Possibilities of using automatic systems for correcting the position of working units of tools including soil cultivation

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Abstract. The progressive technical development of agriculture and the desire to increase the efficiency and quality of agrotechnical processes related to soil cultivation forces the use of more and more complex automation and robotisation processes in agricultural technology. The article introduces the reader to modern control systems for automatic hoeing tools and presents a modern control system for a baler-wrapper, the project of which (POIR.04.01.04-00-0067/18) is implemented by the authors in the Łukasiewicz Research Network - Industrial Institute of Agricultural Engineering consortium with the Metal-Fach company. One of the reasons for the automatisation of agricultural machinery is the departure from chemical methods of cultivating crops, due to the growing awareness of consumers who want ecological and thus healthier products. The influence of automation on organic farming was characterized and its general principles were presented. The automatic cultivators were divided based on the kinematics of the tool movements - they operate on the basis of machine vision. The results of the baler-wrapper tests were presented, confirming the validity of the designed control system. The authors summarized the main advantages and disadvantages of the systems for correcting the position of working tools of machines, considering the profitability of this type of investment on the example of weeder and a baler-wrapper. The article adopts the hypothesis that the development of agricultural automation has a positive effect on the development and popularity of organic farming.

1 Introduction

A significant increase in agriculture automation, including the desire to increase the efficiency of agrotechnical treatments, taking into account the concern for the natural

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environment, has become the reason for the creation of many interesting modern solutions for agricultural machinery. Modern automatic control systems are no longer reserved only for large and complex machines such as tractors or combines. The use of automation in much less complex agricultural machines allows you to increase the efficiency and quality of treatments. The aim of the article is to present the principle of operation of cultivators with visual row detection and tool guidance systems. It is a group of machines designed for the mechanical care of crops in accordance with the requirements of organic farming. The impact of automation and the development of modern agriculture on the ecological cultivation of plants, including those intended for animal feed, will be analyzed. This aspect was presented on the example of a baler-wrapper, the project of which is carried out by the authors of the publication. The aim of the article is also to determine the profitability, advantages and disadvantages of using modern automatic tool correction systems. The paper adopts the hypothesis that the development of agricultural automation has a positive effect on the development and popularity of organic farming.

2 The impact of automation on organic farming

The concept of organic farming is derived from the regulation of the Council of the European Union on organic farming and the labelling of its products and foodstuffs [1]. This manifests itself in the following example actions:

- limiting or abandoning the use of chemical fertilizers and plant protection products (limiting chemicals)
- maintaining and improving the natural fertility of the soil and biodiversity,
- organic fertilization and proper crop rotation,
- running livestock production as an integral part of a farm,
- striving for self-sufficiency of feed on the farm [2].

Striving for ecological functioning of the farm usually entails much greater human workload, regardless of whether it concerns the cultivation of food crops or fodder. This can be well illustrated by the example of treatments aimed at reducing weeds infestation in crops. The application of herbicides to deal with the problem of weeds is simpler and often less expensive, for example in maize crops. The situation is different in the case of vegetable crops, where the use of chemicals is much more expensive and the growing consumer awareness of healthy food additionally motivates farmers to use organic methods. Organic farming is one of the fastest growing branches of agriculture in the European Union. This is evidenced, for example, by the dynamics of growth in the usable area of farms and the number of organic farms. There has been a tenfold increase in the usable area of these farms in the EU since 1993 [2]. The aforementioned increase in usable space and staffing problems related to the outflow of people to large cities are the best proof of the need to automate agriculture, but it is also confirmed by sales data, as well as very positive sales forecasts for the field of automation and robotisation of agriculture.

The Tractica report predicts a very fast and significant increase in the demand for agricultural robots. The market research company forecasts an increase in sales of these machines from around 60,000 units per year to over 727,000 units in 2018-2025. Tractica forecasts that the field robot sales market will reach $ 87.9 billion worldwide by 2025 [3]. The use of automatic agricultural machines has a positive effect on the quality of the processes performed, solves the problem of staff shortages on farms and, above all, has a positive effect on reducing chemical treatment and increases the efficiency of processes. Modern cultivators that are guided to the inter-rows of plants have the above-mentioned advantages. Their types and structure will be discussed in detail later in the article. In addition, the aspect of ecological feed will also be discussed, based on the example of a baler-wrapper created with the participation of the authors of the article as part of a project

carried out by the ŁUKASIEWICZ - PIMR and Metal-Fach consortium co-financed by the National Centre for Research and Development. The above-mentioned examples of machines will confirm the hypothesis assumed in the article that the development of agricultural automation has a positive effect on the development and popularity of organic farming.

