Data acquisition and automated data analysis in prototype development - Testing of the prototype for automated attachment of the supporting wires in hop gardens

Dr. Z. Gobor (Bavarian State Research Center for Agriculture,
Institute for Agricultural Engineering and Animal Husbandry)

A prototype of a device for automated attaching of the supporting wires was developed. The device consists of a main assembly mounted on the front-end loader and a special carrier for the wire coil attached to a three-point linkage of the tractor. The subsystems for positioning, wire attaching and intermediate storage of the wire allow continuous pulling of the wire from the coil and its automated attachment to the longitudinal cables of the 7-8 m high trellis systems. The attachment of the supporting wires is controlled by a programmable logic controller (PLC) and carried out on defined distances whereas the tractor moves forward along the longitudinal cable with up to 1.8 km/h. The possibilities and advantages of the usage of a mobile data acquisition system and automated data analysis during the prototype testing are described and discussed in this paper. The data acquisition system provides important information considering the system performance and allows error analysis in case of outage.

The Hallertau in Bavaria is the worldwide most famous and still largest continuous hop-producing area, comprising more than 15000 ha. The hop in this area is grown in hop gardens, which consist of a horizontal mesh of longitudinal and transversal cables, anchored on a system of poles, and supporting strings, which combination creates a 7-8 m high trellis systems. Maintenance of the poles and cables on a regular basis allows utilization of the garden structures for more than 20 years. Typically, 2000 rootstocks are planted on one ha. In spring, two vines from each rootstock need to be trained to climb and twist around the supporting strings. The supporting strings are attached to the longitudinal cables and should provide direction and growing support for hop vines. Although other materials such as coconut fibre, untreated sisal twin, paper or plastic can be used for preparation of supporting strings, the majority of farmers in Germany apply a 1.2-1.4 mm thick iron wire. The harvesting takes place in August and September during which both the vines and supporting strings are cut from the overhead cables and transported with trailers to the stationary picking machines. Such a harvesting method affects the preparation of the hop garden for the new season, namely each winter or spring approximately 4000 supporting strings per ha need to be replaced.

Description of the problems and objectives

Attaching of the supporting strings to the longitudinal cables is a task, which is usually carried out between October and March, still limited to the manual technique. Field workers perform this task while standing on a special hop cultivation platform, mounted to the front-end loader of the tractor. Manual attaching of the supporting strings involves a considerable risk of accidents especially in hop gardens established on hilly or uneven terrains, common for Bavaria. Main reasons are the platform construction, the way the platform is attached to the tractor and unfavourable weather conditions, typical for winter when the task needs to be carried out. Under extreme conditions with low temperatures, wind and precipitation the efficiency of

caring out of this task can be significantly affected and even impeded.
The facts that the expenditure on manual labour in the sector of hop production in Germany constantly increasing and the number of the farms involved in the hop production, decreased in the period from 1973 until 2012 from 8,591 to 1,294, while the area under hop stayed on the same level need to be considered as additional challenges affecting the contemporary production .
Introducing of smart machines and implements in the production of high value crops to carry out expensive repetitive manual tasks was already in 2005 recognised by Blackmore et al. as an economically justifiable objective of the agricultural mechanisation. A survey carried out by Böttinger et al. in 2010 among the leading representatives, associations and industry leaders involved in the agricultural machinery manufacturing sector, showed that introduction of smart implements in the German agricultural sector among others, will face considerable growth in the next 10 years.
Analysing the problems and development tendencies pointed out above, the automation of the attaching the supporting wires in the hop garden is recognised as important objective which can advance the hop production in future.

Device for automated attaching of the supporting strings

The private limited company Soller GmbH (Geisenfeld) worked for more than 10 years on the development of a machine concept which resulted with a patent and a first evaluation model. In the period between 2008 and 2010 the Bavarian State Research Center for Agriculture and the company Soller carried out a cooperation project in which the previous development and the evaluation model were analysed and the entire system were optimised. Finally a redesigned prototype was built and tested. To collect important data about the state of the system and its performance during the evaluation and adequately document the tests, a data acquisition system was configured and software solution programmed.

