John Deere Modular Vehicle Control Board

ECE445 Project Proposal

Sumanendra Sanyal, Sam Huhta, Zachary Hoberg

Team 17

TA: William Null

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# 1.**Introduction**

## 1.1 **Objective**

John Deere currently manufactures an autonomous residential lawn mower, the Tango, that uses a buried wire to define the boundary of the yard. Installing this wire is a significant burden, requiring a site visit by specially-trained Deere technicians, increasing the cost of the product. In order to reduce installation costs, John Deere is actively working to eliminate the boundary wire by using a localization algorithm fusing several sensors, such as stereo cameras, GNSS receivers, and ultrasonic sensors. However, the current Vehicle Control Unit (VCU) that operates the mower does not have the necessary processing power to run their algorithms. Furthermore, John Deere would like to be able to apply their developed automation solution to other implements the company produces, but the current hardware is specific to the residential mower.

We will develop a new design to replace the existing board with a modular architecture consisting of a universal main board, machine-specific vehicle boards, and an updatable perception board allowing for easy integration of new sensors. The modular design allows the main board to run vehicle-agnostic high-level automation code, with perception boards and vehicle boards swapped out to run a specific piece of equipment. The main board will boot a Linux operating system and run applications for high-level autonomy. The vehicle board will drive existing equipment as appropriate, such as through direct control of actuators or by sending control signals via CANbus or other existing communication protocols. The perception board will accept sensor input, for example from cameras and IMU sensors, and include a GPU for running a Deere-provided neural net or machine learning algorithm. The boards will communicate using ethernet through an off-the-shelf ethernet router.

Problem Statement: To develop autonomous equipment, John Deere needs a modular system that allows them to modularize the controls across various vehicles, so each vehicle uses the same main board and different vehicle board and perception board.

Solution: We will develop a vehicle board that takes commands from the main board (out of scope of this project) via ethernet and operates the mower's blades and drive motors according to those commands. The vehicle board will also interface with vehicle sensors and send data on the vehicle state back to the main board over ethernet. In addition, the vehicle board will implement vehicle-specific low-level safety functions according to industry specification.

## 1.2 Background

John Deere’s competitors in the residential lawn care market have announced plans to release autonomous mowers without boundary wires in the near future. In order to remain competitive, Deere has been developing automation software to allow the Tango to operate without a boundary wire. The development environment consists of various off-the-shelf microcontrollers and single-board computers, such as Raspberry Pis, running the automation processes in a Linux environment and sending commands to the current VCU since the VCU is not capable of running Linux or the autonomy applications. The development board is capable of interfacing with several development sensors such as stereo cameras and GNSS receivers, usually through USB or ethernet. Thus, for production of a new, boundary wire-less Tango, John Deere will need a new VCU capable of running the required software while minimizing costs.

In addition, John Deere has been applying their work on Tango autonomy to other vehicles, and would like to continue to expand the capabilities of their system to new John Deere products. However, developing an entirely new control board for every vehicle would be excessive since the same high-level code can run any vehicle. Thus, a modular design that maintains continuity of certain aspects of the hardware design across vehicles will reduce the overhead when applying the design to new systems.

## 1.3 High-Level Requirements

* The vehicle board will be controlled by a microprocessor capable of booting Linux and communicating with the main board’s ARM processor. Specifically, the two boards must exchange signals using a 64-bit architecture.
* The microprocessor must decode the high-level instructions from the main board into the low-level instructions required for the motor controllers. It must also simultaneously react to inputs from the mower’s various safety sensors, as well as decode data provided by the motor controllers to send to the main board.
* The microprocessor must be capable of sending and receiving all required signals (both to/from the main board and to/from the other blocks on the vehicle board) at a rate of 20 Hz.

## 1.4 Differences

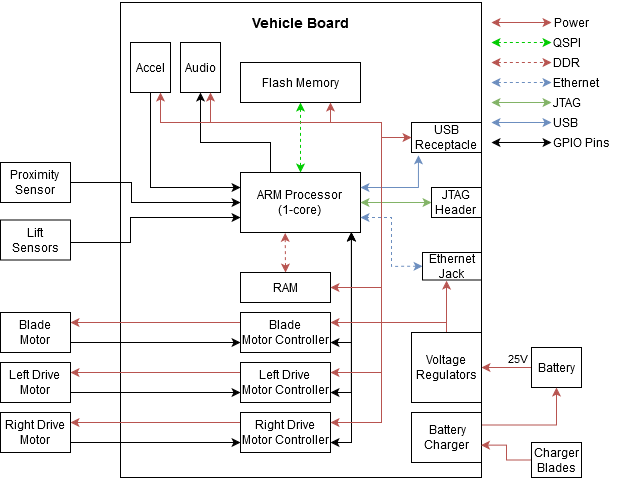
Previously, we were concerned with designing the main board, and the main functionality to be achieved was to boot Linux and run (vehicle-specific) programs that could communicate with the other two boards and output commands via ethernet. While the vehicle board also boots Linux, its primary task is to drive the Tango mower. The vehicle board isn't intended to show how to drive a mower, but instead show a modular concept, i.e. that a vehicle board can be hooked up to the main board to drive a Tango mower. Since the main board hasn't been produced yet, we can use a reference board with the same processor as the main board (LS1046A) and boot Linux and run scripts on the reference board that communicates with the vehicle board. The development of the scripts that are run on the main board and vehicle board would be handled by John Deere software engineers.

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# 2. Design

## 2.1 Block Diagram

As seen in Figure 1, the vehicle board will be essentially a custom single-board computer with a processor capable of running the algorithms needed to control the motors and read input from various safety sensors. Each board will have its own independent voltage regulators connected to the main mower battery in order to maintain supply voltages at the necessary levels, and each board will be capable of communicating over ethernet through an ethernet switch with the other boards. These prototype boards will also all contain JTAG and USB ports for purposes of debugging and testing. Note that all blocks located outside the vehicle board are provided by John Deere.



