TESTING OF FUNICULAR TROLLEY FOR AGRICULTURAL OPERATIONS

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Abstract. In the last few years, many efforts have been spent on autonomous and unmanned systems, having the advantage of operating at relatively low speed and reducing the stress for the farmer. However, one major limitation to the implementation of autonomous systems is the difficulty in properly controlling operation paths. Random movements typically implemented by an automatic mower system are not viable in agriculture, thus new approaches have to be developed. The present paper introduces a different approach based on the traditional funicular technology: new advancement in materials and control electronics make it possible to modernize such old technique, opening new fields of application. The system is characterized by the absence of transmission organs: this design allows a reduction of the total mass, thus minimizing soil disturbance and also the overall pulling force on average lower than 2 kN. The system is equipped with RGB/IR cameras which allows the collection of images on the go during seeding operations. The forward speed of the system is typically ranging between 0.5 and 2 $m \cdot s^{-1}$, and it optimizes seed distribution with coefficients of variation lower than 15% both in the lateral and longitudinal directions.

Keywords: soil tillage, funicular traction, low compaction, trolley.

Introduction

Since the development of agricultural mechanization, farmers have made efforts to improve traction means. Alternative solutions have been proposed in the nineteenth century when some English engineers tested a plow drawn by chains driven by quasi-stationary steam engines for the first time. Funicular plowing had an acceptable working capacity for the time (0.22 hectares per hour), and similar performances could also be achieved for other operations like harrowing and seeding. Technical solutions included the implementation of systems based on a rope surrounding the field and allowing a spiral motion, or machinery including a drum hoist where the implement is pulled by one side of the field. The next step was the introduction of a double hoists system, with engines located at opposed sides of the field and alternatively pulling the implement back and forward in the area to be cultivated. At the beginning of the twentieth century, some models have also been designed based on electric power. However, the weight of the engines was not sufficiently low to allow basic manoeuvrability operations. The funicular technique was then applied also after steam engines, with the development of internal combustion engines, but started to decline as increasing wheel power was available thanks to advent of modern tractors characterized by higher power-to-weight ratios and new tyres [1].

In recent years, advancement in materials and in control electronics have made it possible to modernize the old funicular technique, allowing increased performances and a wider range of fields of applications, even in case of low accessibility conditions [2]. In particular compared to old systems, new ones can provide lower weight of the trolley and of the cables, longer cables and higher pulling forces, thus opening up an increased number of operations, on larger areas, thus with a higher range of applications. Additionally, specific electronic controls on the the wheels allow pulling force to be equally distributed between the four wheels, thus reducing wheel slippage and enhancing the stability and the straightness of the trajectory [3]. The present paper introduces a newly developed prototype, reporting on the first analyses of technical characteristics and performances, potentially improving mechanization of plant production [4].

Materials and methods

The working principle

The proposed solution is based on the upgrade of an original idea deposited as a patent a few years ago [5]. The patent introduced double hoist electric propulsion in cable traction for exploitation in agricultural operations. In the newly tested configuration, two agricultural machineries located in the opposite borders of the field provide a frame, a driving and reversible control unit, the hoist and the cable operate in a synchronous mode to pull and drive a trolley, which can work as a multifunctional carrier for different tools and instruments.

The machineries located in the border of the field operate the trolley in a raster fashion, allowing the field to be fully covered by the trolley. A schematic representation of the funicular system is reported in Fig. 1.

The trolley features a modular frame with wheelbase and track width, which might be easily adapted to specific needs. For the present study, the trolley features 1200×1700 mm dimensions. Thanks to the absence of an engine and of a mechanical transmission, and due to implementation of a simple frame structure, the overall empty weight can be kept as low as less than 300 kg (cable excluded). Four freely pivoting pneumatic wheels (Tire 4.80/4.00-8") provide proper support to the system. Due to the limited weight of the system, and considered adequate support allowed by front and back wheels, an average vertical pressure can be estimated ranging between 150 and 300 kPa, depending on the total payload carried by the trolley. Being the traction outsourced, negligible pulling pressure is expected to contribute to the total soil compaction.

The carrier open structure allows to place different implement tools for different agricultural operations, preferably characterized by low traction power. The system can then be integrated with fertilizer spreaders, pneumatic or mechanic seeders, spring tine harrows or sprayers. Other implements characterized by higher traction power might be operated by the funicular system, but through a different system configuration (without implementation of the carrier). The trolley can be alternatively or additionally equipped with different sensing devices to allow collection of soil or plant information during field operation.

