. There is also no influence of the statistical parameter on the results of the multiple comparisons. LSD_t is dependent on the number of variants, i.e. the number of BHC systems, involved. But as there were only 4 variants compared, LSD_t values would be reduced in a typical comparison test scenario with more systems involved.

But a comparative test is only one possible scenario. Just as important are comparisons of the test results with a limit value. From a statistical prospect this requires another test

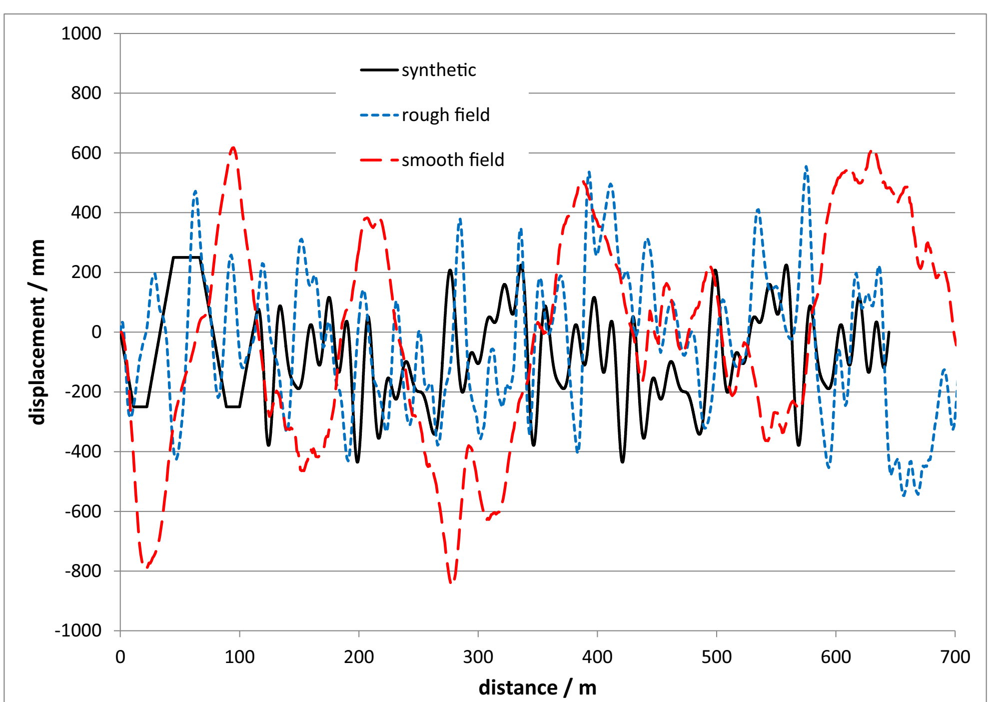

Fig. 7 – Profiles (below left height sensor) used for the tests (test set 1).

