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Policy Brief

Key Messages

- Increasing scarcity and cost of labour are driving forces for the automation of certain agricultural tasks.
- The trend towards precision agriculture will enable farmers to maximize resource use efficiency and avoid or reduce pesticide use.
- Decreasing cost as well as increasing functionality of robotics and enabling technologies will allow economic applications.
- Advances in robotics technology in industrial or automotive environments can accelerate the development for agricultural applications.
- Increasing investment and interest in the sector from governments, corporate bodies, and institutional investors can support market penetration.

Autonomous Agricultural Machinery

By Jens Fehrmann

Introduction

Increasing robotization and automation can be currently observed in agriculture. These trends, which are already enormously advanced in other industries, are still largely in their infancy in agriculture due to its numerous dynamic and biological requirements. Robotics is a key technology for this development as it can increase productivity and quality in times of scarce resources. To accelerate the introduction of new sustainable technologies, the system approaches must be implemented and demonstrated in defined agricultural environments and on mobile machines. The integration of the Global Navigation Satellite System (GNSS) information into the new IT system architecture is essential for logistics, automation and traceability. If investment costs (€/ha, €/t) and output (ha/h, t/h) for a new machine system such as machine swarms or field robots can be reduced to the level of today's mechanization, these concepts will be relevant to the market.

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Global status quo of Autonomous Agricultural Machinery

In addition to plant breeding and developments in plant protection and fertilization, agricultural technology provides the technical basis for production in agriculture. Agricultural engineering is an interdisciplinary area that uses knowledge from mechanical engineering, computer science, information technology, materials engineering and microelectronics to improve technical products and agricultural processes. Decisive development criteria are decreasing process costs, which can be achieved through continuous growth in technology. This increase in productivity has so far been achieved through larger, faster, wider, more powerful and heavier machines and attachments.

To further increase productivity, new ways are being sought. Agricultural process optimization, better utilization of existing capacities, optimal use of operating resources and machine operator assistance are now the drivers of the development. Sub-processes in the machines are automated, such as automatic steering systems, automatic machine settings, headland management (a function with automatic machine processes for turning the tractor and attachment at the edge of the field) and height control on the cutting unit. Precision farming methods have become established for the optimal use of operating resources. Many technological developments of recent years will soon result in a very high degree of automation or, specifically, of agricultural robots. The introduction of the satellite navigation system was particularly decisive for robots in crop production. Only this technology enables orientation in the field without additional infrastructure on the ground. With this geospatial information, machines can be controlled and field processes planned on an area-related basis. Machines can communicate with each other by means of mobile data transmission, work orders and machine settings can be digitally transmitted to machines, and machine data can be stored and processed centrally. The development of machine-internal BUS systems enables the control and regulation of agricultural machines based on received digital data.

High computing power, high storage capacities and the miniaturization of electronic components in the control units of the machines allow the processing of the data and the dynamic setting of machine parameters, which can thus process area-specific agricultural processes such as single-grain sowing in maize or fertilization according to nitrogen requirements [1]. To be able to implement this area-specific cultivation of soil or plants, precisely controllable actuators are required, for example, to remove a weed plant using an electrically controlled mechanical hoe. The precise control of manipulators was made possible especially by developments in the electric drive area and is further promoted by electrically powered vehicles in agriculture. Compact sensor technology from factory automation and automotive or from areas not related to agriculture is used to automatically control combine harvesters and forage harvesters in the field. Compact camera technology is used to recognize the surroundings. For developers, there are tools for control programming and the integration of sensors to program mechatronic systems, which include agricultural robots.

Market overview

In a study on the market development [2] concerning field robots for crop production by the HBLFA, Francisco Josephinum Wieselburg, one of the leading agricultural research institutions in Austria, a total of 136 robot models from 109 manufacturers and 26 countries around the world in different stages of development were listed by October 6, 2021. Agriculture robotics is a topic that is being worked on around the world to develop solutions for agriculture. The US is the front runner in this area with a total of 30 companies, some of which are located in Silicon Valley. In Europe, France stands out with seven robot models already available. This is mainly due to the large number of companies specializing in wine and vegetable growing in France.

