A Novel Statically-Levelling Self-Actuated Long-Range Trackless Compound Linear Motion Mechanism for Use in the Design of Low Cost Agricultural Robots

1. Introduction

In the search for a suitable means of producing low cost robots and thereby increasing their adoption in agricultural processes in developing countries, the design has been established of a compound linear motion mechanism consisting of a mechanism similar to that found in self laying tracks for recirculating the mechanism's legs and a set of legs having different designs selected depending on the target application of the mechanism. The legs provide a means of translating the first mechanism that produces the linear motion along the length of the support frame, acting as its guide system, as well as a means of producing a gripping force that provides both the longitudinal and off-axis stiffness thereby eliminating the need for a guidesystem that spans the entire length of the work area as well as a drive system that spans the entire length. The resulting mechanism is a very versatile one that is support-frame agnostic. With the statc levelling provided by the mechansm any locally available materials including timber, cables, fencing wire, concrete walls, etc that have sufficient strength for the intended application can be used as the support structure for the mechanism. By this means the cost of robots requiring linear motion mechanisms can be greatly reduced. While the primary intended application of the mechanism is in fixed cartesian robots, it can also be used in cable robots as well as in mobile walking robots. Many other uses for the mechanism are left to the imagination of the creative mind.

Advantages of ARS and :: need for them

Agricultural robots (ARs) have become an increasingly important tool in modern farming due to their ability to improve efficiency and productivity (Dórea et al., 2016). By automating tasks such as planting, watering, weeding and harvesting, ARs can reduce the need for labor and allow farmers to focus on other aspects of their operations (Kumar et al., 2018). In addition, the use of precision techniques and reduced reliance on chemical inputs can help to reduce the environmental impact of farming (Zhang et al., 2019). Farmers who would like to adopt agro-ecosystem field management practices which require that the farmers gain an understanding of the local ecosystem services and a holistic understanding of biotic interactions in the field can benefit from the big data created by the robots as well as by more experienced farmers which can be used by the robots such as is available at OpenFarm. ARs also improve food safety by reducing the risk of contamination during handling and processing (Lopez-Garcia et al., 2020). It has also been shown in an economic study [11][1] which analyzed three different robotic weeding applications for the particular case of high-value crops that the cost of robotic applications is lower than the cost of conventional systems. Further benefits of ARs have been demonstrated in a variety of studies (e.g. Dórea et al., 2016; Kumar et al., 2018; Zhang et al., 2019; Lopez-Garcia et al., 2020), and it is clear that the adoption of ARs has the potential to greatly benefit farmers, consumers as well as robotic companies.

Barriers to adoption
However, the adoption of ARs is skewed towards the resourceful large farms[1] leaving out the majority of the world's farmers who are the holders of very small-sized farms, small-sized farms, and medium-sized(SMFs). In the European Union these farms respectively represent 40%, 29%, and 14% of the farms, a total of 83%. [1] Likewise in Africa 90% of farm household have between 0 and 5 hectares. [2] According to a study by Bürkle et al. (2019), the main barriers to the adoption of agricultural robots by small and medium-sized farms are the high costs of these technologies and the lack of suitable financing options. These barriers can be particularly significant for farms in developing countries, where the economic environment may be less favorable for investment in new technologies (Bürkle et al., 2019). In addition, small and medium-sized farms may have limited access to the technical expertise and support needed to implement and maintain agricultural robots (Bürkle et al., 2019). As a result, the adoption of these technologies has been largely limited to larger farms with the resources and capacity to invest in and utilize them effectively (Bürkle et al., 2019).

Cost Contributors
It has been shown in a study that the main cost contributors for ARs is the *small labor capacity* and sensors for precision localization. On the other hand fixed robots increase in cost as their size increases. In May 2020 the production of Farmbot MAX which was the largest model of the range of Farmbot Robots was put on hold pre-launch. Among the reasons given by Farmbot for this was that it was too expensive. (https://farm.bot/blogs/news/putting-farmbot-genesis-max-and-express-max-on-hold). The significant increase in cost of farmbot MAX relative to the other models is due among other factors to the extra length of

aluminium V-slots used for the tracks. Considering that the aluminium itself is a good candidate for the scrap metal business in developing countries, the use of such a robot in outdoor gardens where if would be vulnarable to theft is impractical.

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Depending on the type of robot chosen, whether mobile or fixed, there is the use of superflous components either as sensors or structural components which are not entirely needed for agricultural applications. A weeding robot called Tertil produced by iRobot moves in its environment using a bump-and-go algorithm which eliminates the needs for expensive locazation sensors. While this algorrithm has this advantage, it also has its drawbacks. Bump=and-go cannot be used for some agricultural applications which require structured movement with the farm and it also requires plant guards around young plants to prevent the robot from running over them. Although Tertil which is being sold at $349.00 is still too expensive for developing countries, it illustration how to reduce the cost of robots by eliminating unnecessary sensors for a particular application.

