計測自動制御学会東北支部 第 335 回研究集会 (2021.10.29)
資料番号 335-4

Conversion of a Commercial Electric Cart into a Mobile Platform for Agriculture

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Keywords : agricultural robot, mobile platform, electric cart, external encoder, modular design

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1. Introduction

In the last two decades the world has seen an increase in academic papers, technologies and companies related to applying digital tools to improve crop production, quality and harvest time, as well as reducing costs. Digital Farming has been increasingly implemented into agricultural practices due to the advances in technologies such as wireless communication, cloud storage and data analytics [1)2)].

Japan is no exception, and as farmers' average age increases [3)] both the government and companies look for alternatives to facilitate agricultural tasks, such as crop harvesting and seed sowing.

These tasks are not necessarily complex for humans, even if they are time consuming and exhaustive, but they can pose difficult problems for robots due to environments difficult to traverse, with repetitive patterns, irregular soil, small or delicate crops, etc [4)5)].

In Yamagata prefecture, there is a special crop called "Yamagata Cherry," a delicate red cherry that must be harvested along with its stem. Harvesting this crop can be demanding to the body of farmers, since every cherry must be hand picked.

In an effort to help farmers with this task, we are developing a robot capable of delicately harvesting this crop [6)].

To successfully develop a fully automated cherry harvesting robot, there are a few important milestones to be achieved, such as: the recognition of cherries for harvest, the ability to precisely remove the cherries from the tree branches without damaging them and the ability to navigate inside the cherry orchard safely.

Although the task of harvesting cherries is undeniably challenging, such a robot cannot achieve fully automated harvest without a mobile platform capable of driving itself autonomously inside a cherry orchard.

This platform needs to be able to traverse an irregular terrain, identify and avoid obsta-

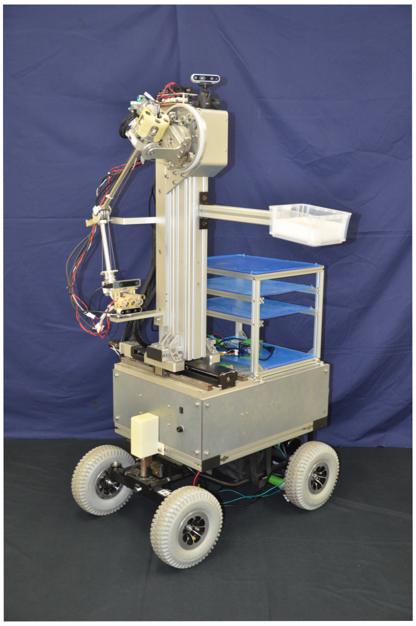

Fig. 1 Cherry Harvesting Robot, developed by the Telerobotics Laboratory at Yamagata University.

cles, and carry the heavy load of all integrated robotic equipment.

The cherry harvesting robot from the Telerobotics Laboratory at Yamagata University follows a modular concept, being composed of three parts: a cart module responsible for moving the robot in the environment, a arm-hand module responsible for collecting the cherries with a high precision manipulator, and a recognition system module responsible for identifying the environment (Fig.1).

In this paper, we present the conversion of a commercially available electrical cart designed for carrying parcels into a fully controllable robotic platform, focusing on building a wireless and modular system.

2. Cart Conversion

This mobile platform is based on the Jasper series EJ20 electrical utility cart from CanyCom Company. The original cart contains a rechargeable 24 V battery pack, four wheels, on/off key-switch, and it has the configuration of front-wheel-steering and back-wheel-driving, controlled by a steering handlebar and an accelerator lever. The maximum load that can be carried is 200 kg, at a maximum speed of 4.5 km/h forward and 2.9 km/h backwards. The main motor is a 24 V DC, 350 W brushless transaxle motor coupled to the back wheels axis.

There are two main reasons as to why a commercial cart conversion was done: time saving and cost management.

Converting a premade cart was a simpler task than designing and manufacturing a cart body, possibly saving months of prototype development.

Meanwhile, when considering the costs of designing and manufacturing a very similar cart body, in addition to the purchase of high performance motors and batteries, there was not a significant price reduction in comparison: in fact, it could amount to a higher value than the original electrical cart price. Considering both reasons together, the option was made to perform the conversion.

2.1 Body

The cart's body was stripped, preserving only the base metal frame and both front and back wheels. The parcel carrying frame was replaced with a metal box of 64.5 × 47.5 × 26.5 cm in size, where the frame is made from aluminum bars and steel side panels, attached directly on top of the original metal frame. The original driving motor was preserved, as well as the 24 V battery pack. The steering handlebar was replaced with a Maxon Combination number 313518 (Maxon Motor 268214 and Encoder

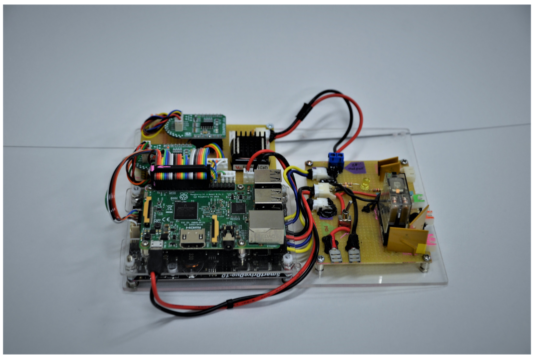

Fig. 2 Motor control system circuit board.