3 Methods of correcting the position of working units of soil cutting tools

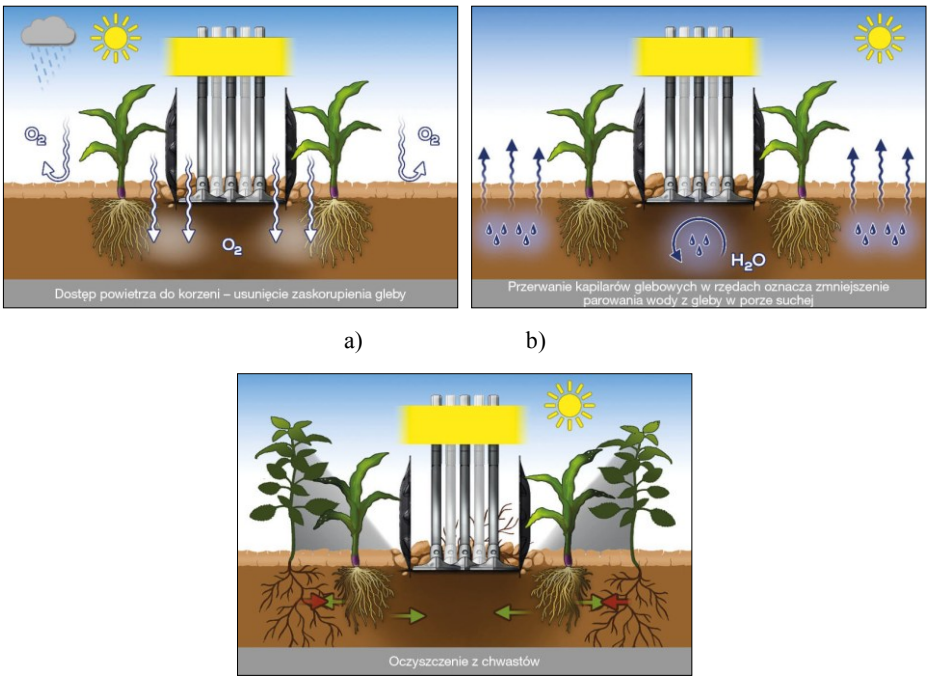
Two main types of tool guidance have been distinguished: lateral correction in the inter-row area and lateral correction in combination with weeding the space between plants in a row. Two sub-types of weeding with pneumatic drive knives and rotor hoes are listed here. All the described methods are based on a visual method of determining the position of plants in relation to machine tools. The article is not devoted to the machine vision, however, it is worth mentioning that the described machines operate on the basis of different technologies - various types of row detection algorithms, different methods of detecting plants based on RGB colour filtration, stereometry or infrared, and thus they use a variety of cameras and electronic equipment. Various methods of counteracting disturbances related to the influence of sunlight, by e.g. illuminating areas with LED light, are also used [3, 4].
The obvious and main purpose of the automatic correction of the position of the machine tools is to relieve the tractor operator and increase the efficiency (speed) of the treatments. However, it is also worth mentioning the advantages of automatic tool guidance systems that have a positive effect on the condition of the cultivated plants. Precise and thorough weeding has a positive effect on the following aspects [5]:

- moving the soil with weeding tools removes soil crust and facilitates air access to the roots (Fig. 1, a),
- reduction of soil evaporation during drought by breaking soil capillaries in rows (Fig. 1, b),
- cleaning of weeds preventing access to light to the cultivated plants and absorbing water and minerals from the soil (Fig. 1, c).

3.1 Horizontal correction for weeding between rows

This is the most common group of automatic weeder. Many different solutions have appeared on the agricultural market. However, it was decided to present one of the most popular - the Culti Cam from Claas (Fig. 2). The cultivator guidance system on the inter-rows of plants consists of: a camera, a controller, an operator panel in the form of a tractor display, LED illuminators and hydraulic valves to control the transverse movement cylinder. The developed tool guidance system for inter-row tools is universal in application because many manufacturers use it in their machines, e.g. Einböck, Busa, Cavalleretti Group. According to the manufacturer, Culti Cam is ideally used in organic farming and herbicide-resistant crops. Increasing the driving speed of the tractor may allow to increase the efficiency of the process while maintaining high-quality weeding by approaching the tools as close as possible to the plants in order to loosen the soil and remove weeds. Thanks to automatic compensation of errors resulting from steering the tractor, the system reduces the risk of damage to crops and relieves the driver. Therefore, it has a positive effect on work ergonomics [6].