Fixed robots can be controlled by very simple control methods which do not require sensors including open loop control. They, however, have a physical range which is limited by the physical properties of the support material as well as the costs of increasing the size of the robot. The aluminium V-Slot Extrusion with built-in Linear Rails used by Farmbot has an accuracy of 0.45mm. (file:///home/brian/Downloads/linear%20motion%20mechanism/An_Accuracy_and_Repeatability_of_a_Robot_made_with.pdf) A 0.45mm accuracy is far greater than the minimum requirement for agricultural applications which have traditionally been done by hand giving room for cost cuttings.

Compomises can be made in the sensors and structure and control methods used for positioning which while they will affect the qualify measures of the robot in terms of accuracy and precision will leave them within acceptable limits for agricultural applications. This is the method employed in the design of the present mechanism. For fixed robots a means is also provided of increasing the range of the robots without significant increase in the cost of the robot.

Yet another major cost contributor is the development of several different robots or the development of different sizes of the same robot. Significant resources are spend in the development of software as well as the design of the hardware and the training required for the expertise to maintain the different robots. A single standard is proposed in the design of the present mechanism which allows the mechanism together with its control systems to be used in the design of several different robots including cartesian fixed robots, cable robot and mobile walking robots.

Motavated by the several available rooms for impovement (summarized in Table 1), the authors developed a new ...

The primary use for the the present mechanism being in linear displacement, the subsequent section handles linear displaement mechanisms, section 3 the design of the proposed linear displacement mechanism, section 4 the design of legs for different configurations of the mechanism, section 5 a theoretical analysis of the perfomance of the mechanism and section 6 use of the mechanism in mobile walking robots.

2. Linear Motion Mechanisms

Linear-motion mechanisms generally consist of a load bearing anchor or frame and a support structure (called the "guide") that guides a portion of the mechanism (called the "carriage" or "shuttle") in linear translation. (2012-J-JMD-METRICS.pdf) The mechanism's accuracy is due in no small measure to the accuracy of the guidance system. The guide usually consists of an anodized aluminum extrusion profile, or steel, making the linear motion system highly rigid. The frame can simultaneously serve as the guideway. *Fig 1* shows such an example.

When a limited range of motion is needed, such as in a 3D printer, an externally powered system can be used to convert rotary motion to linear motion. An example of this is using a toothed belt, driven by a rotational motor through a pulley, to power a translational load. [8] The compliance and elasticity of the belt has the advantage of reducing shock loading. Another option is to use lead screws or ball screws which provide high accuracy in positioning through the use of use rigid elements for the transmission of motion and power. As a general rule, however, externally powered linear systems have a limited range of motion due to the limitations of the length of the motion-transmitting elements such as belts or lead screws.

When a linear system needs a large range of motion, a self-powered drive mechanism can provide consistent performance that is not affected by the range of motion. A common example of such a mechanism is the traditional rack-and-pinion mechanism, which converts the powered rotation of a pinion into linear translation as it meshes with a stationary rack. However, despite its extensive application in various electromechanical systems, the rack-and-pinion mechanism has some weaknesses. While the rigidity which allows accurate positioning in the long range mechanisms is an advantage over elastic and compliant systems, they may generate shock loading and affect the user experience during the interaction. Further, the rack spans the entire length of operation, is continuous over that length and requires accurately machined teeth over the entire length. This is also true for the guides of the other types of both externally powered and self-powered linear motion mechanisms. The long guides needed for a long range of motion are difficult and expensive to manufacture.[Novel]

As a general rule, short range linear motion mechanisms are cheaper, less complicated and have a better performance compared to their long range counterparts. It is therefore a reasonable approach in the design of long range linear motion mechanisms to take the advantages of both the externally powered short range mechanisms as well as those of their long range counterparts (listed in Table 2). This is achieved in a compound mechanism that consists of a short range externally powered mechanism moving as the carriage on a long range guide. The associated costs of having a long guide are reduced by configurations of the compound mechanism that require the carriage to be mated with the guide at specific points of constant interval as opposed to continuously throughout the length of the guide. This difference is illustrated in *Fig 2*. A statically-levelling configuration further reduces the need for an accurately machined guide enabling the use of the load bearing anchor as the guide while maintaing the required accuracy for the mechanism. This gives room for any locally available materials to be used both as the anchor and guide for the mechanism thus reducing the cost of the required long range mechanism to almost the cost of the short range mechanism that acts as its carriage.