

Trends in the agricultural machinery of the future and how electric linear actuators can be used

Scientific Whitepaper by Dr David Reiser and Prof. Dr Hans W. Griepentrog



The Department of Process Engineering in Plant Production at the University of Hohenheim is testing the possibilities of robotics in agriculture with the "Phoenix" experimental vehicle.

Abstract

Today's agriculture is facing major changes caused by digitisation and automation. This white paper is intended to provide an overview of and summarise current developments and tendencies. The focus is on the use of electric actuators and their influence on the development of future machines. Only the application and development in agriculture is considered. For this purpose, a comparison of hydraulic and electric actuators is first performed, then current applications of linear actuators and control and regulation concepts are dealt with and the necessary power requirement of current tasks is estimated. The trends of the agricultural machinery of tomorrow are outlined based on this. Future developments and requirements, digitisation, communication and the future of linear actuators in agricultural machinery and robots are presented here. It is to be expected that linear electric actuators will further advance the development of agricultural machinery in the future and enable new potential for optimisation.



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INTRODUCTION

General

Agriculture has always been a driver of innovation of new technologies and developments, especially in Germany. Johnson describes a direct link between the mechanisation of agriculture and the prosperity of a country¹. This is particularly evident in the number of people working in the agricultural sector. In Germany, the number of people employed in agriculture fell from 22.5% in 1950 to 1.5% today. Despite all this, more food is currently being produced in Germany than ever before². The average yield per hectare of a wheat field has quadrupled since 1900 from 1.85 tonnes to 7.64 tonnes in 2017³.

The mechanisation and automation of production processes had a particular influence on the advancement in agriculture⁴ [4]. According to the German Federal Statistical Office, 6.4 billion euros were spent on new and highly-automated agricultural machinery in 2017 [2]. This high sum underlines the willingness of the agricultural industry in Germany to invest in new innovative technology. The requirements with regard to agricultural machinery have changed over time. Some features of earlier agricultural machines are no longer in demand today, while new skills are required. Typical changes over the years included absolute machine size, engine power, comfort, safety and modern automatic steering and driver assistance systems⁵.

Digitisation does not stop at agricultural engineering and will continue further in the future. "Deep Learning" and "Internet of Things" (IoT) have been around for a long time in agricultural research and are now being used in the first commercial products. Some examples of this in practice are smart phone apps for determining plant diseases and weeds⁶. Automated robotics solutions can now also be purchased and offer added value for the user (e.g. hoeing weeds in row crops). Robots in the field offer the opportunity to extend digitisation down to individual plants. Therefore, on the level of a "digital twin", the development of the plants can be examined even more closely⁷.

1 Δ G. Johnson, "Agriculture and the Wealth of Nations" in Papers and Proceedings of the Hundred and Fourth Annual Meeting of the American Economic Association, 1997, vol. 87, no. 2, pp. 1–12.

2 Statista, "Landwirtschaft in Deutschland", 2019. [Online]. Available: <https://de.statista.com/statistik/studie/id/6455/dokument/landwirtschaft-statista-dossier/>. [Accessed: 04-Sep-2019]

3 P Pascher, U. Hemmerling and S. Naß, Situationsbericht 2018/19 „Trends und Fakten zur Landwirtschaft“. Deutscher Bauernverband e.V., 2018

4 M Kassler, "Agricultural Automation in the new Millennium" Comput. Electron. Agric., vol. 30, no. 1–3, pp. 237–240, Feb. 2001

5 J. N. Wilson, "Guidance of agricultural vehicles - a historical perspective" Comput. Electron. Agric., vol. 25, no. 1-2, pp. 3–9, Jan. 2000.

6 A Kamlaris and F. X. Prenafeta-boldú, "Deep learning in agriculture: A survey" Comput. Electron. Agric., vol. 147, no. February, pp. 70–90, 2018.

7 A Linz, J. Hertzberg and J. Roters, "„ Digitale Zwillinge " als Werkzeug für die Entwicklung von Feldrobotern in landwirtschaftlichen Prozessen Material und Methoden" in Lecture Notes in Informatics (LNI), Gesellschaft für Informatik, Bonn, 2019, pp. 125-130.

With the expansion of digital infrastructure, these technologies will create new opportunities for food production of the future. After many innovation cycles in agriculture such as through mechanisation, pesticide development, mineral fertilisers, plant cultivation and precision farming, digitisation is credited with the potential for the next innovation cycle. It is expected that by adapting and further developing the technology with the help of digitisation, new optimisation potential in agriculture can be identified and used⁸. This includes automation using drones and robots. If you believe forecasts by experts, many swarm-based robots will do the field work of tomorrow in the future, which will further relieve farmers. An overall and sustainable change in agriculture will therefore be promoted. Automation is expected to reduce the size of future machines and tasks will be distributed^{9/10/11}.