**Figure 1. Block Diagram**

## 2.2 Functional Overview and Block Requirements

**Main Board:**

The main board will boot a Linux operating system, wherein all the high-level automation software developed by John Deere will run. This board will take in data from the perception board, which it will use to run path planning and path tracking algorithms, and it will send the results of those algorithms to the vehicle board in the form of commands for the drive system and any implements on the vehicle.

**Vehicle Board:**

The vehicle board will run all processes specific to the vehicle. This includes receiving drive commands from the main board and translating those commands into actual movement, and also executing implement commands from the main board such as turning a lawnmower blade on or lowering a blade deck. The vehicle board also handles vehicle-specific safety functions such as emergency shut-off switches or roll-over sensors. Finally, for the Tango mower, the vehicle board will contain the circuitry for charging the battery.

**Processor:** A 1-core ARM architecture processor that sends control signals to the motor drivers based on input from and sends sensor input back to the main board via Ethernet.

*Requirement 1: Have sufficient processing power to run the applications developed by John Deere at the speeds they require. Put 20 Hz requirements here.*

*Requirement 2: Communicate with the main board over Ethernet at a rate of at least 20 Hz.*

**RAM:** This RAM will act as an expansion for the ARM processor. The exact capacity will be determined in consultation with John Deere.

*Requirement: Exchange data with the ARM processor at nominal DDR3 rates.*

**JTAG:** Communications interface for debugging the ARM processor. Able to function as a debugging tool as described in the ARM processor data sheet.

*Requirement: Interface with ARM processor according to JTAG specification and perform a boundary scan.*

**USB:** Used for debugging and loading the operating system

*Requirement: Communicate between ARM processor and external device according to the USB Standard.*

**Ethernet:** Main method of communication while the vehicle is in use. Used to receive commands from the main board and send vehicle state sensor data to the main board.

*Requirement: Communicate between the ARM processor and the main board via an ethernet switch.*

**Flash Memory:** A formatted drive containing the Linux system and executable processes to be run on the ARM processor.

*Requirement 1: Communicate over SPI bus with the ARM processor.*

*Requirement 2: Boot ARM processor from flash memory.*

**Motor Controllers:** They provide an interface between the ARM controller and the motors. Their main task is to convert the ARM processor’s instructions into the voltages needed to drive the motors at the correct speed. We already have circuits connecting motor controllers to the motors.

*Requirement 1: Control the provided motors at commanded speeds.*

*Requirement 2: Provide feedback on motor speed from motor Hall effect sensors to the ARM processor.*

**Voltage Regulators:** Provide consistent power draw from the battery to the ARM processor and motors so that the voltage and current ranges are consistently within given specifications - we already have access to power circuits fulfilling this requirement.

*Requirement: Provide necessary current to the ICs on the board at rated currents while remaining within their respective supply voltage tolerances.*

**Battery Charger:** Provide the necessary power to charge the battery when the mower is in the charging station.

*Requirement: Given the correct voltage across the charging blades, safely charge the internal mower battery.*

**Accelerometer:** Provides feedback on mower orientation in space.

*Requirement: Send mower orientation and angular velocity to the ARM processor.*

**Audio:** Used to give feedback to user inputs and alert the user to safety stops or other issues.

*Requirement 1: Produce a warning sound loud enough to meet the industry standard when commanded by the ARM processor.*

*Requirement 2: Provided user feedback as necessary when commanded by the ARM processor.*

**Perception Board:**

The perception board takes inputs from various sensors such as stereo cameras and GNSS receivers, and runs localization algorithms to determine vehicle location and trajectory. It will contain a GPU for running the neural net developed for localization. The perception board should also be capable of running software for object detection in order to avoid obstacles and make safety shutdowns when people or animals approach the vehicle. The perception board will need to communicate all of this information to the main board at a fairly fast rate to enable the processes on the main board to run reliably.

**Ethernet Switch:**

Off-the-shelf component that transmits data according to Ethernet specification.

## 2.3 Risk Analysis

We anticipate booting Linux poses the highest risk to our project, because booting an OS on a microcontroller is much more sophisticated than programming a microcontroller to run some script to do something useful. While the current VCU boots Linux, no one at John Deere can give us guidance because it was outsourced to some other company, meaning that unlike the other aspects of the project, we are completely starting from ground zero for booting Linux. Based on our experience with the LS1046A processor for the main board, we will have to take the Linux distro and bootloader and place it on a USB drive or SD card, and specify “boot from drive” on some processor pins specifying the boot source. Then, we will have to boot Linux by specifying “boot from Flash” on the boot pins, interface with the processor via putty terminal, and see if the processor can run something useful.

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# 3. Ethics and Safety

Lawnmowers have a certain level of inherent safety risk due to the spinning blades, and in order to mitigate these risks our design will still follow guidelines from the IEC 60335-2-107 standard regarding battery-powered lawnmowers. However, our project should not have any direct impact on public safety as the boards we develop will be for internal John Deere testing and development only, and will go through several revisions by their engineers before any possible production runs. Despite this, our design will still ensure that existing safety features on the Tango mower continue to function as expected.

In accordance with IEEE Code of Ethics #7, “to seek, accept, and offer honest criticism of technical work,” we will continue our weekly progress meetings with the engineers at John Deere.

In accordance with IEEE Code of Ethics #9, “to avoid injuring others … by false or malicious action,” we have signed an NDA (non-disclosure agreement) with John Deere regarding the proprietary information they have shared with us to develop our project.