Design of the device

The device for automated attaching of the supporting strings consists of a telescopic leader mast (1) which needs to be attached to the front-end loader of the tractor. The leader mast carries the subsystem for wire attaching (2) on its top. The carrier of the wire coil (3) and the external hydraulic power supply unit (4), are attached to a three-point linkage of the tractor. Hydraulic actuators controlled by sensors, integrated into the subsystem for positioning (5), provide accurate tracing of the longitudinal cable through inclination perpendicularly to the driving direction and lifting and lowering of the subsystem for wire attaching. Additional sensors are integrated for detection of the transversal cables for controlling the maximal height of the system in order to avoid collision during the forward movement. Mechanisms for wire preparation, knot tying, wire feeding, wire cutting and pulling from the intermediate storage are parts of the subsystem for wire attaching. The intermediate storage of the wire (6) is a mechanism which allows fail-save feeding of the wire with higher rate, which was not possible during the attempts to pull the wire directly from the wire coil because the wire get jammed. (see Figure 1).

Figure 1: Prototype for automated attaching of the supporting strings in action during the testing in March 2013. Legend: (1) telescopic leader mast; (2)

subsystem for wire attaching; (3) intermediate storage of the wire; (4) wire coil; (5) external hydraulic power supply unit; (6) subsystem for positioning; (7) electrical cabinet

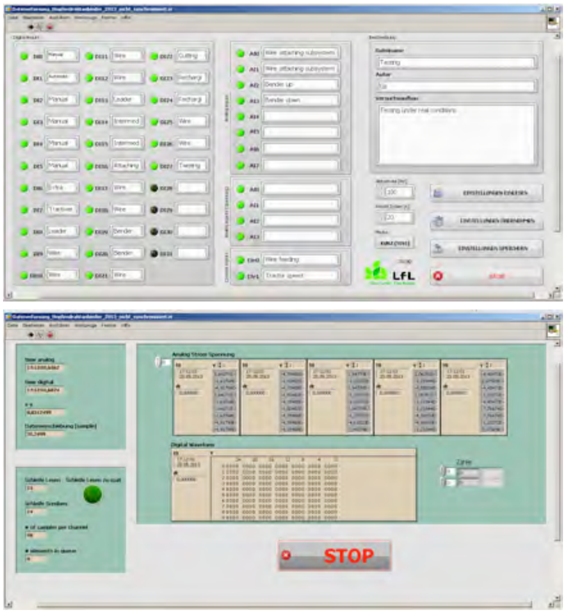
The entire system is controlled by a programmable logic controller (PLC) which is housed in the electrical cabinet (7 Figure 1).
In the frame of the cooperation project, the subsystems for wire attaching, positioning subsystem and the intermediate storage of the wire were considerably redesigned and improved. The insights obtained during experimental testing were implemented during the design. To increase the performance and reliability of the device and to provide independency from the tractors hydraulic an external hydraulic power supply unit was integrated into the system. Finally, the new redesigned prototype was manufactured and tested. Detailed information about the development, optimisation and testing of the new prototype are published (Gobor et al. 2010; Gobor et al. 2011, Gobor et al. 2012, Gobor et al. 2013).
The device can operate in manual and automatic mode. In both modes the engine of the tractor needs to be started and the power take-off (PTO) activated, in order to keep running the external hydraulic power supply. In the manual mode the operator can change the horizontal and vertical position of the wire attaching subsystem, through inclination and extending or retracting of the leader mast. Control buttons on the operator panel allow performing of all the operations related to the wire attaching. The operation parameters of the PLC software can be defined and changed using a touch screen integrated into the operator panel. The manual operating mode is particularly suitable for wire attaching on non-standard segments of the hop garden and for testing of the subsystems. Completely autonomous wire attaching can be carried out in automatic operating mode, while the operator only needs to steer the tractor parallel to the hop rows. Manual override of automatic control with the joystick, control buttons and touch screen is permitted. For monitoring of the wire attaching process in real-time a display screen of a video system is mounted in the cabin of the tractor. The position of the camera is chosen to provide detailed view of the mechanism for tracing the longitudinal cable and the subsystem for wire attaching.