However, for the practical use of these machines and robots, the necessary technology and infrastructure must first be available. The success of digitisation depends heavily on the actuators used. Because only if information gained through digitisation can be suitably converted into activities and actions can a benefit be generated for the farmer. Currently, the increase in the resulting data is exponential. Artificial Intelligence (AI) applications require a doubled computing requirement every 3.5 months on average¹². This also increases the costs for data analysis, data management and the necessary digital infrastructure. This generates a lot of data that is never used to increase productivity. Even if intelligent algorithms generate added value from the data, this knowledge must be put into practice. This is only possible with suitable automation of the processes. Therefore, the success of digitisation and AI is directly related to robotics and automation. New information obtained through digitisation should be automated, accurate, energy-efficient and user-friendly in actions and recommendations for action can be transferred. Therefore, the requirement arises for independently operating robots and machines to take as many decision steps as possible for the user, or at least to support the user in doing so. The mechanics must be able to convert the finely resolved data and information practically in order to be able to control sections or even perform an individual plant processing. The future lies in the direct, local application of sensor data, which is supported by cloud-based information.

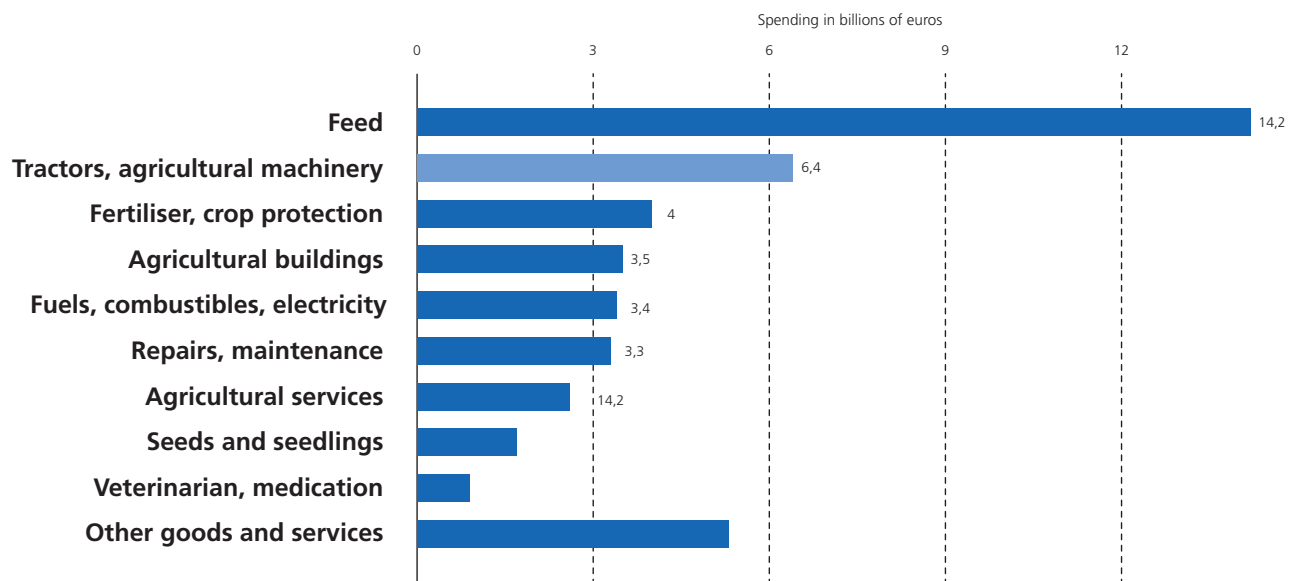
8 BMEL, "Digitalisierung in der Landwirtschaft Chancen nutzen - Risiken minimieren", 2019.

9 S. M. Pedersen, S. Fountas, H. Have and B. S. Blackmore, "Agricultural robots - system analysis and economic feasibility" *Precis. Agric.*, vol. 7, no. 4, pp. 295–308, Jul. 2006.

10 B S. Blackmore, HW Griepentrog and S. Fountas, "Autonomous Systems for European Agriculture" in *Automation Technology for Off-Road Equipment*, 2006.

11 T Duckett et al., "Agricultural Robotics: The Future of Robotic Agriculture" UK-RAS White Pap., pp. 36, 2018

12 F Müssig, "AMD- CEO Lisa Su schaut in die Halbleiter-Zukunft" heise online, 2019. [Online]. Available: <https://www.heise.de/newsticker/meldung/AMD-CEO-Lisa-Su-schaut-in-die-Halbleiter-Zukunft-4500699.html>. [Accessed: 04-Sep2019]



Source: Statista Dossier Landwirtschaft ID6477

Current problems in agriculture

Cuts in subsidies, rising production costs, environmental regulations and a bad social image pose particular challenges for today's agriculture. In particular, compliance with drinking water and water conservation as well as counteracting bee mortality and decreasing biodiversity are expectations for agriculture. There are additional demands for the current climate protection plan to achieve a permanent reduction in CO₂ in agriculture by more than 30% by 2030. This will be implemented through savings on fertilisers and fossil fuels¹³. Likewise, there is increasing pressure on national politics to enforce Europe-wide guidelines, as the current amendment to the Fertiliser Ordinance (2019) shows.