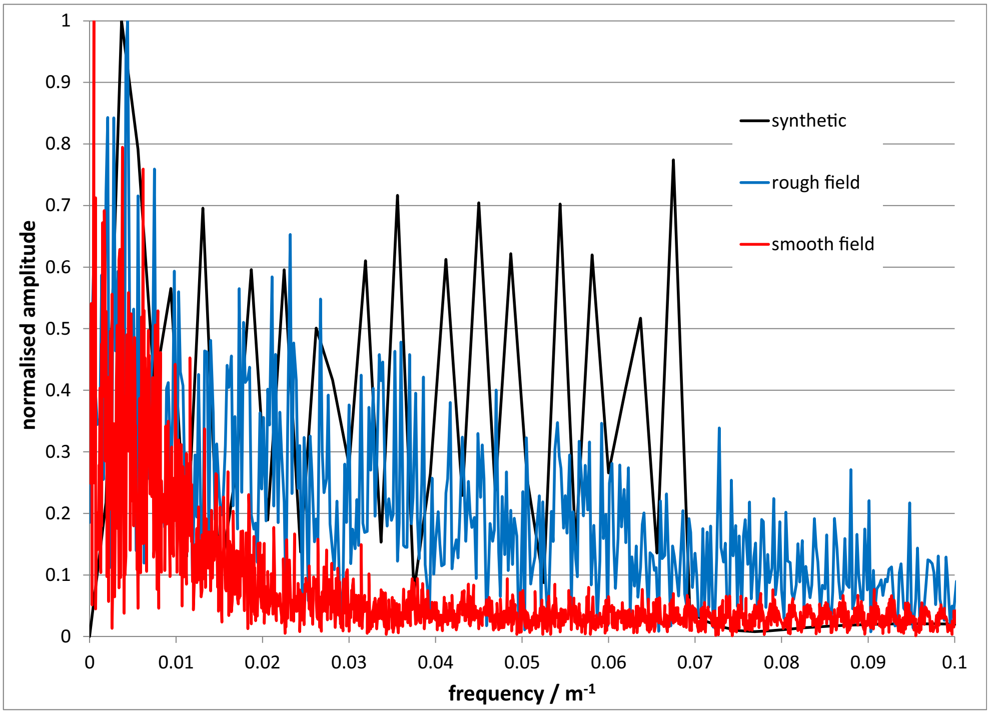

Fig. 8 – Normalised frequency spectrum of the profiles.

procedure since the standard deviation and degrees of freedom used for *LSD* calculation are different from a multiple comparison. The results of the *LSD* calculation for tests against a limit value are shown in Table 5. In general, the increase in number of replications would cut the *LSD* values by half, independent from the statistical parameter, but all *LSD* are relatively low. Comparing the LSD_n, i.e. the *LSD* values normalised with the average of each parameter, some differences in the consistency of the replications become obvious for different statistical parameters. The average LSD_n for the Hockley-Index *HI* is lower than for the other parameters.

4. Discussion and conclusions

The test bench and the protocol developed appear to be appropriate for testing the performance of BHC systems. The main advantage compared to field tests is that the stationary test provides very well defined conditions. The tests proved reproducible and capable of discriminating the performance of different systems. The results of test replications were consistent. For multiple comparative tests as well as for tests of compliance with a limit value, three replications of the test should be sufficient to obtain least significant difference values that are actually relevant.

Table 2 – Performance of BHC systems with different test profiles.

Profile	Control	BHC1			BHC2		
		SD/mm	f_{10}/%	HI/%	SD/mm	f_{10}/%	HI/%
Synthetic	Height	125	57	87	43	99	100
	Tilt	136	51	84	82	77	94
Rough field	Height	**112**	**57**	**89**	36	100	100
	Tilt	**94**	**71**	**92**	63	89	97
Smooth field	Height	81	75	94	**42**	**100**	**100**
	Tilt	92	67	92	**37**	**99**	**100**

Different test profiles were used, one synthetic composition of harmonics and two field profiles. The frequency characteristics and amplitudes of these profiles influenced the results of the tests. The ranking of several BHC systems changed with the profiles. But this is not considered specific for the test bench. These interactions would probably be found in field tests as well. Nevertheless, the test profiles will need further examination. A future standard test profile should provide practical relevance as well as sufficient selectivity. Profiles derived from real field reliefs are always debatable since they only represent local conditions. The synthetic profile developed could be a compromise. Its frequency spectrum is similar to field profiles but there is still room for the amplitudes to be increased.

Using the test bench it was easy to evaluate the BHC systems in height and tilt control mode separately. All BHC systems tested perform differently when controlling boom height or tilt. In general, the tilt control is less accurate compared to the height control. This kind of comparison is another big advantage of the method compared to field tests. On the other hand, it would be no problem to use the test bench for assessing the systems in practical mode, i.e. height and tilt control together, applying two different synthetic profiles to each target area unit. It is also possible to use the test bench for specific frequency analyses applying harmonics or white noise profiles in order to identify critical frequencies within the design process of BHC systems.

