John Deere Modular Vehicle Control Board

Team 17 - Sumanendra Sanyal, Sam Huhta, Zach Hoegberg
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TA: David Null

1. Introduction

1.1. Objective

John Deere currently manufactures an autonomous residential lawnmower, 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, while swapping out perception boards and vehicle boards allow for running 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.

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 and 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 main board will have a 4-core ARM microprocessor that will boot Linux.
- The main board will be capable of communication over ethernet.
- The ARM processor must be capable of running the applications provided by John Deere, including minimum communication rates with the daughter boards and minimum update rates for the Linux processes.

2. Design

2.1. Block Diagram

The main board will be essentially a custom single-board computer with a processor capable of running John Deere's automation software at sufficient speeds in a Linux environment, and able to communicate with the perception board and vehicle board at sufficient rates for their algorithms. 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 HDMI and USB ports for purposes of debugging and testing.

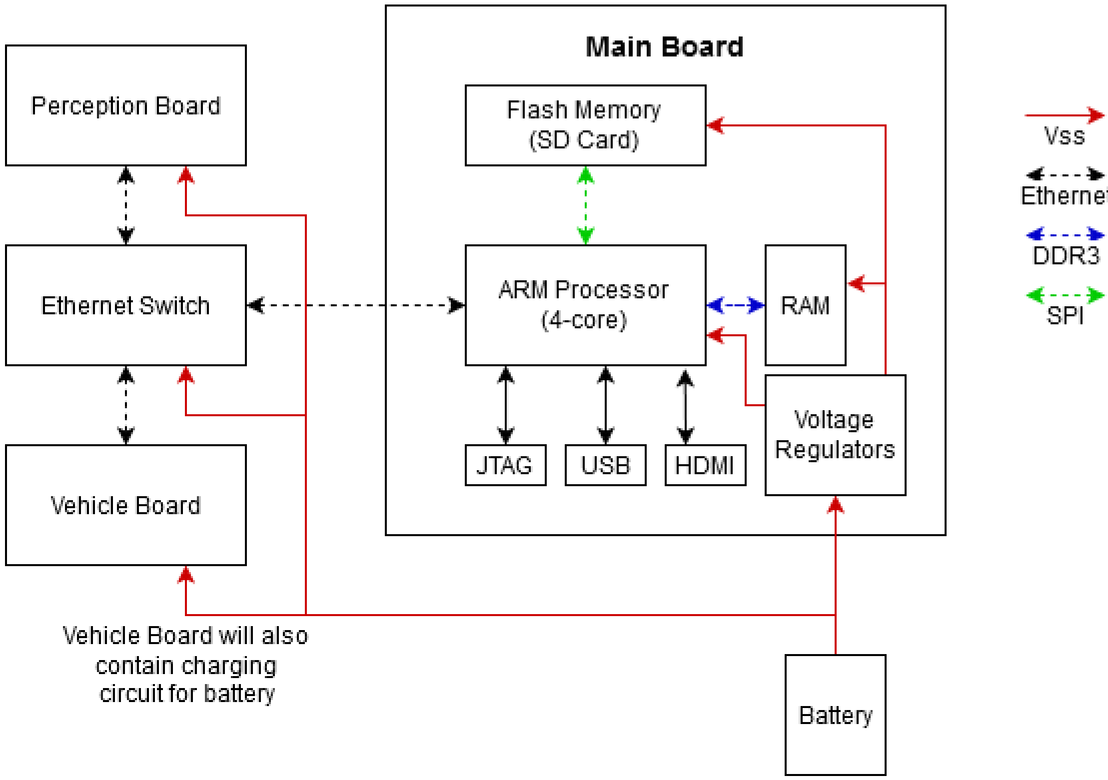

Figure 1. Block Diagram

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.

Processor: A 4-core ARM architecture processor that boots Linux, runs the applications developed by John Deere, and communicates with the other boards via Ethernet

Requirement 1: Have sufficient processing power to run the applications developed by John Deere at the speeds they require.

Requirement 2: Communicate over Ethernet with the vehicle board and perception board.

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

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

HDMI: Communications interface for displays. Able to display output from ARM processor.

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

USB: Communications interface. Able to transmit data according to USB spec.

Flash Memory: A formatted drive - SD card - containing the LINUX system. Able to be used as a boot drive.

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 within their respective supply voltage tolerances.

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.

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.

Battery:Provided by John Deere, around 200W.

Ethernet Switch: Communications Interface that transmits data.Able to transmit data according to Ethernet spec.

2.3. Risk Analysis

The main board ARM controller poses the greatest risk as it is a sophisticated integrated circuit that requires attention to many details. The board design will be complex due to the number of pins and different communication protocols that must be broken out in order for our project to function. However, the larger obstacle for our team will be booting the processor once the board is built and getting the OS loaded and running. This is something that none of our team members have experience with so we will most likely need to seek outside assistance such as UIUC faculty and staff or John Deere engineers with experience in this area.

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. However, 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 meet with John Deere engineers weekly to provide updates on our progress, ask questions, and seek feedback on our work.

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