The described row guidance system is distinguished by the use of camera stereometry. The detection of plant rows is mainly based on the detection of clusters of the colour of the crop plants of interest to the user and on this basis performing the tool correction.



a) b)

c)

Fig. 1. The advantages of mechanical weeding, where: a - air access to the roots by removing soil crust, b - breakage of soil capillaries resulting in a reduction of water evaporation from the soil in the dry season, c - removal of weeds [5].

Fig. 2. Cultivator with Culti Cam vision system for guiding tools to the inter-rows of plants [6].

This solution gives very satisfactory results in conditions of low weeds infestation in the field. According to the manufacturer, the use of measuring the distance between the plants and the camera allows you to work also in conditions of high weeds infestation, provided

that the plants planted in rows are much higher than the weeds. Choosing an interesting colour is possible from the operator panel [6].

3.2 Lateral correction with weeding of the spaces between plants in a row

This type of automatic weeder is mainly used in vegetable crops where weeding of inter-row and inter-plant spaces are of equal importance. Along with modern autonomous vehicles, a number of automatic and increasingly complex tools appear on the agricultural machinery market. Below are the most interesting examples of machines according to the authors.

3.2.1 Weeding with knives with pneumatic drive

The specified group of automatic machines for weeding the spaces between plants in a row is approximated using the IC-Weeder solution by Steketee (Fig. 3). According to the manufacturer, the machine enables precise positioning of tools, which depends mainly on the driving speed of the tractor - the machine operates at a maximum speed of 0,83 $\mathrm{m \cdot s^{-1}}$ and is intended mainly for weeding vegetables, e.g. lettuce. The vision system is equipped with 3 cameras to recognize individual plants. In order to avoid the harmful effects of sunlight on the cameras, they are placed under the cover. The area under analysis is illuminated with LED lamps, thanks to which repeatable working conditions were obtained. The recognition of plant rows and the guidance of the machine works independently of the tractor, most often using a hydraulic cylinder due to the significant transverse forces of the tools and the ease of supply from the tractor's hydraulics.

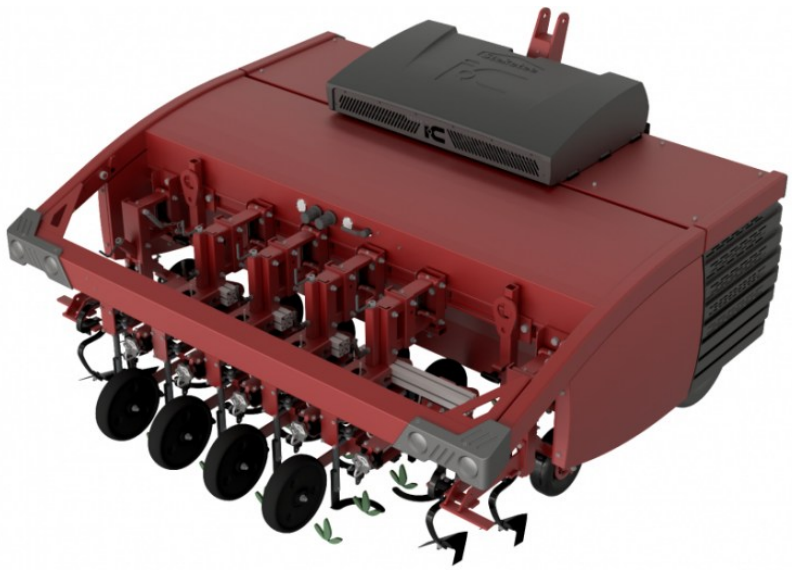


Fig. 3. Automatic IC-Weeder by Steketee for weeding inter-row and inter-plant spaces in a row [8].

The described solution allows the user to determine the colour of the plant he is interested in the machine controller, because it works on the basis of background filtering based on the colour of the cultivated plants. The possibility of parameterization allows to take into account changes in the colour of green plants caused by e.g. nitrogen or water deficiency. The machine detects several rows of plants simultaneously in order to avoid

transients for the machine caused by uneven crop emergence in the rows. The device is equipped with its own compressor for powering and moving active tools [7,8].