System for the data acquisition

The device for automated attaching of the supporting wires is highly complex and its state and performance depends on several factors including the working environment. Already in the optimisation phase of the project it was necessary to collect significant information on the behaviour of the first evaluation model during testing under laboratory and field conditions. For this purpose a compact modular data logging system CompactDAQ (National Instrument) and an adequate software solution for data acquisition, created in LabVIEW (National Instrument), was used for data acquisition. The hydraulic pressure on the main hydraulic hoses were measured using pressure sensors MBS 3250 series 060 G1 869 (Danfoss) and the current states of the I/O ports of the PLC were acquired in order to determine the response time of the actuators and ascertain the duration of main process sequences. Also, the measurement of the flow-rate with a turbine flow sensor RE 4 (Hydrotechnik) with integrated Pt 100 for simultaneous temperature measurement was optionally offered.
The same measurement instrumentation was used for the performance analyses of the optimised prototype during the field testing. To simplify the setup of the data acquisition hardware changes of the hardware configuration were carried out. The PLC I/O signals were routed to the extension modules as output signals and connected to the CompactDAQ through a plug connector mounted on the electric cabinet of the prototype. During the tests the data acquisition system can be placed in the tractor cabin and in such a way the research scientist can configure, start and

stop the data acquisition and keep track of all events while directly communicating with the driver.

The previous software solution was improved in order to provide faster data streaming. The recording of raw information from the CompactDAQ in the TDMS file format, without any signal conditioning and analysis, was chosen. This is the recommended data format for streaming of time-based measurement data because of higher file writing speed and smaller disk footprint in relation to the ASCII files format. To achieve these advantages the parameters of the streamed data need to be properly configured. Additionally, the software was adapted to the multi-core architecture of the used PC. The new software solution allows acquisition of 27 digital inputs (DI) 9 analog inputs (AI) and two counters with different sampling rate. The number of acquired channels and their order in the TDMS file can be configured. The screenshots of the data acquisition software and resulting log file are illustrated in figure 2.



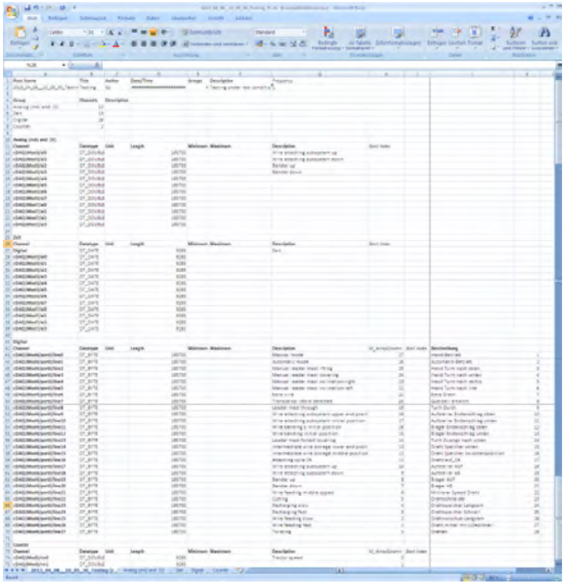


Figure 2: Screenshot of the data acquisition software configuration front panel and the resulting TDMS log file

The sampling rate of the data acquisition can be selected depending on the type and scope of the experiment, from 50 Hz to 500 Hz.

At the moment the automated analysis of the collected data is carried out in an additional step using a function written in Scilab. Unfortunately, the used version of Scilab in contrast to Matlab does not offer the possibility to directly read the .TDMS files. In an intermediate step the .TDMS file can be saved in .XLS format using the add-in in the Microsoft Excel and the created.XLS file read with the existing function within the Scilab. The main disadvantage of this method is that the used version of Scilab offers only a read function for .XLS and not for .XLSX. For this reason the size of the files which can be read automatically is limited to 65536 rows per worksheet.

The developed Scilab function allows automated visualisation and analysis of the data collected during the testing. The function returns matrices containing information about the beginning and ending of single operations, time required for execution of single operations such as wire feeding, recharging of the intermediate storage within every wire attaching sequence and the total time of each complete wire attaching sequence.