The developers mainly focus on two topics: sustainability and reducing manual activities. In the Western countries in particular, society and politics are calling for a reduction or the abandonment of chemical pesticides, but the increased resistance of weeds is also driving developments. It is therefore hardly surprising that a total of 36 robot models are intended for physical crop protection. However, the use of robots often allows deviating from conventional methods and, thanks to image processing and artificial intelligence (AI), the field is no longer driven "blindly", but the weed plants are treated individually. The methods range from "classic" tearing out or spilling to spraying with hot vegetable oil [3] or burning with a laser beam [4]. In chemical crop protection, too, the path is moving away from full-surface application towards treating individual plants and thus reducing the application rates.

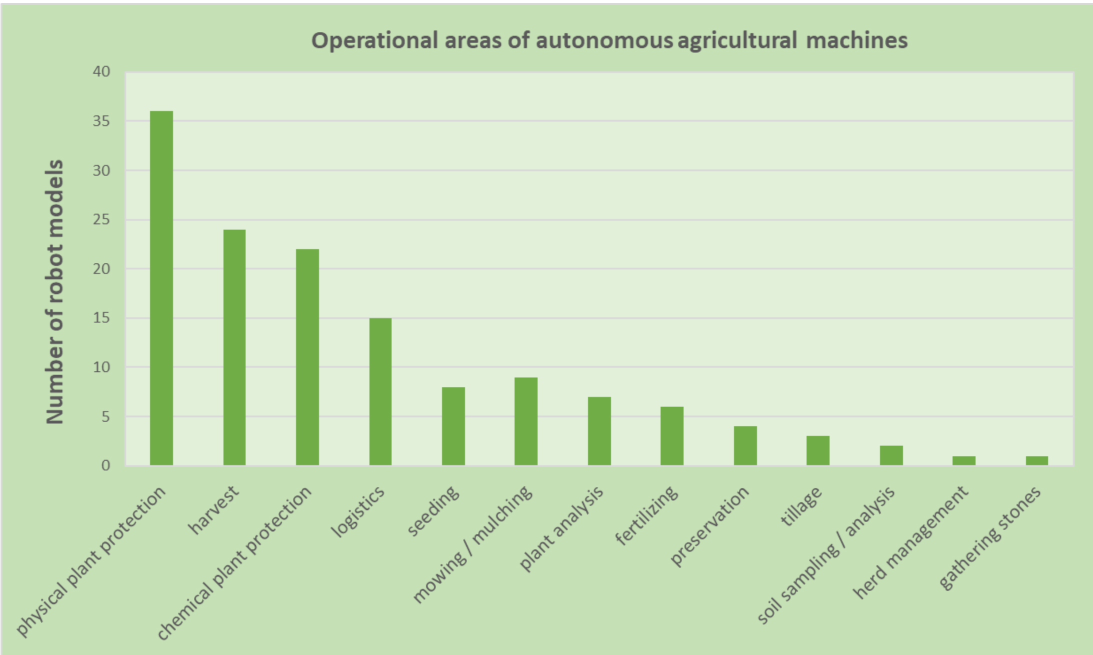

Figure 1: Operational areas of autonomous agricultural machines [2]

The second major innovation driver in agricultural robotics is the reduction of manual work, as this is a major cost factor, in particular, in crops like fruits and vegetables. The innovations range from logistics robots, which bring the manually harvested crops to central collection points, to robots for the autonomous harvest of the fruit, to special applications such as phenotyping of different types of sugar beet in farms. Most manufacturers keep a low profile when it comes to pricing, especially if development is still ongoing. No price could be found for 79 models. Hardly any specific information is given regarding the costs of the services either, here manufacturers often point to costs that are similar to those of conventional methods.

Economic considerations

In scientific literature on autonomous agricultural engineering, there are very few publications on economic efficiency. Many authors still see the high costs for sensor technology, electronics and RTK-GPS systems as a major hurdle for autonomous small machines. In the future, due to technical progress in other industries, considerable potential for cost savings is expected.

In [5], a small machine scenario was therefore theoretically developed to be able to estimate costs and to compare them with a large-scale technology scenario (KTBL 2017). Approach, conception and estimation of the work completion costs with current conventional machinery and in the small autonomous robots scenario can be found in the literature [5].

