Electromechanical Drawbar
A practical, flexible, economical and efficient way for transporting agricultural robots

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Abstract

Automatically operating agricultural robots could unlock a new level of productivity in agricultural production. Many research facilities, companies, and farmers are currently deploying the first generation of these machines. The primary goals of these activities are to ensure safe operation and high process quality. Once these goals are achieved and agricultural robots gain more traction, OEMs and farmers worldwide will face the challenge of transporting these robots to the field. Currently discussed and available options, such as towing with a tractor, using a low-loader/flatbed, or employing an electronic/virtual drawbar, have significant disadvantages in terms of practicability, flexibility, economy, and efficiency. We therefore propose the electromechanical drawbar as an innovative alternative for transporting agricultural robots, aimed at overcoming these disadvantages.

1. Introduction

As depicted in Figure 1, several options for the road transport of agricultural robots to their working places are typically proposed. Towing options a, b and c require powerful and expensive towing tractors and potentially additional equipment like a low-loader or a flatbed. On top of that, preparations for the transport are very time consuming,

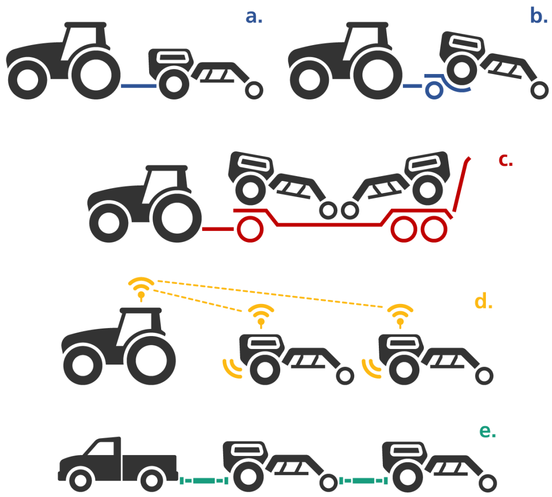

Figure 1: Robot transport options:

a/b: drawbar/platform pulling with a tractor
c: low-loader/flatbed pulling with a tractor
d: sensor-guided platooning with a specially prepared lead vehicle
e: electromechanical drawbar for self-propelled following of a standard vehicle

especially for option c due to the setup and lashing effort. If, like today, only a few robots are being transported, options a, b and c are feasible. But, if we envision a future, where farmers or service providers deploy, relocate and gather multiple robots every day, this task becomes much more challenging. Using an equal number of robots, tractors and operators appears to be unreasonable and cost-inefficient in a future, where many tasks are done autonomously and where only fewer tractors are kept as multi-purpose machines for a similarly lower number of machine operators. Farmers and service providers also emphasize transport flexibility as a key requirement for the integration of robots into their production processes. An often-discussed solution to the transport challenge is option d with sensor-based platooning, where the agricultural robots would follow a specially prepared guidance vehicle automatically during road transport. While this approach could be very practical, it results in huge development challenges, efforts and costs. Option d practically requires solving many of the challenges for autonomous driving on public roads. In the foreseeable future this is well beyond the means and funds of agricultural robot OEMs. Therefore, we propose option e, the electromechanical drawbar. It is a practical, flexible, economical and efficient approach for transporting agricultural robots to their working places. It consists of a sensor-equipped spring-damper element, which is not used for pulling robots physically, but for generating displacement measurements as control inputs for their locomotion. The agricultural robots then follow the path of a standard vehicle, which does not require expensive modifications, aside from a standard trailer hitch and a wireless control display. The solution is currently being patented and developed at the Fraunhofer IVI. In this paper we will present results of a feasibility study, which includes a review of the state of the art, technical features, regulatory constraints as well as economic and practicability considerations, which are the basis for the ongoing prototypical implementation of the concept.