Agricultural technology will have to react to such requirements if agriculture does not want to lose its social acceptance. Overall, the multitude of legal regulations is increasing significantly, making it difficult for individual farmers to comply with all rules and regulations. Future agricultural machinery will therefore have to act more in co-operation and more networked in order to meet the various increasing demands. Likewise, the energy efficiency and the carbon footprint of the machines must be optimised. This includes the automatic adaptation and optimisation of processes, the integration of external sensors and information sources, as well as the ability to provide and analyse information about the actual process in real time. In addition, electrification offers new potential savings, which could be used in an even better way in the future.

Subject Area and Structure

In order to limit the scope of this white paper, the focus is on agriculture in Germany. The focus is on the use of linear movements and actuators for machines in an average German arable farm. The state of the art chapter deals with the current “actual state” of agricultural machinery and vehicles. The used technology and control for linear movements and with what purpose they are used are considered. Machine size, tasks, power and energy requirements are determined and analysed. Current control principles, energy supply and communication protocols are also described in this chapter. In the following chapter Trends in Agricultural Machinery of Tomorrow, the points of the previous chapter will be revisited and linked with development and research, as well as with future perspectives in agriculture. In conclusion, the findings are summarised and evaluated.



Hydraulic and Electric Actuators

Currently, linear motions are mainly regulated by hydraulic cylinders in agricultural machinery. Typical examples are the front and rear hitch of the tractor. The big advantage of hydraulics is that high forces can be generated with space-saving actuators. These are also very simple in their basic structure. They consist of a few individual parts and can therefore be produced and repaired cheaply. The additionally required components such as the pump and the oil tank can be flexibly arranged on the machine. Another advantage is the simple control, which is implemented via the oil pressure and a suitable control valve. Likewise, hydraulic systems have a damping effect that can absorb high force peaks. Due to the flexibility of oil, hoses and the pump, the actuators can yield counteracting forces without risking a destruction of the mechanism. Disadvantages are the necessary hoses or lines, which must be placed on the actuator in the machine. These bulky hoses can affect the flexibility of the design and the mechanical properties of the device. This results in high maintenance, especially in moving systems. Theoretically, the hoses of mobile construction machinery should be completely renewed every six years, which is hardly implemented in practice¹³. Similarly, contamination of the environment with oil is a problem, as actuators, ports and couplings may "leak" or connections may be leaking. In practice, oil hoses can also burst, which can lead to an emptying of the entire oil supply (usually over 50 litres) of the machine and represents a safety risk for the user. The precise control with hydraulics is very complex, since influencing factors such as hysteresis, seal wear and temperature change the result of the control.

These disadvantages mean that more is being placed on electric actuators. This form of actuator is on the rise in areas where contamination with oil is undesirable and unacceptable. Even in areas where low power but high precision are required, electric actuators have advantages and are already being used today. Electromechanical actuators usually use a ball or roller screw drive, which is driven by a locally mounted electric motor. Since the entire drive system is installed in the actuator, this is much more flexible and requires only a matching power and control line to act. Although electric actuators

13 DGUV, "Hydraulik-Schlauchleitungen - Prüfen und Auswechseln" no. 03, 2018.



Hydraulic cylinder



Electric actuator

| HYDRAULIC ACTUATORS | ELECTRIC ACTUATORS |
|---|--|
| <p>Operating principle: A pump removes oil from a storage tank and creates pressure in the line. The pressurised oil is introduced into the hydraulic cylinder using a control valve or returned to the oil storage tank. The resulting force is determined by oil pressure and cylinder size.</p> | <p>Operating principle: An electric motor generates a rotating motion, which is transmitted into a linear motion via a mechanical gear. The energy is supplied via a power line to a power source such as a generator or an alternator.</p> |
| <ul style="list-style-type: none"> + High forces + Lower costs + High robustness + Low actuator weight ÷ High maintenance cost ÷ Hysteresis and seal output ÷ Danger of pollution ÷ Bulkiness through hoses ÷ Operator protection, working with high pressures | <ul style="list-style-type: none"> + High acceleration + High repeat accuracy + Accurate and easy control + Cable instead of hoses + Simple digital control + Low maintenance + High energy efficiency ÷ Limited strength ÷ Higher costs ÷ No damping property ÷ Higher actuator weight |

are heavier in comparison to their hydraulic partner since they require a motor and transmission, they have the advantage that they usually have a higher power range and offer a much higher positioning accuracy. In addition, the pump and pipes are omitted, which increases the flexibility of the drives in the configuration. The fast response, the precision and the repeatability allow significantly more precise control and regulation than can be achieved with hydraulic systems. In most cases, however, the costs for the electric drives are slightly higher than those of the hydraulic competitors. The table above explains the basic principles of hydraulics and electromechanics and their advantages and disadvantages.

Linear actuators in agricultural machinery and attachments

The following tasks typically occur in an arable farm over the year:

- Tillage
- Sowing
- Stand care (weed and pest control, fertilisation)
- Harvest
- Transport / storage

These tasks are implemented in the combination of tractors with suitable attachments or with a specially made self-propelled machine such as a combine harvester. Most of the attachments are only used for a small amount of time each year, which means that they should save the user money. For example, the cost of deployed mineral fertilisers is many times higher than the initial cost of the spreader itself. Large and expensive self-propelled machines such as combine harvester or field chopper are only purchased by larger companies. For medium-sized and small businesses, these are booked and provided through machinery contractors or machine pool. The individual tasks of an arable farm and the typical tasks and optimisation parameters are described below.