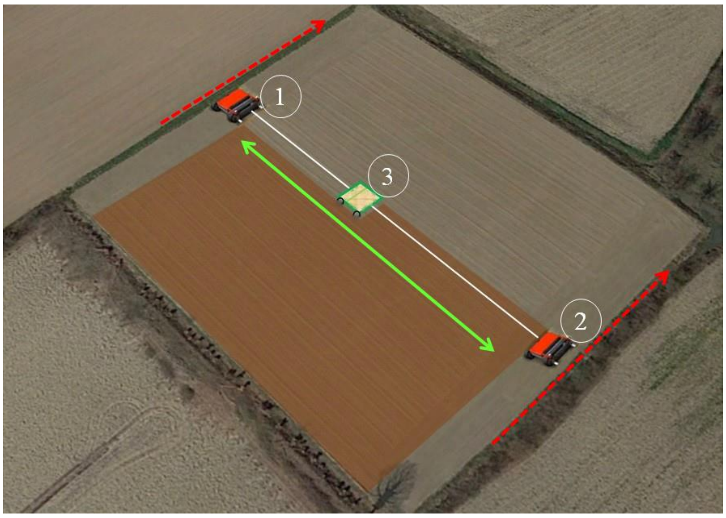

Fig. 1. **Schematic representation of the developed system:** 1 and 2 – machinery at the opposite headlands of the field, moving along the slow movement directions (as indicated by the red dotted arrows); 3 –trolley, alternatively moving back and forward (as indicated by the green arrow direction)

The tested prototype

To test the developed system, the trolley was equipped with an 8 outlet electric pneumatic seeder (PS 200 M1, by APV - Technische Produkte GmbH), supplied by 12V/25A power (Fig. 2). Electric power allows high flexibility in motion control and management [6; 7]. The tank has a volume of about 200 l, and the total weight (excluding seeds) is less than 80 kg. The system was additionally integrated with an RGB/IR camera, to allow the collection of images on the go during seeding operations. The forward speed of the system is typically ranging between 0.5 and 2 $m \cdot s^{-1}$, depending on the cable rewinding speed. Such relatively low speeds guarantee low vibrations in the frame with positive effect both on the homogeneity of the distribution and on the quality of collected images. In particular, the camera positioned at a height lower than 1.5 m from the ground (Fig. 2), allowed images to be collected with a ground resolution higher than 2 mm (Fig. 3). Such images, collected at a frame rate of 1 Hz, can be conveniently mosaicked to provide a full map of the cultivated area [8; 9]. Furthermore, implementation of proper segmentation operations on functional vegetation indices [10], e.g. based on machine learning algorithms [11], can allow seeds to be identified providing a feedback to the seeding system or to the farmer.

Fig. 2. **Funicular system in the experimental layout:** 1 – trolley equipped with a pneumatic seeder; 2 – RGB/IR camera attached to the side of the frame

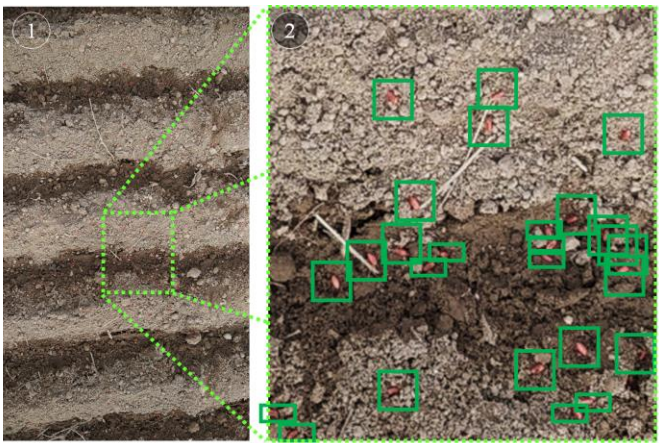

Fig. 3. **RGB images collected by the installed camera:** 1 – snapshot of soil; 2 – in the zoom box the segmentation process allows identification and quantification of seeds

Experimental tests

To verify the accuracy of the developed prototype, multiple seed distributions tests have been carried out, quantifying the seed density both in transversal direction (variability between outlets/rows) and in longitudinal direction (variability in the row). Wheat seeds have been considered for the scope, distributed over a total covered distance equal to 40 m. Experiments have been taking place considering a forward speed of 0.9 $m \cdot s^{-1}$, achieved through a pulling force on average equal to 1773 N (standard deviation $\sigma = 271$ N). The net power absorbed by the implement is equal to 0.3 kW for the pneumatic system and 1.5 kW for the pulling force, corresponding to a gross power lower than 6 kW.

The main results are reported in Fig. 4. Regarding the transversal coefficient of variation [12], this has been kept on values lower than 15%: the seed density values exhibit a slight alteration at the left and right sides, due to edge effects.

