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Abstract

Research within agricultural technology focuses mainly on increasing the efficiency of crop production. Electric powered machines have several advantages. The machine control is much easier in terms of sensor integration, active navigation and task application compared with traditional machine types. Furthermore, low machine weights and the use of renewable energy to provide the necessary energy contribute to soil protection and low emission performance. The aim of the paper was to describe the design, the control and the renewable energy supply for a small electric powered robot for outdoor field monitoring and other operations. Furthermore the energy consumption for the different operations scenarios was determined based on power consumption measurements for the basic navigation modes. Additionally two different charging scenarios have been investigated. The investigation has shown that it is possible to power a robot using PV cells for an operation time of 11 to 13 hours. The PV charging solutions are expensive compared with using the public power grid. They are only viable when there is no access to the grid.

Key words: energy consumption, robotics, weed control, controller software, renewable energy

1. Introduction

Research within agricultural technology focuses mainly on increasing the efficiency of crop production. Efficiency in production can be optimized by improving machine behaviors as well as by creating better growing conditions. Small and smart autonomous machines have the potential to significantly contribute to both by utilizing more multi-factorial real-time sensing and embedding mathematical modelling of technical and biological parameter interactions.

Electric powered machines have several advantages. The machine control is much easier in terms of sensor integration, active navigation and task application compared with traditional machine types. Furthermore, low machine weights and the use of renewable energy to provide the necessary energy contribute to soil protection and low emission performance. Currently electric powered robots are costly, and most of the commercial available robots are not modular in design. Modular designed robots can be adapted to and used for different tasks and used in different environments. Modularity also contributes to acceptable prices.

To take the electric powered vehicle one step further, it should be powered by renewable energy. The primary energy source for the Armadillo Scout will be photovoltaic cells. By measuring the robot's power consumption during basic field works and for different operation scenarios it is possible to calculate the time needed for operating and charging and the necessary solar panel size. Once the robot and the power plant are set up the robot will conduct terrain exploration and mapping as well as precise and efficient actions within an agricultural field.

The aim of the paper is to describe the design, the control and the renewable energy supply for a small electric powered robot for outdoor field monitoring and other operations.

Furthermore the energy consumption for the different operations scenarios will be determined based on power consumption measurements for the basic navigation modes.

2. Methods and Materials

2.1. The machine

The small and smart electric robot at Hohenheim University is based on the Armadillo Scout machine which was developed by both the University of Southern Denmark (SDU) and the Danish company LYNEX (Jensen et al., 2012). The idea was to design a modular robot having the mechanical design kept as simple as possible. The design makes it easy to build, to maintain and to modify if needed. Armadillo Scout is the first public version of the ARMADILLO, and will be used at Hohenheim University as a machine platform for advanced research and teaching projects.

The Armadillo Scout field robotic tool carrier (30 k€ cost) has a modular design which makes the robot configurable and adaptable to a wide range of precision agriculture research projects. The Armadillo Scout weighs about 425 kg and consists of two 18 x 80 cm footprint belt modules and an integrated 3.5 kW electric motor, gear and motor controller for each belt. The belt modules are mounted on the sides of an exchangeable tool platform which allows an adjustable width and clearance height of the robot.

The Armadillo Scout is controlled by an on board computer, a Frobobox, with Linux Ubuntu 11.10 operating system. It has CAN-, Serial-, USB- and Ethernet interfaces for connecting sensors and actuators.

The robot is powered by a 48 V exchangeable Lithium Ion power pack (LFP160AH from Power Group). It is a package with 16 cells with 3.2 V each and connected in serial. This gives a total voltage at 16 cell·3.2 V = 51.2 V but is used as a 48 V and has a capacity of 160 Ah.

FIGURE 1: The electric powered belt driven platform (7 kW)

2.2. The controller software

MobotWare is a software framework for controlling agricultural robots. The system is called a multilayer controller due to its structure. The structure consists of the user interface including mission definition and high and low level control.

It is based on MobotWare developed at Denmarks Technical University (DTU). MobotWare is currently implemented on a wide range of mobile robots, from small educational indoor robots to a conventional Claas Axion 840 research prototype (Beck et al., 2010).

The Multi-Layer Controller is already implemented on another Hohenheim machine, the Autonomous Mechanisation System (AMS) (Griepentrog et al., 2011). The software has been proved that it can control robots powered by combustion engines as well by electric motors. Furthermore it has been demonstrated that machine safety can be improved by adding dedicated functionality (Griepentrog et al., 2009).

Along with MobotWare the Armadillo Scout can also be controlled using FroboMind, which is developed at University of Southern Denmark (SDU). FroboMind is based on ROS (Robot Operating System) and is currently being used to control the Armadillo Scout manually with a WiiMote.

2.3. Providing solar energy (PV generator system)

For the operation scenarios a renewable energy providing system consisting of a PV generator, a battery and a docking station is proposed. At the docking station the robot can go for recharging or getting even small autonomous repairs as well as picking up extra equipment and materials (e.g. refilling chemicals for weeding). The docking station itself consists of mechanical connectors for electricity and material transfer as well as communication facilities. The battery storage is needed because the electricity from the PV does not necessarily reflect the charge demands of the robot.

One battery charging strategy can be to use a stationary battery in the docking station and a fixed one on the robot. The energy can then be stored when robot is working. Another strategy is to have a battery system for both to be exchangeable. That would free the robot from charging time at the station and it would need only the time for swapping the batteries. The design of the docking station as well as the robot itself will need significant modifications.