The function determines the response time of the actuators through parallel acquisition of the PLC control signals and reactions detected by sensors. Furthermore, the function generates graphical windows containing combined diagrams of the sensors-actuators control signal states and diagrams with pressure values in the main hydraulic hoses with parallel representation of the actuators control signal states. Additionally for several single operations the frequency of the duration is calculated and diagrammed, providing information about the accuracy, stability and reliability of the subsystems of the prototype. The time required for headland turns and the duration of the failure correction can be reconstructed in order to predict the area capacity and accordingly the operational time per ha calculated. Screenshots of the generated diagrams are showed in figure 3.

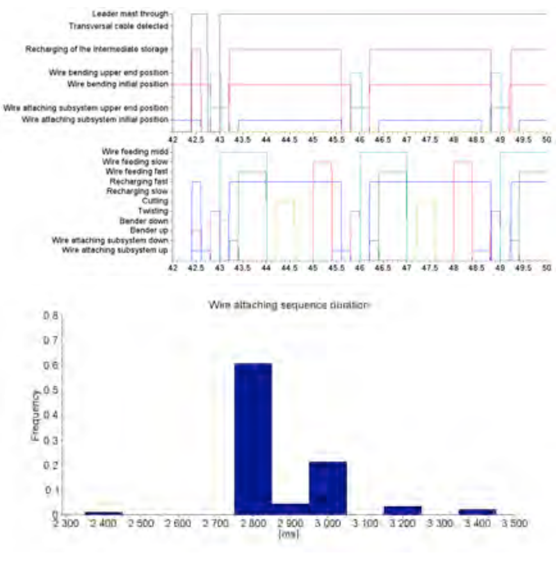


Figure 3: Representative diagrams created within the automated data analysis

Results of the field testing and performance of the device in 2013

Using the automated data analysis the behaviour of the prototype in series of tests during the optimisation process was compared, allowing detection of the potentials for improvement within the control software. The redesigned prototype showed considerable improvement regarding to stability, accuracy and reliability in comparison with the evaluation model. At the moment the system is able to perform a complete wire attaching sequence in just about 3 s. Hence, the wire attaching process can be performed faster, with higher average forward speed of the tractor in relation to the evaluation model and consequently the area capacity have been improved. Considering the reliability of the system it needs to be mentioned that during the previous two seasons approximately 50000 supporting strings (corresponds to an area of 12 ha) each year have been successfully attached with the prototype. The area capacity depends on the shape, configuration and age of the hop garden, but during the testing an area capacity between 0.21 and 0.23 ha/h and an average speed between 1.45 and 1.65 km/h were reached. In the adequately prepared gardens a speed peaks up to 1.9 km/h were determined. Table 2 presents the predicted operational time, calculated based on the results of the testing carried out in April 2013, necessary for wire attaching in hop gardens with 50 hop rows in total and size of 1 ha and 2 ha.

Table 1: Predicted values of the operational time necessary for attaching of supporting wires on area of 1 ha with the device for automated fastening of the supporting wires

	Cultivation area	
	1ha	2ha
Approximate number of supporting wires	4000	8000
Number of hop rows	50	50
Number of plants per row	80	160
Time required for wire attaching (s)	12720	25440
Time required for headland turns (s)	60	60
Operational time (s)	15720	28440

Operational time (h/ha)	**4,37**	**3,95**
Outage time (s)	1248	2496
Operational time including outage time (h/ha)	**4,71**	**4,30**

Conclusions and Outlook

The hop production is labour-intensive and especially the seasonal preparations, like tying up the supporting strings to the cables involves a lot of manual work. Due to the fact that hop belongs to the speciality crops, cultivated on relatively small area in relation to the major crops, an introduction and implementation of new technologies and machinery is limited.

Using contemporary design and analysis tools such as digital prototyping, real-time acquisition of the relevant parameters and their automated analysis combined capturing of high-speed videos during the testing of the systems allowed faster and more reliable design of a novel system for automated attaching of the supporting wires without high expenditures.