3.2.2 Rotor cultivators

The most complicated group of weeding machines in terms of control are rotor cultivators with the rotor oriented vertically or horizontally in relation to the soil. The article focuses on the first sub-type of machines. A weeding tool having four to eight teeth and rotating them is shown in Fig. 4, a. The movement of the implement in combination with the straight-line movement from the tractor forms a cycloid (Fig. 4, b). The device was developed by the University of Osnabrück in Germany in collaboration with Amazon Werke. The main goal was to develop a cultivator to control weeds in maize crops. The rotational speed of the tool is adjusted to the driving speed, which reaches a maximum value of 2,36 $m \cdot s^{-1}$. The control system of the device is based on the machine vision, but also uses distance sensors to determine the exact position of the plants in relation to the machine [9].

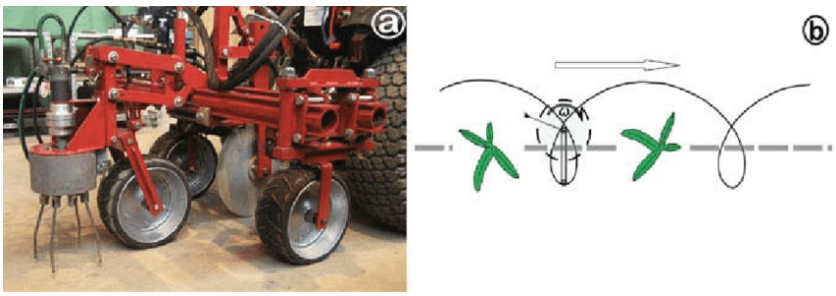


Fig. 4. Automatic rotary cultivator developed by the University of Osnabrück in Germany in cooperation with Amazon Werke [9]: a - rotor hoe design, b - cycloid outlined by weeding tools

A commercial example of a rotor hoe is the Garford robocrop inrow (Fig. 5). The 6 m wide device can operate at a speed of 2 $m \cdot s^{-1}$. It is dedicated to vegetable crops, where it achieves a capacity of 4.2 ha / h. At the tips of the weeding tines there are discs, the profile of which has been specially designed to minimize damage to crops [10].

4 Guiding working tools of the baler-wrapper on the swath

Round baler wrappers follow the trends of ecological agriculture because they are used for the natural conservation of green plant mass in order to maintain the highest possible quality, and thus the greatest possible amount of nutrients in the feed [11]. This translates directly into greater efficiency in milk production. In order to obtain the best quality bales as a result of the pressing and wrapping processes, the machines are equipped with a number of electronic solutions supporting the operation of the machine. An example is a modern baler-wrapper (Fig. 6), which is being developed under the POIR.04.01.04-00-0067/18 project. The machine will be equipped with a modern system for guiding the pick-up of the baler-wrapper onto the swath based on the signal from the 3D camera (Fig. 7), taking into account also the signal from the bale density sensors [12]. Machines automatic systems research is conducted by the employees of the Łukasiewicz Research Network - Industrial Institute of Agricultural Engineering, Department of Experimental Research of Agricultural and Forestry Machines.

Fig. 5. Robocrop inrow Garford company - inter-row and inter-plant weeder [10]

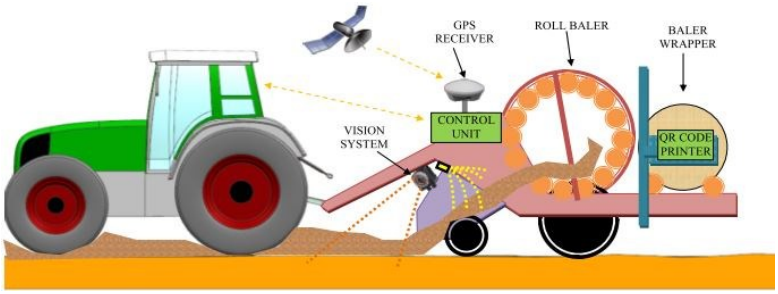


Fig. 6. Baler wrapper-combination for harvesting roughage in round bales with systems of monitoring and impact on the process of its production [12]

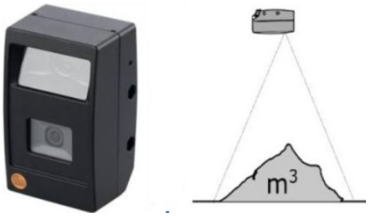


Fig. 7. O3M251 3D camera from IFM - sensor for mobile applications [12]

The use of a 3D camera allows you to read information about the volume and the structure of the raking material. Based on this information, it is possible to direct the tractor, and thus the pick-up of the machine, towards the collected material - thanks to this, it is possible to relieve the tractor operator from the tedious maintenance of the trajectory and to control the even compaction of the bale by directing the machine to the collected material. The volume signal in combination with GPS geolocation data is additionally used to record information about the size of the crop for the purposes of precision farming.