Tillage (T): In the case of tillage, the focus is on the uniform and, depending on the target, specific processing of the area. Typical optimisation parameters are the processing quality (e.g. crumbling and soil loosening), the minimisation of the energy input and the optimisation of the speed. In addition, soil erosion due to processing adapted to the site must be minimised. In practice, the arrangement of the processing equipment into its position, angle and depth is set manually. The depth guidance is controlled mechanically via rollers and trailing wheels. In order to ensure that the tools ease off in the event of obstacles (e.g. stones), the tools usually have spring suspension. The spring strength, the tools and the arrangement are manually adjusted to the specific location. Only the lifting and digging is controlled by the rear power hitch of the tractor. However, there are first machines with “Section Control” for the insertion and removal of individual ploughshares and the automatic adjustment of cutting widths and row spacing. Likewise, the automatic and site-specific adjustment of the tool pressure is possible.

Sowing (S): When sowing, the influencing factors such as the sowing depth, the row spacing and the singling or even distribution of the seed are important. If these are guaranteed, the focus will be on a conventional attachment to allow more area to be processed in less time. Standard machines usually

only allow a manual parameter setting. Changes in sowing strength are now also automatically adjustable on new machines. Tillage is often combined with the sowing. The no-till and strip-till techniques are interesting variations. The latter works only on the area of sowing and leaves the rest of the field untouched. Here, too, the desire is to be able to flexibly control the influencing factors specified without having to carry out a lot of manual adjustment work.

Stand care (SC): All work which serves the preservation and the care of the stand after its establishment is summarised under stand care. This includes fertilisation, weed control, and pest and disease control. Different requirements arise depending on the task and the stock. Basically, it is important to act in a particularly plant-friendly manner and to carry out the process optimally and precisely. Precision agriculture offers the greatest potential here. On the one hand, this is due to the possible material and cost savings and on the other hand to the legal regulations which mainly regulate this area of agriculture (plant protection regulations, fertiliser regulations, water protection, insect protection, etc.). The variable application of mineral fertiliser was one of the first practical precision agricultural applications. Other examples are active field sprayer section control and control of hoeing equipment. In addition, this area covers the largest period of time over the year. While sowing and harvesting have only small working windows, stock management must be carried out and adapted over several months (in small distributed time windows). Likewise, correct stock management improves yield and quality by supporting the stock in its development (e.g. through weed control, pest control and fertilisation).

Harvest (H): Basically, it is important to harvest as much area and crop as possible in a short window of time/weather when harvesting in arable farming. In addition, the harvest should be collected and transported in good quality. For these reasons, harvesters are the largest and most expensive machines in agriculture. For some time, these have already reached the maximum permitted sizes for road traffic. The main focus for development in recent years has been on further optimising crop quality (sensor-assisted machine setting) and minimising harvest losses. Further focal points are the reduction of damage caused by ground pressure and the use of driver assistance systems. At harvest time, some of these machines are operated around the clock in order to recoup the high machine costs. For this reason, higher demands are placed on durability and robustness (ultimately reliability) than in other areas.

Transport / Storage (TS): Especially during harvesting, transportation is essential for the smooth running of a harvest chain. Usually several vehicle combinations are required to transport the harvest from the harvesting machine. There is potential for optimisation in approach, overloading time, overloading position and loading quality. For example, when chopping maize, the tractor with loader wagon must be able to drive parallel to the forage harvester during the overloading period so that no crop is lost. This can partly already be done with sensor support, e.g. by means of a camera. The “machine to machine” communication for controlling the tractor speed is also already implemented during the overloading period. Ingredient measurements using near-infrared spectroscopy systems can now be used to determine the dry matter and nutrient content on a site-specific basis. This can be used for billing and storage optimisation.

Currently, many parameters, especially for attachments, are only manually adjustable and cannot be manipulated via actuators. The direct automatic manipulation of these parameters using sensors and actuators offers high optimisation potential and an increase in the ease of use for machines and attachments of the future. The following table lists some examples of machines for individual work steps and evaluates the influencing variables according to power requirement, setting frequency, optimisation potential and cost savings for the farmer. For the evaluation, these were each divided into three classes (high/frequent, medium, low/rare). The following guide values were used to determine the classes:

The table shows that, while there are many possible controls in current machines, the usage potential is very different. In most cases, the greatest benefit is the increased comfort and faster setting of the machine parameters. Process optimisation and direct cost savings are possible if the quality of the process can be improved by precise control. Precise control can reduce the loss of material (e.g. spray, fertiliser, seed) and crop. This effect can be further enhanced by autonomous machines and robots.