The cultivation of an area of 150 ha of wheat in the Magdeburger Börde is simulated. The selected small-scale technology scenario relates to wheat with close plant spacing. First, the number of robots required for one of the agricultural process steps is determined. For tillage, sowing and harvesting, the available field working days are derived from KTBL data sheets (2016). For soil cultivation, an average value is calculated from Level 2 (seedbed preparation, sowing) and Level 3 (stubble cultivation). This takes into account that due to their lower soil pressure, lighter field robots can also drive with higher soil moisture contents. If the whole area shall be fertilized in one day , as it is done nowadays, a correspondingly large number of robots are necessary. The number of robots has been calculated for nitrogen applications of up to 130 kg urea/ha.

Theoretically, however, small and light field robots can drive longer in moist soil conditions than today's tractor-machine combinations and are also probably not as susceptible to wind when applying fertilizer. Assuming seven available field working days rather than one day, the requirement drops from around 200 to 30 robots for a total area of 150 ha. A time frame of four or seven days is assumed for plant cultivation The range is chosen to be no longer than a week so that there is a minimum nitrogen concentration in the soil for plant development. The earlier and more accurate future technology can recognize the infestation sources, the easier it is to implement part-area-specific treatment, which would tend to require fewer robots. For mechanical weed control, it has been assumed that three treatments will be done in autumn and two treatments in spring, each seven days apart. This assumption is based on previous experience in organic farming so that weeds can still be controlled with the harrow. The number of robots has been calculated for each process to ensure that the activities can be carried out separately from one another. The robots required could be reduced by using the robots in other processes or by allowing the designed robots to perform different tasks at the same time. For this purpose, further model calculations can be carried out in the future to show potential savings. The results of the cost calculation are shown in the following table:

operating costs		**tillage and seeding**	**harvest and logistics**	**fertilizing** 7 - 4 days	**chemical plant protection** 6 -1 days	**physical plant protection**
number of robots		1	1 harvesting robot 1 logistic robot 1 threshing station	30 - 50	3 - 15	64
price robot	[€]	23,300	17,300 12,400 22,300	1,000	1,200	900
capital costs	[€/ha]	12	27	15 - 26	2 - 11	30
Maintainance costs	[€/ha]	3	7	4 - 7	0.5 - 3	8
energy costs	[€/ha]	11	18	1	0.5	2
Sum (costs robots)	**[€/ha]**	**26**	**52**	**20 - 34**	**3 - 15**	**40**
Costs conventional technology (KTBL 2017)	[€/ha]	28; 36	107	25	7	55

Figure 2: Operating costs with today's conventional technology compared to the simulated field robot scenario [5]

In this scenario, the variable costs of operation of the small robots are already competitive to the conventional technologies for selected field operations like harvesting or physical plant protection.

The profitability of the small technology depends heavily on the number of machines required. If machines can be used in multiple processes, the utilization can be increased and the costs reduced. Further economic advantages for farms with autonomous small-scale technology could result from the direct costs (pesticides, fertilizers). However, the effectiveness of autonomous field robots must be examined in field tests to make more precise assumptions.

Policies and measures to regulate the use of Autonomous Agricultural Machinery

The question of liability for damage caused by the use of autonomous vehicles has not yet been conclusively clarified. It is a matter of dispute whether vehicle manufacturers or users are liable. In any case, the user of autonomous agricultural systems is subject to traffic safety obligations, the scope of which depends on the degree of risk caused. A breach of these traffic safety obligations leads to liability on the part of the user. This is a general principle of liability, the person who opens up a source of danger is liable for a sufficient level of safety precautions so that no privileges are required here. In addition, there is, in principle, a risk that attempts will be made to formulate contractual liability stipulations when purchasing a vehicle to the detriment of future vehicle users. It remains to be seen whether such behaviour, which already appears to be vulnerable under civil law, will trigger the need for legislative action in order to avoid a one-sided distribution of risk. [6]

The German legislation (§ 1a STVG) provides that motor vehicles can also contain fully automated driving functions under certain conditions. For the reasons mentioned above, there is no corresponding special regulation for agricultural machinery. They fall within the scope of the EU agricultural machinery directive. For the future use of automated vehicles in agriculture, just as in road traffic, clarification of the liability situation will be decisive. It can be assumed that the draft law for road vehicles announced by the BMVI will deal with the issue. A regulation for agricultural machinery can possibly be based on this. [7]