The described solution of guidance on the swath provides information on the arrangement of the material, which is processed by an algorithm that provides guidelines for the tractor driver regarding the trajectory of the tractor. In order to verify the guidelines, the machine has been equipped with an additional function of checking the bale compression pressure, which is registered by two independent pressure sensors on opposite sides of the machine. Differences in the compression pressure signals for both sides of the machine were shown (Fig. 8), which allowed for the design of the machine guidance system for the swath, taking into account the compression pressure compensation in order to press equal in terms of the shape and structure of the bales. The signal from the pressure sensors is a feedback for the described solution. This system is part of patent application. Further research will be aimed at designing an ergonomic operator panel and further refining the pick-up guidance algorithms in order to obtain the best parameters of the baled bales.

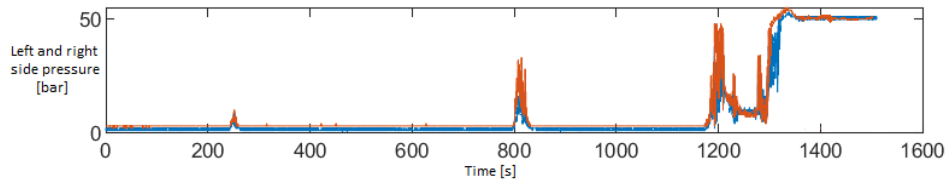


Fig. 8. Bale pressing pressures read from the hydraulic pressure control systems on the left and right side of the machine [source: own work]

5 Advantages and disadvantages of systems for correcting the position of working units on the example of automatic hoes - investment profitability

Between 1970 and 1980, most farmers switched to chemical weeds control using herbicides. After 40 years, for the reasons mentioned earlier in this article, mechanical weeding of crops has been resumed. The economic profitability of mechanical weeding using an automatic hoe is comparable to chemical methods - the higher cost of herbicides is made up for by the high spraying speed [7]. Due to the fact that herbicides act on all weeds within the sprayed area, the chemical method should be compared to the mechanical weeding variant taking into account the space between plants in inter-rows and rows. As previously stated, automatic cultivators meeting this condition, which are commercially available, operate at maximum speeds of up to 0,83 $m \cdot s^{-1}$. Considering the profitability of changing the method of weeds control to mechanical, it should be done based on the price of the final product that will be sold. The prices of organic vegetables are on average 50% higher than that of plants grown in conventional agriculture [13]. Ecological cultivation of plants always entails more work related to fertilizing or weeding plants. Thanks to highly automated machines, it is possible to increase the production of organic plants and thus increase the profit on the sale of high-quality natural products. This type of weeds infestation regulation cannot compete with chemical methods in terms of the speed of the treatment, but it is undoubtedly much more efficient than manual weeds removal methods and does not involve the risk of staff shortages. From the user's point of view, the undoubted disadvantages include the high price of the device - it is estimated that it is over 5 times higher than that of standard mechanical weeder [14]. Considering that the cultivators with automatic tool position correction in generally available commercial versions were introduced to the market around 2019, it is a still developing machine technology, which will certainly become more common and cheaper. Undoubtedly, the

greatest advantage is the relief of the operator from the tedious and precise driving of the tractor and the increased accuracy and quality of mechanical weeding.

6 Summary

The examples of agricultural machines presented in the article, using advanced control and control systems, show a great potential and an increase in the popularity of automatic machines with tool position correction systems. The purpose of using modern solutions in agricultural machinery is to increase the efficiency and quality of agrotechnical processes, especially those related to the technique of cutting and soil processing. Examples of the positive impact of automation on organic farming are presented, proving the assumed thesis. Organic farming is not only food products, but also the production of high-quality animal feed. The presented author's example of a baler-wrapper follows this tendency. Automation and robotisation of agricultural machinery have gained a rapid pace of growth and is the future for its development. We are witnessing another agrarian revolution.

Acknowledgments: The article has been written in the framework of the project POIR.04.01.04-00-0067/18, financed under Priority axis IV „Increasing the research potential", 4.1 „Research and development works", 4.1.4 „Implementation projects" of the Smart Growth Operational Programme 2014-2020.

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