Power requirement: “high” - over 700 W; “medium” - 700-300 W; “low” - under 300 W

Setting frequency: “high” - continuous; “Medium” - 1x per headland; “Low” - 1x per operation

Optimisation potential: “high” - over 5 %; “medium” - 5-1 %; “low” - under 1 %

Selected examples of process parameters with an estimate of power requirement, setting frequency and optimisation potential

| Process | Machine | Cause variable | Power requirement | Adjustment frequency | Optimisation potential/ cost savings |
|---------|-----------------------------|------------------------------|-------------------|----------------------|---|
| T | Cultivator, disc harrow | Machining depth | medium | infrequent | low |
| T | Plough | Pull point adjustment | high | infrequent | low |
| T | Plough | Working width | medium | often | medium |
| S | Single grain sowing machine | Singling | low | infrequent | medium |
| S | Single grain sowing machine | Placement depth | medium | infrequent | medium |
| S | Seed drill | Track marker control | medium | medium | low |
| S | Single grain sowing machine | Coulter pressure | medium | often | medium |
| SC | Field sprayer | Boom control | medium | often | medium |
| SC | Weed hoe | Cross adjustment | medium | often | high |
| SC | Weed hoe | Working width aggregates | low | infrequent | medium |
| SC | Weed harrow | Intensity (incline of tines) | low | often | high |
| SC | Centrifugal spreader | Distribution | low | medium | high |
| SC | Centrifugal spreader | Dosage | low | often | high |
| H | Combine harvester | Adjustment of components | medium | often | medium |
| TS | Overload control | Quality | low | often | high |

Control and regulation concepts, power requirement

The communication between different devices in agricultural machinery is very uniform, so almost all machines use the CAN bus protocol (SAE J1939). It serves as a machine bus system and in a special variant for communication between the machine and attachments, or terminals and sensors, the so-called ISOBUS (ISO 11783)¹⁴. These protocols are supplemented with proprietary systems, e.g. for the transmission of video signals or sensor data. Standard interfaces such as USB and RS232 are still used for the integration of external data (e.g. georeferenced map material). New models can already access external data via WLAN or mobile network. These are not used for direct control and regulation of the machines, but serve as a transitional interface between sensors, servers and "cloud services".

The advantages of the CAN bus system are the wide distribution and the possibility of message prioritization. It is also possible to track whether a signal has been successfully transmitted to the receiver. However, the data rate is limited to approx. 1 Mbit/s, which limits the transmission of video and sensor data. For this reason, only information, pre-processed signals and commands are usually transmitted which generate low data rates and do not lead to an overflow of the bus system. In addition, other protocols are in use for the data transmission of sensor information such as from reverse cameras. However, these protocols have not been used for direct control so far, but only for additional monitoring for the driver.

The standard power supply from the tractor alternator is 14 V, which is based on the charging voltage of the 12 V nominal battery voltage used. This voltage can be obtained directly from the connectors and usually supplies a rated current of 200 A via the alternator. The sockets are designed for a power of up to 60 A, which enables a power transmission of 840 W ($= 14 \text{ V} \cdot 60 \text{ A}$)¹⁵. For higher motor powers, the energy supply of the machine must be adjusted. Since a higher power consumption of the actuators requires a higher current

14 Δ S. Paraforos, G. M. Sharipov and H. W. Griepentrog, "ISO 11783-compatible industrial sensor and control systems and related research: A review" *Comput. Electron. Agric.*, vol. 163, no. June, pp. 104863, 2019.

15 T Agrar, "Schlepper unter Strom" *Top Agrar*, 2010. [Online]. Available: <https://www.topagrar.com/technik/aus-dem-heft/schlepper-unter-strom-9694009.html>. [Accessed: 23-Aug-2019].

CAN bus protocol

The CAN bus protocol SAE J1939 is often used



strength, the cross-section of the cables must also be increased as the power consumption increases. This results in increased costs for the plug connections and the risk of contact corrosion¹⁶. One way to obtain more electrical power is to use additional PTO generators. They use the PTO shaft of the tractor as the generator drive to provide enough energy for the electric drives.

The integration of actuators can already be done very easily using control signals and power supply. Control can be via standard CAN controllers, CAN controls or the tractor terminal. The integration of sensors in the drives makes maintenance and servicing easier. Malfunctions can be detected and rectified via remote maintenance services. The replacement of entire actuators makes it possible to carry out repairs quickly and easily.

¹⁶ G. Edwards, D. Bochtis and C. G. Sørensen, "Multi-machine Coordination: Scheduling Operations based on Readiness Criteria and using a modified Tabu Search Algorithm" in 4th IFAC Conference on Modelling and Control in Agriculture, Horticulture and Post Harvest Industry, 2013, pp. 191–195..

Machine sizes and automation level

In the near future, many farmers will probably continue to rely on existing technology and only slowly use new systems such as robotics, remote sensing using drones or cloud-based IT structures. However, social change can very soon lead to a situation in which only robotics can maintain economic viability. Due to the fact that chemical pest and weed controls may soon be required by law, more crossings with chippers or similar will be necessary in the future¹⁷. If the trend continues and the effectiveness of a farmer must increase further, this cannot be achieved by even larger machines, but only by partial automation and optimisation of the tasks.