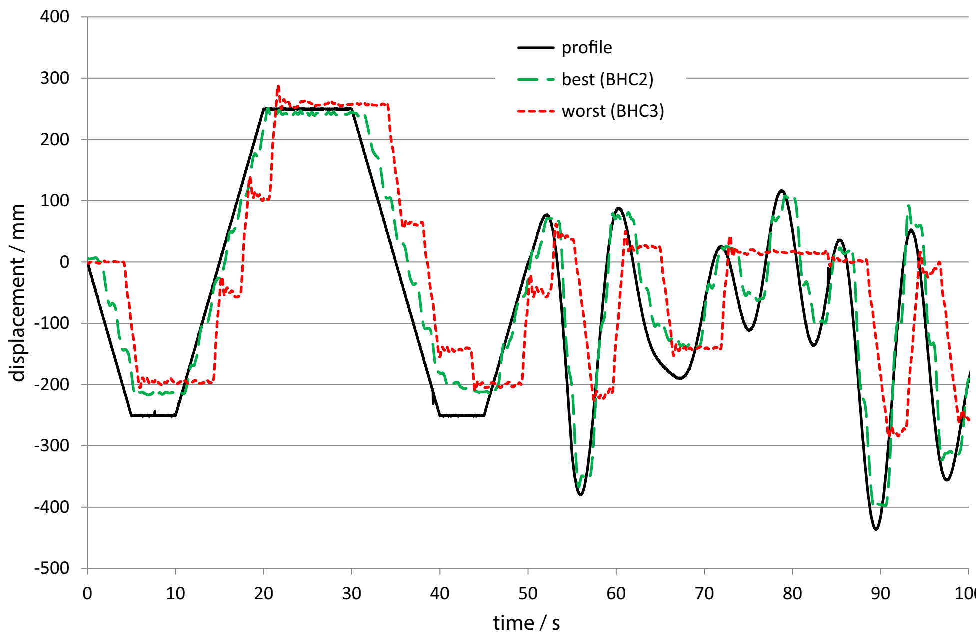

Fig. 9 – Displacements of the target area (profile) and the spray boom at the position of the left side height sensor for the best and worst BHC system in height control mode (right side profile with same sign).

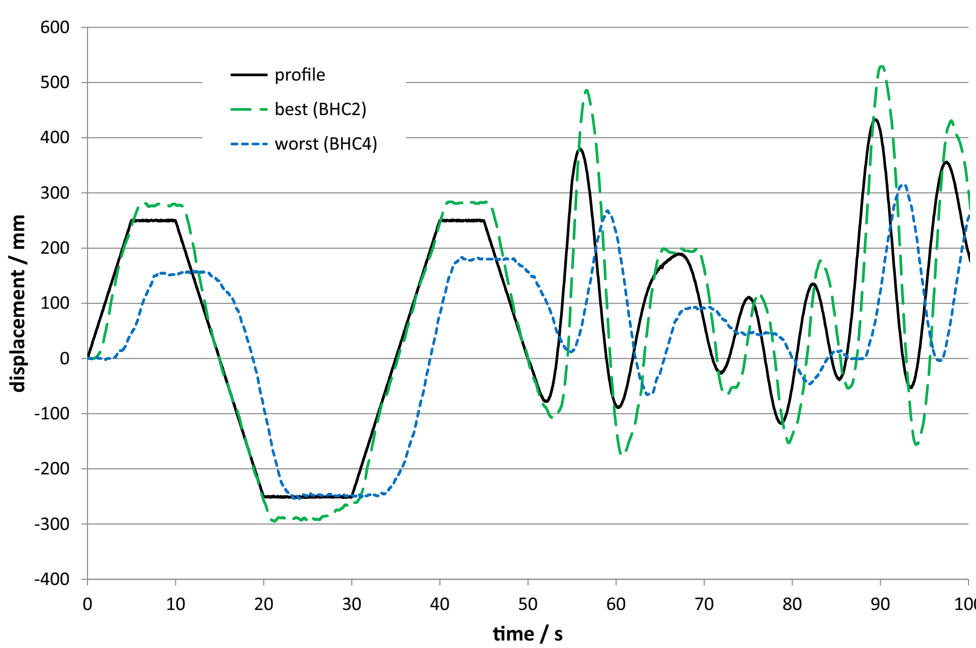

Fig. 10 – Displacements of the target area (profile) and the spray boom at the position of the left side height sensor for the best and worst BHC system in tilt control mode (right side profile with opposite sign).

All statistical parameters used to describe the performance of BHC systems gave the same ranking of the systems when tested with the synthetic profile. The statistical evaluation of the test repetitions gave lower relative *LSD* values for the Hockley-Index *HI* compared to *SD* and f_{10}. On the other hand, the tests using the smooth field profile showed that the selectivity of *HI* and f_{10} is limited. For BHC systems performing relatively well, it is likely that these parameters would reach

Table 3 – Statistical parameters obtained from each replication of the tests for two different BHC systems in height and tilt control mode.