2. State of the Art

Over the course of the last decade robotic solutions in agriculture turned from a distant vision into a realistic option for farmers to increase productivity while also coping with changing demographics and labor shortages. One of the most widely applied field robots currently is the FarmDroid FD20, a fully autonomous, solar-powered field robot that performs precision RTK-GPS-guided seeding and both inter-row and intra-row mechanical weeding. It is intended to operate continuously – up to 18–24 hours daily – on a field covering up to 6.5 ha per day. Thus, in general this compact robot stays on one field permanently and is not required to be transported regularly. FarmDroid [1] however offers two different transport options: A field bracket for towing with a tractor on private grounds and a road transport platform for carrying with a tractor on public roads. Both appear to be reasonable and practical solutions, since transport will only happen occasionally. Larger and heavier agricultural robots like the Field Swarm Unit II developed in the research project Field Swarm require transport with a low-loader and a semi-trailer [2]. While this is a natural transport solution, it requires the truck/trailer-combination, dedicated and trained personnel and extended effort for loading and unloading. A similar concept is currently used for the Agbots from AgXeed, which are currently already commercially available and gain quite some traction among farmers worldwide. Road transport is typically done with a flatbed attached to a tractor [3], [4]. However, the required equipment and the loading/unloading effort make this form of transport rather unattractive, which is shown by a farm in Australia, who transfer their Agbot on their extensive private grounds by following it with a car while simultaneously controlling the robot with its remote. While this eliminates the need for equipment as well as the loading effort, the speed limitation to 10 km/h makes them hope for a better form of transportation in the future [5]. On public roads, this form of transport would not be permitted. Two German farmers, who were among the first users in Germany, describe the current transport method for the AgBot as the limiting factor for its suitability in agricultural practice [6]: "**If you have to put the robot on a low-loader for just 5 hectares, you've already worked half the area with the tractor.**" / "**Any-one with widely scattered and small fields who has to load the AgBot onto the low-loader three times a day can forget about it.**" Thus, a key demand from farmers is a flexible transport solution that fits seamlessly into their production processes. Another constraint of the low-loader or flatbed transport solution is that the total height of large agricultural robots – including folded implements – might exceed the maximum permitted vehicle height of 4 m on public roads in Germany and the EU. Exceeding this height not only risks regulatory non-compliance but also necessitates costly and time-consuming measures such as special permits, escort vehicles, or even structural modifications to the robot, the implements or the transport trailer. A more refined approach to address the transport issue is the Vehicle Transport System (VTS) developed by Combined Powers (a Lemken/Krone spin-off). Their autonomous field unit Verfahrenstechnische Einheit (VTE) incorporates a fixed drawbar that allows a conventional tractor to tow the robot with implements attached as if it were a conventional trailer. When connected, the robot mechanically follows behind the tractor on public roads, without requiring manned driving or loading onto a trailer. The robot is designed to be towed with supplemental lights and brakes, enabling seamless relocation between fields using existing farm vehicles [7]. While this is quite a practical solution, it will not scale well, when the robots on a farm eventually outnumber available tractors. A potential breakthrough could be autonomous driving approaches. Platooning – where one vehicle follows another using sensors and communication – has been researched for over 20 years in trucking and transport, often referred to in early EU initiatives as the “electronic drawbar” [8]. However, due to its complexity in terms of reliable sensor fusion, safety protocols and regulatory challenges, it commercially remains primarily at the level of driver-assistance systems and small-scale on-field trials in agriculture [9]. As a result, platooning currently offers no practical transport option for agricultural robots crossing public roads. Advanced autonomous driving systems like the Waymo Driver, which utilizes high-cost sensor suites (LiDAR, radar, cameras) and compute platforms, could—hypothetically—transport agricultural robots on-road independently. Yet their current cost with approximately $ 150.000 (sensor kit + computers + per vehicle) and substantial requirements like up-to-date HD maps make such solutions prohibitively expensive and complex for the agricultural niche in the medium term [10]. Consequently, while full autonomy remains a long-term vision, it is not a financially viable transport strategy for farm robots in the short or mid-term.