The current machines have reached the maximum size to be driven and transported on public roads. It is therefore to be expected that in the future the machines will not be any larger. When robots take over the tasks, the absolute size of the units only depends on the technical possibilities such as the range, the running time and the controllability of the machines. It is to be expected that soil cultivation requires the highest power requirement and therefore defines the lower possible limit of the machines. However, miniaturisation will not work up to the level of a garden mower, as the necessary power, running time and terrain mobility can only be guaranteed at a certain size.

Robotics as a solution is already offered for sale by several companies (e.g. Naio and Agrobot). These robots can work autonomously, but must be supervised by the user. In order to work with these machines, the fields must be adapted to the characteristics of the robots. This includes e.g. planning suitable routes and providing the infrastructure (e.g. electricity, mobile internet). Purely battery-powered and electrically operated machines are within reach. At the moment, the range of conventional fuel driven machinery is still significantly higher than that of their electrified competitors. However, there are already applications where complete electrification can be implemented. This mainly concerns small plots which are well integrated into the local infrastructure. Basically, it can be assumed that the switch to electric motors will lead to an increase in the efficiency of the machines¹⁸. However, it is not yet possible to predict how energy storage can be meaningfully implemented, whether with batteries, hydrogen or other synthetic fuels.

It is also to be expected that automation will not only enable machines and robots to copy conventional technology and replace the driver, but also adapt the tools to the size, speed and range of the robots. This depends on the task, power and required safety of the machines. In addition, the use of robots creates new working windows, as the machines can theoretically work continuously, even at night.

17 G. Edwards, D. Bochtis and C. G. Sørensen, "Multi-machine Coordination: Scheduling Operations based on Readiness Criteria and using a modified Tabu Search Algorithm" in 4th IFAC Conference on Modelling and Control in Agriculture, Horticulture and Post Harvest Industry, 2013, pp. 191-195.

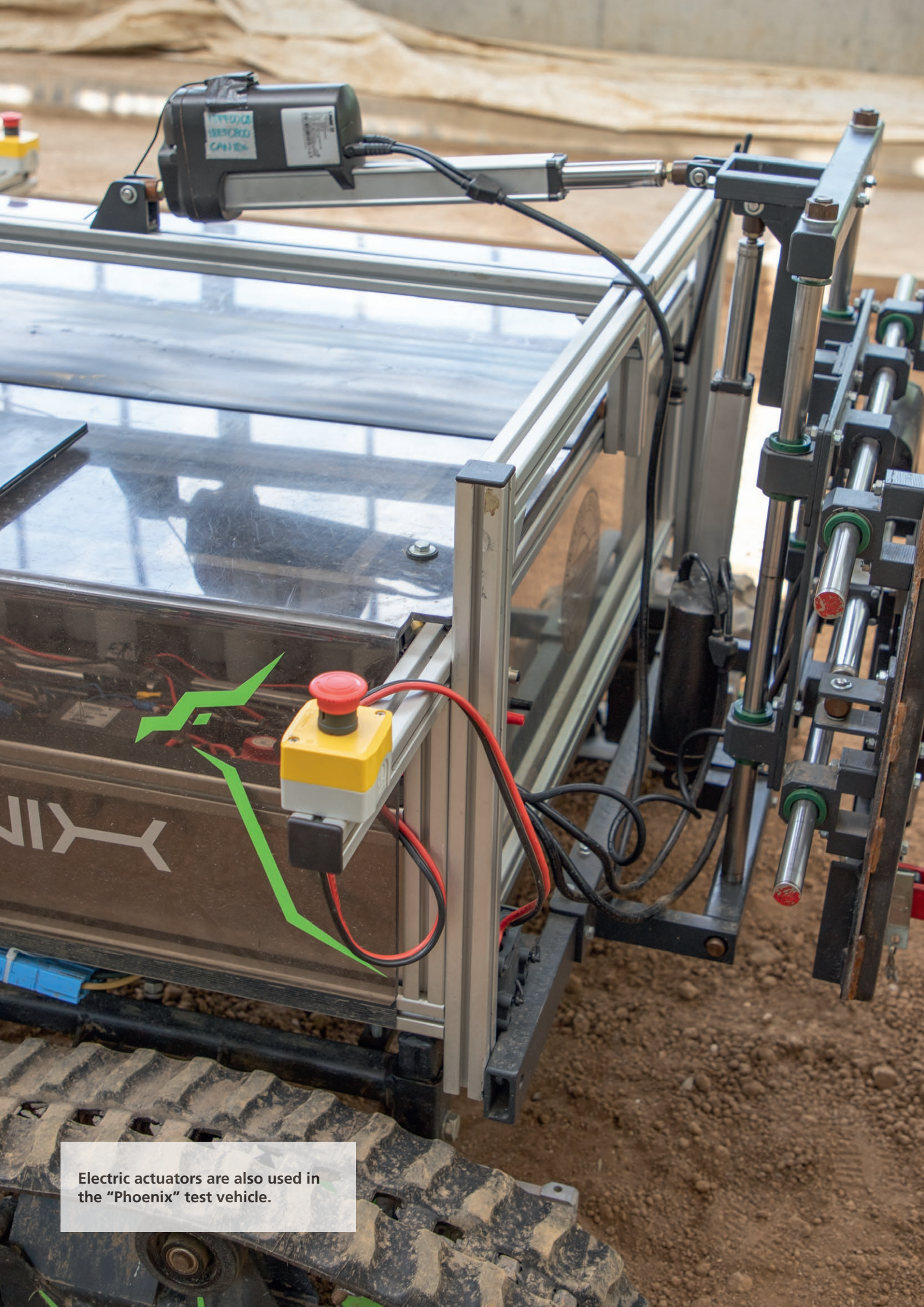
18 G. P. Moreda, M. A. Muñoz-García and P. Barreiro, "High voltage electrification of tractor and agricultural machinery – A review" *Energy Convers. Manag.*, vol. 115, pp. 117-131, 2016.