		1	2	3	4	5
SD/mm						
BHC3	Height	129	132	131	132	129
	Tilt	158	150	151	156	150
BHC4	Height	109	105	104	105	104
	Tilt	161	160	157	158	160
f_{10}/%						
BHC3	Height	59.6	58.9	59.6	58.5	60
	Tilt	47.7	51.1	50.2	50.1	50
BHC4	Height	66.9	68.9	68.1	68.4	69
	Tilt	50.3	53.1	51.3	49.8	51.5
HI/%						
BHC3	Height	86	85	85	85	86
	Tilt	79	81	81	80	81
BHC4	Height	90	91	91	91	91
	Tilt	79	80	80	80	80

their maximum value of 100%, which would not allow for further discrimination, while deviations of the boom height from the set value are still evident. This means that the standard deviation *SD* should be used for the evaluation of tests requiring a high selectivity, providing the tests give sufficient statistical precision.

All results presented refer to the position of the height sensor. This is representing the whole boom in case of height control mode but the position of the height sensors in relation to the boom tip may be important for the evaluation of the results for tilt control. Considering the relatively inflexible structure of the spray boom in vertical direction, it is possible to calculate the actual distance of any point at the boom to any virtual target area from the test results. But the BHC system can only account for the target area profiles below the height sensor positions. This is why the performance of the BHC system should be evaluated only considering these positions.

The test bench used consists of two target area units. With this it is possible to test only boom control systems with two sensors controlling boom height and tilt. But the test bench is designed in a modular way. It can easily be extended to enable tests of more complex BHC systems for spray booms with a variable geometry. It is also planned to combine the test bench with a shaking platform (Herbst, 2011) which can excite sprayer movements. This is necessary for adequate testing of BHC systems equipped with additional sensors measuring the sprayer roll angle.

Official performance limits or test schemes for boom sprayers do not currently include BHC systems, although these systems have become more common in recent years. The test bench developed for this study can be considered a potential basis of a standardised protocol for BHC assessment as well as for the definition of performance limits. This should allow including the BHC performance in future sprayer evaluation schemes.

Table 5 – Absolute and normalised values of *LSD* of the parameters calculated from the test results (test set 2) for different sample sizes for the comparison of each measurement to a limit value (significance level 95%).

		$k = 3$		$k = 5$	
		LSD	LSD_n/%	*LSD*	LSD_n/%
SD/mm					
BHC3	Height	2.6	2.0	1.4	1.1
	Tilt	7.3	4.8	3.6	2.3
BHC4	Height	4.5	4.2	2.0	1.9
	Tilt	3.5	2.2	1.6	1.0
f_{10}/%					
BHC3	Height	0.7	1.1	0.6	1.0
	Tilt	3.0	6.0	1.2	2.4
BHC4	Height	1.7	2.5	0.8	1.2
	Tilt	2.4	4.6	1.2	2.4
HI/%					
BHC3	Height	1.0	1.1	0.5	0.6
	Tilt	1.9	2.4	0.9	1.1
BHC4	Height	1.0	1.1	0.4	0.5
	Tilt	1.0	1.2	0.4	0.5

Table 4 – Statistics of the parameters calculated from the test results (test set 2) for different sample sizes (LSD_t refer to the multiple comparison of all variants, significance level 95%).

		$k = 3$				$k = 5$			
		average	s	LSD_t	rank	average	s	LSD_t	rank
SD/mm									
BHC3	Height	131	1.5	10.4	2	131	1.5	8.1	2
	Tilt	153	4.4		3	153	3.7		3
BHC4	Height	106	2.6		1	105	2.1		1
	Tilt	159	2.1		3	159	1.6		3
f_{10}/%									
BHC3	Height	59	0.4	4.6	2	59	0.6	3.5	2
	Tilt	50	1.8		3	50	1.3		3
BHC4	Height	68	1.0		1	68	0.8		1
	Tilt	52	1.4		3	51	1.3		3
HI/%									
BHC3	Height	85	0.6	2.8	2	85	0.5	2.1	2
	Tilt	80	1.2		3	80	0.9		3
BHC4	Height	91	0.6		1	91	0.4		1
	Tilt	80	0.6		3	80	0.4		3

Conflicts on interest

The authors wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

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