3. Electromechanical Drawbar

As outlined above the electromechanical drawbar is intended to offer a practical, flexible, economical and efficient alternative to the current state of the art for transporting agricultural robots. As schematically depicted in Figure 2 we envision an intelligent drawbar, that consists of a sensorized spring-damper element, that connects a lead vehicle with an agricultural robot.

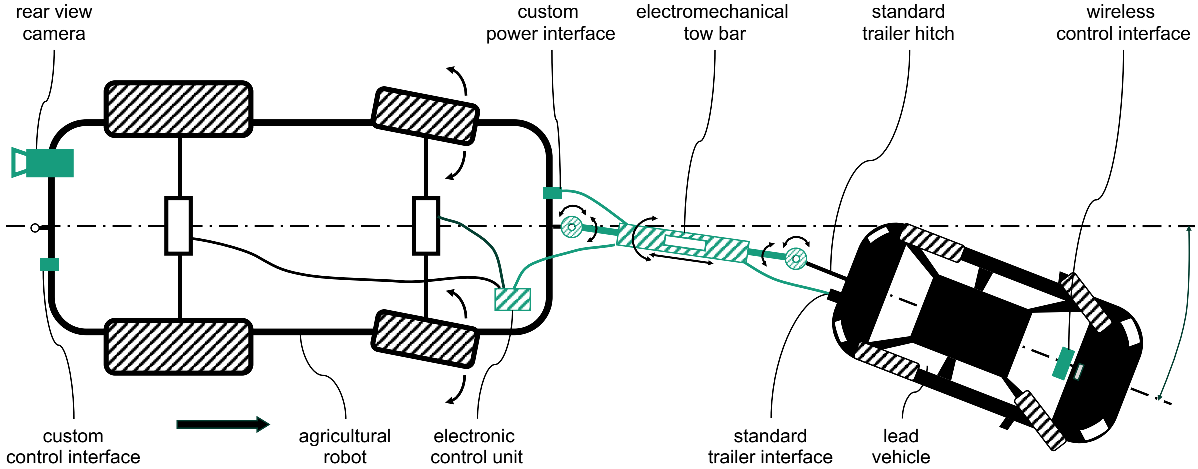

Figure 2: Schematic depiction of a possible variant of the electromechanical drawbar for guiding an agricultural robot with a lead vehicle

Potentially a second agricultural robot could be connected to the first robot with a second electromechanical drawbar, allowing one lead vehicle to guide two robots simultaneously. The lead vehicle is a standard passenger car with a standard trailer hitch and a standard trailer connector. The electromechanical drawbar is connected to an electronic control unit, which calculates control commands for the robot based on the displacement of the drawbar. The controller is intended to minimize forces on the lead vehicle and to guide the agricultural robot(s) safely within a dedicated set of operation conditions. Therefore, the electromechanical drawbar may also be designed to actively control its displacement, with power drawn from the robot(s). Via a wireless control interface, the driver of the lead vehicle can set dedicated operation modes like standard forward driving, reverse driving, tight turn or similar. The interface is also used to provide a rear-view camera stream as well as feedback on whether the formation is operated within its intended conditions. It is assumed that drivers will require specific training for the operation of such a formation. The depicted variant of the electromechanical drawbar highlights one potential implementation. Features of a potential commercial product will vary.