Working at night offers considerable advantages for weed, pest and disease control, which can be better harnessed with robotics. Likewise, the probability of coming across people at night is lower, which could prevent serious accidents. The autonomous performance of simple activities at night could also improve the effectiveness between man and machine. For example, the farmer could send the final instructions to the machine at the end of the working day to check the quality of the work the next morning. In order to work effectively, the fields must be adapted to the characteristics of the robots. This includes e.g. the pre-planning of suitable paths, the calibration of field boundaries and the provision of infrastructure (e.g. power supply and mobile internet).

Autonomous driving in agriculture is already possible and feasible today, but it is not without risks. In the future, there will always be a certain probability of malfunctions caused by incorrect operation, external influences, software errors or faulty sensors and mechanics. Therefore, the implementation will be determined by the case law¹⁹. To a certain extent, the legal framework can be transferred from the field of autonomous driving to agriculture. The current legal situation is such that the protection of people always has priority. Liability is divided between the driver, the owner and the manufacturer²⁰. A clear distinction is made here between the reasons why an accident could occur and the question of guilt. The case that there is no driver is not yet included in case law. Therefore, automated systems are legally covered, but autonomous systems are not. It is therefore likely that in the near future only systems monitored by a user will be available. This means that the user must take the machine into the field and not allow it to travel autonomously across the field. The most conceivable solution is a small-scale implementation of machines that have enough power to work and do not cause too much damage in the event of a malfunction. It is also possible to monitor several machines using suitable telemetry systems. A major advantage of agriculture is that agricultural areas are subject to a legal prohibition of access during cultivation (example: Baden-Württemberg: Section 44 of the State Nature Conservation Act). However, first precedents need to be clarified as to how this will affect case law.

19 B Gogarty and M. Hagger, "The Laws of Man over Vehicles Unmanned: The Legal Response to Robotic Revolution on Sea, Land and Air" J. Law, Inf. Sci., vol. 19, pp. 73-145, 2008.

20 Daimler, "Automatisiertes und autonomes Fahren. Rechtlicher Rahmen", 2019. [Online]. Available: <https://www.daimler.com/innovation/case/autonomous/rechtlicher-rahmen.html>. [Accessed: 27-Aug-2019].



Electric actuators are also used in the "Phoenix" test vehicle.



Requirements for actuators such as power, control and interfaces

Automated and autonomous machines require intelligent sensors and actuators. Actuators of the future will therefore not only be pure controllers, but will also provide feedback on their actions. This includes characteristics such as position, action, performance, load and cycles. If this information is placed in the right context, additional added value can already be generated with this information. Therefore, in the future, the load and wear could be independently recognised and evaluated in intelligent actuators. Maintenance and service could be carried out efficiently and with little effort. The absolute position of the actuator must always be known for automated processes. An intelligent action of the actuator is also desired, so that e.g. a resistance or a blocking of the actuator is automatically detected and reported and the controller can react to it. The information that is collected, such as force and interaction, can be used to determine additional information about the environment when the data is placed in the right context. This information can be used, for example, to optimise machining or even to plan the next work steps in order to minimise machining peaks. Similar to human workers, autonomous robots will need haptic feedback systems in the future, ideally directly integrated into the actuators. This makes it possible to “feel” the environment and actively interact with it.

In the electrification of cars, high-voltage motors have long been used, e.g. the prototype of a wired agricultural robot of the GridCon project, which works with a voltage of 700 V²¹. This enables significantly higher performance, but also increases the risk of injuries during repair and maintenance. One solution is to switch to a 24 V on-board power supply system, which is used in lorries and construction machinery. This results in a doubling of the transferable power. In order to be able to work in a “touch-safe” area, it is possible to extend the system to a nominal voltage of 48 V (possibly 42 V to keep the charging voltage below 50 V). At 60 A a usable power of 2.8 kW already results here. This power is already more than sufficient for most tasks. This would also be sufficient to replace most linear hydraulic cylinders with electric actuators. With the miniaturisation and automation of the machines it is to be expected that the required performance will decrease.