2.4. The operation scenarios

The robot is supposed to conduct different operation tasks like outdoor monitoring, scouting or for example perform a weed control treatment. In this section each of these skills are defined. An estimate of the power consumption in each scenario is made. Besides the power consumption of each application scenario the robot also consumes energy just by driving and turning.

Navigation

For navigating the robot needs reliable positional information. It uses RTK-GNSS, encoders for odometry and a Kalman filter for the fusion. The robot has one caterpillar track (belt) on each side. For the measurements the robot was programmed to drive forward 10 m with a speed of 0.3 m/s.

It can turn even though the belts can only move backwards and forwards. If one belt is not driving and the other one drives forward or backward the robot will turn. The belts then skid or slip over the surface while turning. It is expected that while turning the energy consumption will be higher than driving straight. For the measurements the robot was programmed to make a turn of 90 ° followed by a 180 ° turn.

Scouting and monitoring

Scouting is the ability to collect timely and accurate information about field and plant conditions. Scouting also means creating maps of the field by geo-referencing the collected

information. Accurate spatial information about the occurrence of weed plants are of special interest because conventional weeding often is costly and has negative environmental impacts (chemical inputs). There are various and mainly optical sensors (cameras) available which allow reliable weed plant recognition (Griepentrog et al., 2010). The total power consumption of the machine is added by energy needed to supply the required sensing systems.

Weed control

Weeds in a field are a problem, because they compete with crops for moisture, nutrients and light. But weeds provide ground cover, fix nutrients and improve biodiversity. Therefore, not all weed plants are unwanted. If a weed control method could keep the 'good' weeds untouched and remove the 'bad' ones then this principle is called 'selective weeding'. This method is of high interest because energy is focussing only on removing the problematic weeds. If scouting and monitoring can provide weed maps then a treatment operation can be based on mechanical (blades, knifes or tine rotor), chemical (spraying), electrical (electro static) and thermal (flame, steam, radiation, hot water or oil) principles. A basic requirement is that the actuator is small enough to operate with a high spatial resolution for targeting individual plants. We assumed a small electric powered mechanical actuator for treating the weeds. This method is soil engaged and cuts roots, uproots weeds or covers the plants with soil.

2.5 Measuring power consumption

The power consumption measurements of the Armadillo Scout was done by measuring the total current flow from the batteries. The current was measured with a clip-on amp-meter, which outputs a low voltage. The voltage measurement was logged using 1-wire voltmeter and software that stored the data on a computer.

More comprehensive system and calculation details are described in Dühring (2012).

3. Results and Discussion

3.1. Energy consumption

When driving in a straight line the robot uses 434 W and when turning it uses 466 W. Normally the robot will drive all the way down the field and at the end make a 180° turn and drive back. The average between the 180° turn and the 10 m forward driving is:

$P_{driving}$ = (466 + 434) / 2 = 450 W. This value (450 W) for the power consumption while driving and turning is added to each application scenario.

For the navigation scenario the robot consumes $P_{driving}$ plus the power for sensing (70 W). The total power consumption is 450 W + 70 W = 520 W.

For the scouting scenario the robot consumes $P_{driving}$ plus the power for scouting (80 W). The total power consumption is 450 W + 80 W = 530 W

For the weeding scenario the robot consumes $P_{driving}$ plus the power for the electric actuator (175 W). The total power consumption is 450 W + 175 W = 625 W

3.2. Charging the battery

The used charger delivered 30 A to the battery. When the battery is fully depleted it is assumed that it still has 10 % capacity left. The time it takes to charge this battery is: (160 Ah • 0.9) / 30 A = 4.8 hours.

3.3 Operating Time

The battery capacity is 160 Ah at 48 V. It is assumed the battery can deliver 90 % of its capacity. The total power the battery can deliver is calculated as

$$P_{160\ battery\ deliver} = 48\ V \bullet (160\ Ah \bullet 0.9) = 6.912\ kWh$$

This gives the following operating time for each scenario:

Navigation: Operating Time = 6.9 kWh / 520 W = 13 hours

Scouting: Operating Time = 6.9 kWh / 530 W = 13 hours

Weeding: Operating Time = 6.9 kWh / 625 W = 11 hours

3.4. PV Generator Design

Two charging scenarios have been considered. Scenario 1: One stationary battery at the docking station, and one fixed battery on the robot. The robot is recharged at the docking station. Scenario 2: One battery at the docking station and one battery on the robot. The batteries can then be exchanged.

The scenarios are investigated in Dühring (2012). When using the setup proposed, the PV cell area for scenario 1 is 44 m^2 and for scenario 2 49 m^2. If a sun tracker is used the area can be reduced with 14 m^2.

Price comparison and payback time in comparison to using the power grid is shown in table 1. The price of the two scenarios is high, which causes the high payback time for both scenarios. The average lifetime of a PV cell is 25 years which indicates that using a PV generator does not save money, but only saves energy.

Using a PV generator can on the other hand be a good solution if there is no access to the power grid. It can even be cheaper than getting access to the power grid at an isolated field.

TABLE 1: Price and payback time

	Replaceable battery	Stationary battery
Price of system	12 375 €	18 145 €
Charging times	6 188	9 073
Payback time	25.5 years	38 years

4. Summary / Conclusions

Two different scenarios have been investigated for charging an electrically powered agricultural robot. The investigation has showed that it is possible to power a robot using PV cells. But both solutions are very expensive compared with using the power grid. The solutions are viable when there is no access to the public power grid.

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