4. Regulatory Constraints

Agricultural robots, distributed in the EU, must meet the requirements of the EU Machinery Directive (2006/42/EC) until 2027, and subsequently the Machinery Regulation (EU 2023/1230), both of which establish harmonized procedures for placing them on the market. However, the Agricultural and Forestry Tractor Regulation (EU 167/2013) does not apply to driverless robots without a cabin. Homologation or road approval remains a national responsibility: each EU country sets its own rules, with no current harmonization across borders. To address this, Regulation (EU) 2025/14, effective from early 2025, introduces vehicle category U for non-road mobile machinery (NRMM). This covers machines not primarily designed to transport goods, but which may operate occasionally or regularly on public roads at speeds between 6 km/h and 40 km/h. Category U is intended to streamline approval across member states, and it is expected that delegated technical rules – similar to categories C and T for tractors – will define requirements for steering, braking, lighting, emissions and safety systems. EU regulations also specify performance requirements by speed tier: up to 25 km/h puts moderate requirements on brake deceleration capabilities and requires no ABS; above 25 km/h up to 40 km/h mandates higher braking performance, but still generally excludes ABS. Hydrostatic-drive machines have a slightly higher threshold (up to 30 km/h) for stricter rules to apply. In Germany, the Straßenverkehrsordnung (StVZO) governs road eligibility, stating that self-propelled work machines require a type-specific operating permit. Up to 20 km/h, such machines are exempt from registration and license plates; above 20 km/h, registration is mandatory. The StVZO is expected to be updated to accommodate category U machines. In practice, an agricultural robot pulled via an electromechanical drawbar would likely fall into category U and be capped at a top speed of 25 km/h. That places it in a regulatory tier with low braking requirements and no need for ABS, limiting development complexity and cost.

5. Economic and Practicability Considerations

Agricultural robots promise a future where large parts of currently manual processes are executed automatically, which reduces the time spent for manual labor and reduces the overall costs for these tasks. The validity of this promise will greatly depend on the cost/performance ratio of the robots on the field, compared to the cost/performance ratio of standard tractors with (potentially scarce) human operators. However, even if field robots have a superior cost/performance ratio on the field, they might induce additional overhead for transport and preparation. As discussed before, the transport of cabin-less robots is such a case. Many farmers argue that setup times have a great impact on their overall effectiveness and thus work hard to reduce these setup times. One common strategy to accomplish this is to establish field staging depots, which are used for assembling, preparing and organizing resources, personnel and equipment before their deployment to a specific field. This reduces frequent long-distance transports, often resulting in average transport distances of less than 10 km.

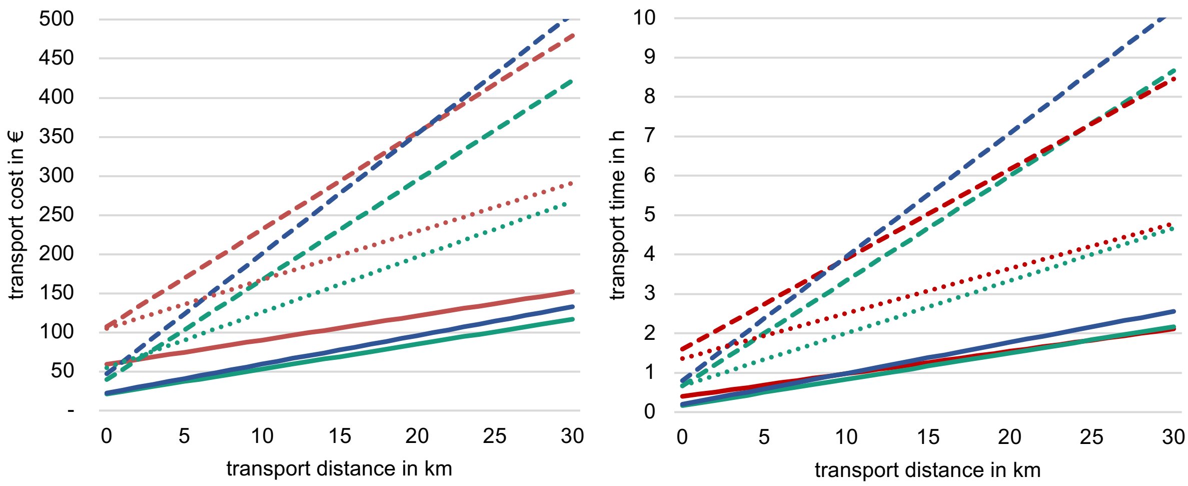

Figure 3: Transport cost/time[1] over transport distance for different transport options:

drawbar + powerful tractor[2]: — 1x1 robot, - - 4x1 robot

low-loader/flatbed + powerful tractor[3]: — 1x1 robot, - - 4x1 robot, ··· 2x2 robots

electromechanical drawbar + lead vehicle[4]: — 1x1 robot, - - 4x1 robot, ··· 2x2 robots