Such altered behaviour causes an increase in the coefficient of variation; on the other hand, it is worth noting that such deviation might be easily compensated considering a partial overlap of the following passage during the return track. Higher repeatability was highlighted during longitudinal tests: in this case, a coefficient of variation lower than 10% was indeed estimated. Residual variability in this second test is mainly ascribable to vibration effects and unstable pulling force, which introduce some instability during trolley back and forward motion. In general higher homogeneity in seeding operation can eventually reduce competitiveness within the crop and promote improvement of yield potential [13].

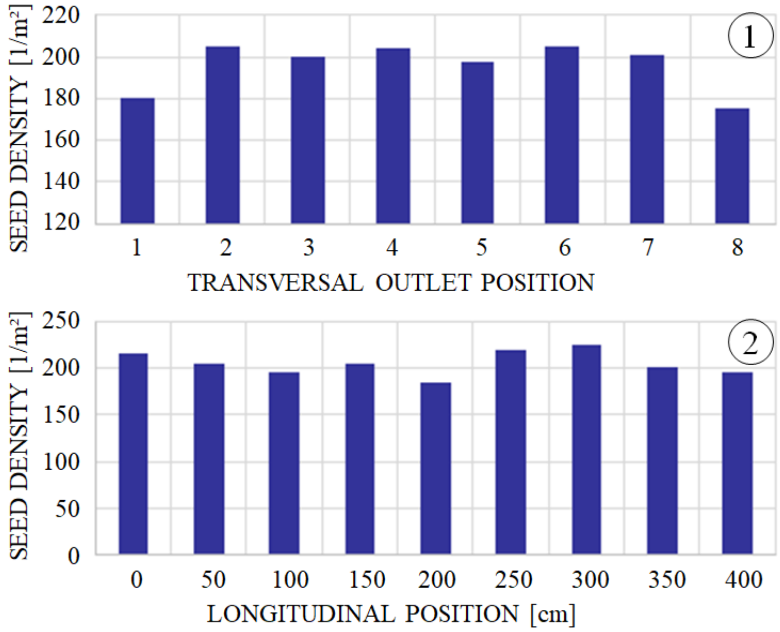

Fig. 4. **Seeding homogeneity:** 1 – transversal variability between the different outlets; 2 – longitudinal variability in the row

Results and discussion

The fact of relocating the power plant to the sidelines (engine, tank, guide, transmission, ...) allows for most of the mass to be concentrated outside the cultivated area, concentrating only on the working parts and the relative support frame in the field. This approach brings substantial benefits (as listed below) useful for positioning the system in the market.

1. The absence of transmission organs, differentials, propulsion system, driving system, gives a considerable lowering of the total mass which allows the use of smaller locomotion organs: with the same soil compaction, the use of smaller wheels gives less disturbance to the soil and to the crop, with less area occupied by ruts.
2. The use of a handling system based on metal cables and lifters at the ends and in general the use of a shorter work site allows to minimize the maneuvering areas at the headland: smaller headlands therefore make possible cultivation of different crops in rows, even if of limited length, [2].
3. The system based on metal cables minimizes the limitations imposed by the slope of sloping land, where even a tracked tractor would have difficulty in maintaining the minimum safety conditions required during the execution of cultivation operations.
4. Despite the low load on the wheels, the system has very limited or no slippage problems. The system can also be converted from wheels to skids, allowing entry into the field even in very soft areas or in very humid soils or submerged conditions which are prohibitive for any other vehicle. In addition, this latter aspect allows the implementation of the presented system with cover crops [14].
5. The system guarantees the absence of gaseous emissions in the proximity of the working parts (as the movement systems and motors are relocated to the field): this aspect makes the proposed solution particularly attractive also for crops in greenhouses or indoors, or for crops (for example, for biomedical use or for neonatal feeding) where very high levels of health and total absence of contaminants are required.
6. The system is suitable for low working speeds, compensated by long working times guaranteed by automatic handling and driving. The low speeds allow very high machining precision, with a consequent increase in the operation quality.

Conclusion

In general the proposed approach should be considered not as a substitute to traditional mechanization, but as an alternative when specific limitations (low accessibility, soil stability, etc.) are reducing the possible introduction of conventional tractors and implements. Indeed, if low speed might be an advantage under certain conditions (as reported in the previous last point), on the other hand, reduced working capacity is expected to increase by 20% to 60% on average, thus potentially reducing the effectiveness and the profitability of those operations where timeliness is a specific agronomic issue.

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Author contributions

Conceptualization, F.P., M.D. and M.G.; methodology, K.L.; formal analysis, K.L; investigation, K.L.; writing – original draft preparation, K.L.; writing – review and editing, K.L., F.P., M.D. and M.G.; project administration, F.P.; funding acquisition, F.P. All authors have read and agreed to the published version of the manuscript.

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