Sensor 225785), added to a reduction gearhead of 1/100 ratio.

3. Electronics

A compact control circuit was designed based on the 24 V battery pack, the original 24 VDC brushless driving transaxle motor and the replaced steering motor. All components were affixed into a 15 × 20 cm square of acrylic plastic, resulting in a control board of the same size and of 5 cm height (Fig. 2).

These dimensions facilitate the installation of the board inside the robot's main body, making it possible to fixate it both horizontally and vertically, and allowing for more space inside the main body for other systems.

A Raspberry Pi 3 B board was chosen as the microcontroller, due to its compatibility with a wireless design (integrated Wi-Fi and bluetooth antennas) and large input/output interface (40 GPIO pins). A Cytron MDDS10 SmartDrive board was chosen as the motor controller board, as it has the function of a H-bridge controller capable of controlling two motors at the same time, as well as having overvoltage and overcurrent protection.

The MDDS10 takes a high/low digital signal from the Raspberry Pi board to signal motor direction and a Pulse-Width Modulation (PWM) analog signal to determine motor speed for each motor, and directly converts it to an equivalent power output to the motors based on the available battery power connected (in this case, the 24V battery pack).

Between the motor controller and the motors, there are two different configurations of motor protection circuit. As recommended by the manufacturer, a resettable PPTC [7] (Polymeric Positive Temperature Coefficient device) fuse of 4 A was added to the connector of the steering motor to prevent overcurrent damage. As this motor is dedicated to steering, such a simple protection circuit is admissible.

The transaxle motor had a built-in thermal sensor and a solenoid brake from the manufacturer, so these were considered in the design. The thermal sensor is a Normally Closed (NC) switch that opens in case of motor overtemperature, triggered around 100°C. To integrate this, we added a Normally Open (NO) coil relay switch between the motor controller and the motor connectors, activated by the thermal sensor power line: if the thermal sensor is triggered, the connection opens, and the power to the motor is immediately cut-off. The solenoid breaker is a magnetic clamp that prevents the motor from turning. It can act as an emergency brake, and also prevents the motor from turning when power is not applied or the cart is parked. It is necessary to apply 24 V to it to release the motor axis and allow for movement. As soon as power to the motor is cut, this mechanical braker is activated, stopping the cart.

The steering motor (Maxon Combination) has a built-in high-precision quadrature encoder, but the transaxle motor did not have

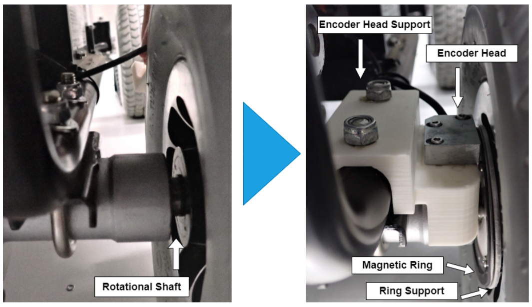

Fig. 3 External encoder implementation.

any sensing device. The placement of the motor from the manufacturer made it difficult to implement an internal encoder, so we opted for an external encoder device.

This has proved to be an issue more complicated than what we initially thought, due to the limited space available in the main shaft. Beside the space limitation, we also needed an equipment that would be resistant to humidity, water drops, vibration, dust, etc. For this reason, we opted to use the MR080N Axial magnetic ring and LM10 incremental magnetic encoder sensor from RLS. To implement this sensor, we have designed support parts to facilitate the installation of both the magnetic ring and the encoder head: it consists of an accessory 3D printed ring that fixates the magnetic ring to the wheel coupling and of a 3D printed support for the encoder head (Fig. 3).

To facilitate interfacing the encoders with the microcontroller, a pulse counter Integrated Circuit (IC) was added. The component chosen was the MikroE Counter Click, which is a distribution board based on the 32-bit quadrature counter IC LS7366R. This IC is capable of counting the quadrature pulses from the encoders up to an order of 32-bits and 40 MHz, and uses a Serial Peripheral Interface (SPI) for communication.

Finally, the user input interface is done

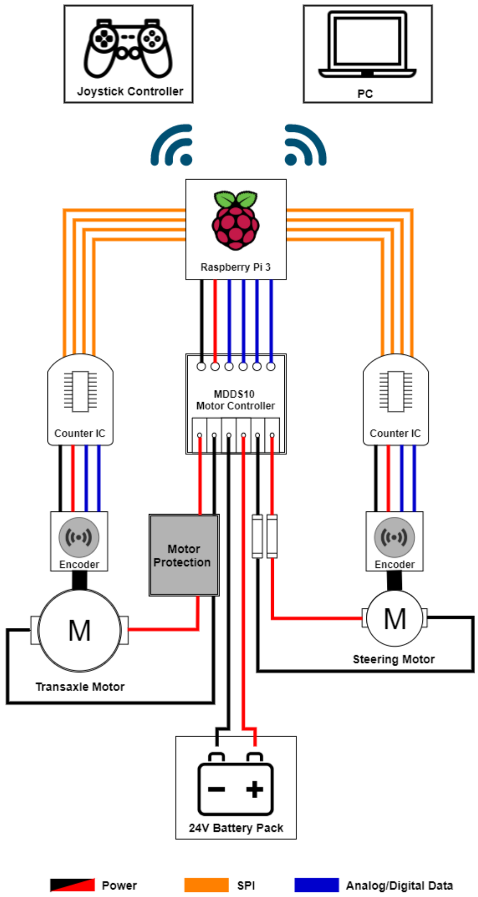

Fig. 4 Electronics architecture for motor control system.