Figure 3 provides the results of a cost/time-analysis for the deployment of cabin-less agricultural robots via drawbar plus powerful tractor, low-loader/flatbed plus powerful tractor and electromechanical drawbar plus lead vehicle. The deployment or transport of a machine therefore is defined as transport of the robot in one direction and the return of the transport system to the origin. The setup time for the tow-bar-based transport is assumed to be 6 min, with an average transport speed of 20 km/h and an average return speed of 35 km/h. The setup time for the low-loader/flatbed-based transport is assumed to be 15 min, with an average transport

[1] 1.79 €/l diesel cost, 30 €/h operator cost, 4 robots in operation at the farm, 100 field transports per year for each robot

[2] Investment of 10 k€ for the drawbar + 150 k€ for the tractor, 10 years usage duration, 5 % yearly maintenance, 6 min setup duration, 20 km/h transport velocity, 35 km/h return velocity, 20 l/100km fuel consumption (tractor + robot as trailer)

[3] Investment of 35 k€ for the low-loader/flatbed + 150 k€ for the tractor, 10 years usage duration, 5 % yearly maintenance, 15 min setup duration, 35 km/h transport velocity, 35 km/h return velocity, 25 l/100km fuel consumption (tractor + robot on trailer)

[4] Investment of 10 k€ for the electromechanical drawbar + 60 k€ for a passenger vehicle or pickup, 10 years usage duration, 5 % yearly maintenance, 5 min setup duration, 20 km/h transport velocity, 60 km/h return velocity, 10 l/100km fuel consumption of the lead vehicle + 20 l/100km fuel consumption of the robot

speed of 35 km/h and an average return speed of 35 km/h. The setup time for using the electromechanical drawbar is assumed to be 5 min and the average transport speed can be up to 20 km/h and an average return speed of 60 km/h. Based on all underlying assumptions[1,2,3,4], the graphs show that the deployment via the electromechanical drawbar (green lines) is the cheapest of all three options. It is significantly less expensive than low-loader/flatbed transport (red lines) and takes less time for distances smaller than 25 km. The analysis shows that low-loader/flatbed-based transport is only suitable for transport between field staging depots. The electromechanical drawbar is also more cost and time efficient than a standard drawbar (blue lines). This is due to its lower investment – no tractor required –, slightly lower setup times and higher return speeds. It is especially true if multiple robots need to be transported (dashed lines). Since the electromechanical drawbar has the potential of transporting two robots at once (dotted lines), the cost and time for transport could be cut in half, resulting in a substantial efficiency gain compared to standard drawbar transport.

6. Summary

This paper introduced the electromechanical drawbar as a practical, economical, and efficient transport solution for agricultural robots. As the adoption of agricultural robots grows and the availability of human-drivable tractors decreases, transporting them between fields becomes increasingly relevant. Conventional methods such as low-loaders, flatbeds, and manual towing require significant setup effort, costly equipment, and face regulatory challenges – particularly concerning size limits and road approval. A review of current transport solutions – including FarmDroid FD20, AgXeed AgBot, and Combined Powers' VTE – revealed that while suitable for specific cases, they often lack flexibility or economic viability for daily operations, especially if multiple robots have to be transported regularly. Technologies like platooning and fully autonomous driving remain prohibitively expensive and technically immature for this domain in the near future. The electromechanical drawbar addresses these issues by allowing an autonomous robot to follow a lead vehicle via a sensor-equipped spring-damper unit, eliminating the need for full autonomy while increasing flexibility and setup efficiency. This concept aligns with the upcoming EU vehicle class U (Regulation EU 2025/14), which simplifies type approval for non-transport agricultural machines using public roads at moderate speeds. An economic analysis showed clear advantages compared to other transport options. The electromechanical drawbar offers a flexible transport option for decentralized farm operations. It requires only a limited amount of manpower and equipment resources but requires additional homologation effort during development. Designed for speeds up to 25 km/h, it strikes a balance between operational efficiency and regulatory compliance.

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