In the future, the possibility to communicate between the data acquisition system and the PLC using OLE for Process Control (OPC) needs to be tested. Integration of real-time programmable automation controller or novel modular data acquisition systems needs to be considered in case that higher frequencies or data from additional counters needs to be acquired. The developed software solution will be used as a diagnostic tool for fast troubleshooting. A possibility of simulating and visualising the acquired data *in situ* needs to be considered, in order to better understand the process and easily discover the sources of the failure in case of outage.

The safety aspects of the systems need to be incorporated in the final design and related problems solved according to the new machinery directive 2006/42/EC (Fraser, 2010).

Acknowledgements

The projects “Development of a device for a fully automated wire suspension in hops” was and “Development and optimisation of an automatic hop picking machine” is funded by the German Federal Agency for Agriculture and Food (BLE) as a part of the innovation support program of the German Federal Ministry of Food, Agriculture, and Consumer Protection (BMELV). The authors would like to thank the employees of the Institute for Agricultural Engineering and Animal Husbandry and the Institute for Crop Science and Plant Breeding of the Bavarian State Research Center for Agriculture which were involved in the projects and the private limited companies Soller (Geisenfeld, Germany) and Fuß Fahrzeug- und Maschinenbau GmbH & Co. KG (Pfeffenhausen, Germany) for successful cooperation.

Author: Dr.-Ing. Zoltan Gobor

Company: Bavarian State Research Center for Agriculture, Institute for Agricultural Engineering and Animal Husbandry

Address: Vöttinger Str. 36, 85354 Freising Germany

Phone: +49 8161 71-3897

Fax: +49 8161 71-4363

E-mail: zoltan.gobor@LfL.bayern.de

Internet: http://www.lfl.bayern.de/ilt/

References

[1] Blackmore, S., Stout, B., Wang, M. and Runov, B. 2005. Robotic Agriculture - the future of agricultural mechanization? In J.V. Stafford (Ed.), Precision Agriculture '05. (pp. 621-628). Wageningen: Wageningen Academic Publishers.

[2] Böttinger, S., Doluschitz, R., Volz, R., Jenane, C. and Paterson, S. 2010. World Trends and Evolution of the Agricultural Machinery Manufacturing Sector. International Conference on Agricultural Engineering AgEng 2010, Clermont-Ferrand (France), 06-08. September 2010, USB Flash Drive. Paper no.: REF 449

[3] Fraser, I. (general editor). 2010. Guide to application of the Machinery Directive 2006/42/EC. 2nd ed. Available at: ec.europa.eu/enterprise/sectors/mechanical/files/machinery/guide-appl-2006-42-ec-2nd-201006_en.pdf. Accessed 22 June 2012

[4] Gobor, Z., G. Fröhlich, and J. Portner. 2010. Development of a mechatronic device for automated fastening of the wire that the hop (Humulus lupulus) vines grow on in high-trellis hop gardens. Intl. Conf. on Agricultural Engineering AgEng 2010, electronic file. Paper No. REF 070. France: Clermont-Ferrand.

[5] Gobor, Z., Fröhlich, G., Mair, J., Nestler, J., Soller, H., Portner. J.: Development and optimization of a device for automated attachment of the supporting wires in high-trellis hop gardens. In: VDI-Berichte Nr. 2124, Düsseldorf, VDI-Verlag 2011 (Proceedings of the 69th Conference VDI-MEG LAND.TECHNIK AgEng, Hannover, November 11-12 2011), pp. 115-121

[6] Gobor, Z., Fröhlich, G., Soller, H., Portner. J. (2012).First operating experiences with a prototype for automated attaching of the supporting strings that the hop vines grow on in high-trellis hop gardens. International conference of agricultural engineering, CIGR-AgEng2012, Valencia 8-12 July 2012, Papers book, ISBN 978-84-615-9928-8 p.6

[7] Gobor, Z., Fröhlich, G. Portner. J. (2013). Automated Attachment of Supporting Wires in High Trellis of Hops – Initial Investigation and Study of Performance of an Advanced Prototype. In: *Applied Engineering in Agriculture*. 29(1): 11-16. @2013