21 BMWi, “Gridcon Project”, 2019. [Online]. Available: <http://www.gridcon-project.de/>. [Accessed: 28-Aug-2019].

Digitisation of the machines

The future machine will develop into a “smart device” by continuously recording measurement data with the aid of sensors. The main objective of automated machines and robots in agriculture is to understand and react to the behaviour of the environment and plants. This is made possible by intelligent actuators. This increases the required data rate, which also indicates the limits of the current protocols for internal communication with actuators. Since the exchange of image material from camera sensors is also best sent via the same interface, the implementation with CAN bus is not realistic due to the maximum possible data rate of 1 Mbps. Alternatives include Flexray, Automotive Ethernet, MOST bus or EtherCAT, which all enable higher transfer rates. It is also possible to install several bus systems on the same device and to divide them according to safety-relevant parameters and data transmission rates. In modern passenger cars, more than 150 control devices are already networked with each other and there will certainly be more in the future. Agricultural machinery is also being assembled with an increasing number of individual components, control units and actuators. Currently, some automotive manufacturers rely on the Flexray Bus. It is possible that this will also become established in agriculture due to the higher transmission rate of 10 Mbps. However, in the next 5-10 years there will probably not be much change in the common protocols J1939 and ISOBUS for the classic tractor



combination. As product life cycles in agriculture are significantly longer than in other industries, the change will be slow.

It is different with autonomous robots. Since the communication between the attachment and the machine is not in the foreground here, an isolated solution can be implemented. The main possible approaches are industrial automation and the use of intelligent sensors to keep the data rate between the individual components as low as possible. A robot is more likely to be a “computer on wheels” than a conventional “tractor with computer”.

The service of the future will differ from the practice of today. Working hours for repairs will become more and more expensive and therefore unprofitable. Therefore, the trend is to replace entire parts and components instead of repairing individual details. This will also be the case more and more frequently in agricultural machinery. It is also possible to use new technologies such as virtual reality and remote maintenance. A central service technician gives instructions to the user to carry out the repair with their instructions. By determining the service life and load of drives, a new part can be ordered and delivered even before the drive fails. Therefore, breakdown risks can be minimised in advance.



The future of linear actuators in future machines

Some tasks will also be implemented by conventional machines with drivers in the near future. It is therefore to be expected that no fully autonomous combine harvesters will drive across the fields for the time being. The reasons for this are the already high efficiency of harvesting machines of today, safety and the low share of labour costs in the total costs. Here solutions with telemetry approach are possible, so that a driver controls and cares for a fleet of vehicles. In such cases, the use of linear actuators serves to ensure flexible and user-friendly operation. Likewise, the expert knowledge of a driver can be transferred to a downstream remote-controlled vehicle or a less experienced driver. In addition, occurring forces can be determined via the current consumption of the actuators and used for additional analysis of the process.

The situation is different in tasks such as tillage, sowing and maintenance. It is to be expected that semi-autonomous systems will be used very soon. It is not yet clear how flexible the machines and robots of the future will be. Either they are specialised in one task or they are generalist machines which can carry out several tasks throughout the year. Generalist machines must offer the user as much variability as possible. Specialised machines are operated by large companies and contractors in order to recoup the costs. Contractors can specialise in individual tasks and therefore use high machine costs profitably. This also changes the requirements for built-in linear actuators.

It is to be expected that the miniaturisation of the machines will make hydraulics less relevant as lower power levels are required. In a fully electrified machine, it makes more sense to work with electric linear actuators if the power range permits. Therefore, the power loss can be reduced by the energy conversion. In addition, the sensor information can be used in the future to gain added value from the automation of individual settings, e.g. when the actuator position is logged along with the position, it can be used to automatically control the machine. The automation of machines and robots requires significantly more adjustment options than is currently the case with conventional machines, as the farmer previously had to make the adjustments manually. In the future, the machine should be able to adjust itself independently, but this requires more actuators.

CONCLUSION

The implementation of autonomous field management will trigger a disruptive change in agriculture over the next few years. Robots will probably only be used in parallel with existing systems and machines and then gradually take on new tasks. In addition, driver assistance systems in existing agricultural machinery will continue to be expanded. The start of robotics will presumably be the use in inventory maintenance and will then be extended to other tasks. Autonomous robots will become economically interesting as soon as the costs for the machines are affordable and the effort is worthwhile for the farmer or contractor to transport the machine to the field and remove it again after the work is done. A possible scenario could be that the farmer has several machines, all of which can be transported on a trailer. The tasks are defined and planned in advance by the farmer based on weather and remote sensing data. The machines are then taken to their working area. On a large scale, the work can be taken over by several machines of the same construction in order to provide sufficient power. The conclusion is therefore that the machine size must be as small as possible and as large as necessary.

The electrification of agriculture will be socially demanded in the future and will initially be implemented in agricultural robotics. In an electrically operated system, which should work in a minimally invasive way, it makes little sense to rely on hydraulic drives, if the required power can also be provided by electric actuators. By using higher voltages, the power range of existing linear actuators can be extended, therefore offering a wider range of applications. Intelligent, linear drives will have an important role in the implementation of automated systems in the future. They will create opportunities to collect data that is not yet considered today. This will expand the future agricultural machine into a “smart device”, which will continuously generate data about the process, with which new optimisations will be possible in the future.

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