Requirements regarding data infrastructure, data exchange and data sovereignty

Since autonomous agricultural systems are dependent on data or data exchange, a sufficient data infrastructure is a basic requirement. The type of infrastructure required depends on the particular application. For navigation, satellite data are necessary, while communication between humans and machines or between machines requires either communication via a local network without an Internet connection or a mobile radio network with an Internet connection. In principle, a high-performance cellular network is an essential prerequisite for many autonomous applications on agricultural land and is at least helpful for most of them.

To enable data transfer between different systems and manufacturers, it is also necessary that better standardization takes place and that data interfaces are transparently documented. An essential aspect is the consideration of resilience. The maintenance of the minimum function of autonomous agricultural systems in the event of data loss or failure of services in the event of a crisis must be guaranteed. It is essential for the farmer that they retain sovereignty over their data. [7]

How to support the adoption of Autonomous Agricultural Machinery?

The agricultural profession has increased in complexity over the past few years. The activities go far beyond the production of good, safe food. In a digitally transformed agriculture, the farmer will develop into the manager of operational processes and, to a greater extent, make use of qualified services in planning, evaluation and use of technology, most of which could be integrated via farm management systems. In collaborative automation strategies with "Shared Autonomy", the scope of duties of the automation of mobile machines is expanded significantly in the direction of the development, implementation and evaluation of assistance strategies that promote the acquisition and maintenance of complex problem-solving skills of the operator. The consideration of external costs not covered by market prices (e.g., sustainability aspects, environmental protection or social aspects) becomes increasingly important in food production. When it comes to social aspects, it is primarily the time and physical load that is gaining importance. With digital tools and an increasing degree of automation, farmers can better meet the new challenges. Very time-consuming or physically demanding work can be taken over or made easier by autonomous agricultural systems. However, these new techniques cannot replace a farmer's expertise and experience. Overarching tasks such as overall management and final decisions are in the hands of the farmers. This status quo must be supported by suitable human-machine interaction and knowledge representation.

Recommendations

To improve the acceptance and promote the use of autonomous agricultural machines, the following recommendations for action were formulated by a panel of experts [7]:

1. Increase practical experience and the establishment of test and consulting options to show the benefits, opportunities and risks of autonomous agricultural systems, to clearly evaluate them using qualitative and quantitative criteria and to be able to quantify the importance of ecological, economic and social aspects. The support from the public sector can be based on the European funding program EIP-AGRI (https://ec.europa.eu/eip/agriculture/en) . Research and development work, practical applications and introduction to farmers in operational groups are combined here.
2. Ensure a higher level of investment security through effective knowledge transfer models, the promotion of pilot projects with practical application and targeted information about existing opportunities to small and medium-sized farms in particular.
3. Reduce and clarify legal uncertainties for agricultural technology manufacturers, agricultural service providers and farmers.
4. Create framework conditions for placing (autonomous) agricultural machines on the market that promote interfaces for data exchange, open transmission protocols, describe minimal data sets and metadata. In this context, reference should be made to the “Feasibility study on state digital data platforms for agriculture” [8].
5. Provide interdisciplinary, practice-oriented research funding regarding knowledge representation in practical agriculture (learning from, through and with machines and people in a team) as well as relevant training and further education.

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About the project

The Sino-German Agricultural Centre is a joint initiative of the German Federal Ministry of Food and Agriculture (BMEL) and the Ministry of Agriculture and Rural Affairs of the People's Republic of China (MARA). It was established in March 2015 as a central contact and information point and for coordinating bilateral cooperation between Germany and China in the agricultural and food sector. The DCZ brings together stakeholders from the public and private sector and the scientific community. It creates forums in which agricultural issues of common interest are addressed. The spectrum of Sino-German cooperation in the agricultural sector is reflected in the three components of the DCZ: Agricultural Policy Dialogue, Agri-Food Business Dialogue and Scientific Dialogue. Further information can be found on the project website.
https://dcz-china.org/en/the-project.html