through a joystick controller, a Playstation DualShock 4 Wireless Controller, connected to the Raspberry board through bluetooth. It is also possible to fully control the Raspberry board wirelessly by configuring it to connect to a pocket Wi-Fi or network device beforehand. Although access through SSH and terminal commands is possible, the author uses the NoMachine freeware software for this purpose.

Fig. 4 shows a diagram of the described architecture.

4. Software

The Raspberry board has proven to be the correct choice for this project since it was easy to interface with all peripherals.

A few algorithms based on Python and ROS[8] (Robot Operating System) were developed to perform the tasks of: receiving joystick input, translating joystick input into a "desired speed" command sent to the motors, sending speed commands to the motors after PID adjustment, collecting encoder data and translating encoder data into measured speed. Since we have both a "desired speed" input and "actual speed" information taken from the encoder sensors, the motor control is a closed feedback loop system that improves motor control accuracy.

Mobile platform operation is fairly simple: first, we connect a Notebook PC to the Raspberry board through a Wi-Fi network using the NoMachine software. Then the joystick is connected through Bluetooth to the Raspberry, and a script is started that constantly listens to joystick inputs. When a joystick input is received, that information is translated into a desired motor speed quantity in meters per second.

The desired speed information is then passed through a PID[9] control calibrated for each motor individually, and an adjusted command is sent to the motor controller board (MDDS10).

Meanwhile, another script initializes the counter ICs and proceeds to listen to its readings. If there is a change in direction, overflow or underflow of the counter, the IC signals a flag event, which is heard by the script and a flag is signaled to adjust the readings accordingly. These counter readings are then translated to the current motor speed for each motor. Total travel speed is also available, based on the motor maximum speed and wheel size.

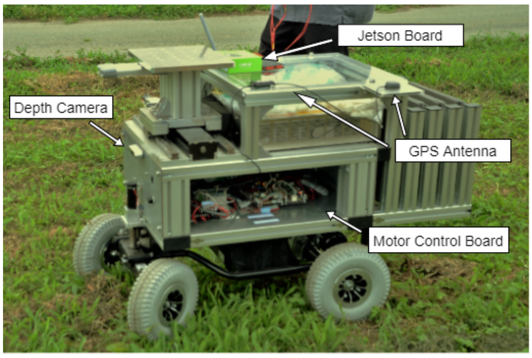

Fig. 5 Cart prototype with in-development world recognition system.

5. World Recognition

Besides the basic motor control electronics and software, the mobile platform prototype also includes an independent RTK GPS sensor and an in-development environment recognition and mapping system (Fig. 5).

The environment recognition and mapping system is composed of a Jetson Nano 2GB board and a D435 RealSense RGB-D camera. Video (image and depth) data is recorded by the Jetson board at 15 frames per second, and later it can be post-processed to evaluate Visual Odometry and object recognition. Currently the project uses RTAB-Map SLAM[10] software for mapping and Visual Odometry.

The RTK-GPS is an Emlid Reach M+ system, consisting of two Emlid Reach M+ boards and GPS antennas. This sensor has centimeter precision when well calibrated and with good satellite vision (not cloudy, no overhead obstacles), as such, GPS data can be used to correct odometry data, but is currently being used as ground truth. The GPS rover module outputs its current location into a text file on the Raspberry board through a Python script every 200 ms.

This extra equipment continues to follow the modular design of the project, since it is independent from other systems, but it can be easily interfaced with through USB serial communication, I/O pins or even wirelessly.

6. Conclusion and Future Work

The mobile platform developed consists of a system with calibrated motor control, reliable encoder readings and accurate ground truth GPS data information available for post-processing. Since the program simply takes a "desired speed" command for both steering and driving, this architecture will be compatible with an autonomous driving software that outputs the desired translation and rotation speed. The further implementation of a vision system (Jetson board and RealSense camera) evolved the prototype into the possibility of an autonomous drivable cart, with environment and obstacle recognition. Hence, this mobile platform achieves the necessary basic requirements of its initial proposal.

Highlights of the developed prototype are its wireless and modular design, and easy to interface hardware and software.

Future work intends to expand to accurate environment mapping and autonomous navigation in an agricultural scenario, and is currently being developed. The odometry data and GPS data collected by the current software can be used to improve mapping and odometry through many available open source SLAM algorithms, including the initially proposed RTAB-Map SLAM.

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