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Design of Embedded System and Data Communication for an Agricultural Autonomous Vehicle

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Abstract

This paper describes an implemented design of an autonomous vehicle used in precision agriculture for weed and crop map construction with special focus on the onboard controlsystem, the embedded system and the datacommunication system.

The vehicle is four wheel driven and four wheel steered (eight DC motors in total) with dimension of approx. 1x1x1 meters. It is constructed with four simular wheel units each consisting of 2 DC motors and sensors for measuring wheel angle, wheel speed and momentum.

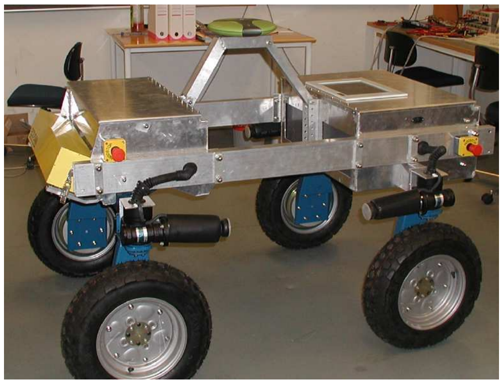

Figure 1: The Autonomous Platform (API)

1 Introduction

This work is part of the research project: "API - An Autonomous Information System for Crop and Weed Registration". The API project is a joint research and development venture between Aalborg University and The Danish Institute of Agricultural Science. [1].

Recently farming has come to rely on intensive use of chemicals for crop protection. A way to reduce the consumption of chemicals is to use precision techniques for placing chemicals where they have an optimal effect with minimal quantity. An important part of this is to locate the weed for automatic selective spraying.

Examples of robotics in agricultural and horticultural applications are [4], among others. Control of autonomous robots are treated in numerous articles, refer to e.g., [1, 2, 3, 7] and the references therein.

In the project an autonomous robot able to survey an agricultural field autonomously is being developed. The robot is four-wheel driven and four-wheel steered as shown in figure 1. The vehicle has to navigate to certain way points where measurements of the crop and weed density are obtained. This information is processed and combined into a digital map of the field, allowing the farm manager to deal with weed infestations in a spatially precise manner. The robot is equipped with GPS, gyros, magneto-meter and odometers, to facilitate exact determination of the location for image takening, as well as to provide measurements for an estimate of the robot's position and orientation for a tracking algorithm. Actuation is achieved using independent steering and drive on four wheel assemblies (4+4 brush less DC motors in total). To enable farmer supervision and on-line data transmission the platform is connected to a base station.

An important issue is the ability to carry out autonomous missions in a reliable safe way. This is assured by a reliable on-board-platform control system, data handling and communication implying design of a robust embedded control system. Steering, navigation and control as well as platform to base communication makes it necessary to handle the widely differing time requirementss at different control levels on-board the vehicle. In addition the data handling includes integration of sensors and actuators using different communication protocols, integration of wireless commu-

[1]The project is funded by The Danish Ministry of Food, Agriculture and Fisheries and carried out in cooperation with Sauer-Danfoss A/S, Dronningborg A/S, Hardi International A/S and Eco-Dan.

nication to the base station and payload data handling. A method handling these issues is presented in this paper.

2 Platform Requirements

To map the growth and density of crops and weeds the API platform is equipped with a high resolution camera analyzing single plants at different growth stages implying that the position of the inspection camera must be accurate within few centimeters. Additionally to avoid damage on crops the platform must move between the rows. Therefore to operate in the field the maneuverability precision of the vehicle must be high. The field mapping can be done in a fixed spatial grid or by use of adaptive route planning. All pictures has to be transferred to the base station within a reasonable time for further treatment.

Based on these functionalities the requirements for the platform can be listed as:

- Fast reliable transport of the inspection camera
- Position precision of the inspection camera within 10 centimeters
- Platform position prediction within 10 centimeters
- Platform velocity: 10 km/hour in the field
- Wireless communication from the vehicle to a base station
- Medium operation range of 1000 meters
- Time of operation between battery charging minimum 5 hours
- Robustness, reliability and safety

As robustness, reliability, safety and accuracy in the field are major requirements, it is obvious that normal laboratory prototype equipment not will give a satisfactory solution.

3 Hierarchy in implementation

The main functionalities to handle onboard the platform are the platform motion control and navigation, the platform weed and crop registration system and the wireless transmission to the base station.

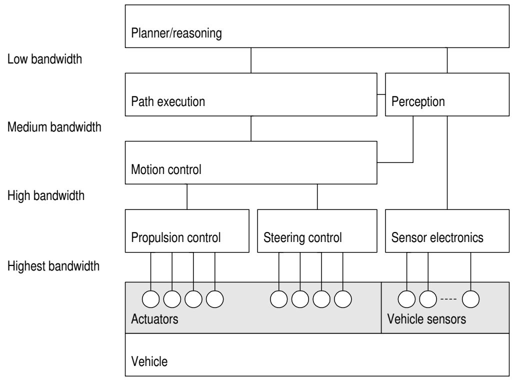

Figure 2: Control layers of the vehicle

Platform motion control and navigation

In the control system architecture the vehicle tasks are separated into four well defined layers as showen in figure 2.

The lowests layer is the propulsion control and steering control. These controllers uses feedback from encoders and motor momentum, the controllers operates with fast and fixed sampling frequency and a low software complexity. The second layer is the motion control coordinating the movements of the wheel units based on third layer information. The third layer is the path execution and the perception and the upper layer is the planning and reasoning system.

Platform Payload

The payload dataprocessing related to weed and crop registration is carried out on a separate payload computer meaning that platform communication requirements are limited to transmission of processed map information and registration specifications. The information contains a hugh amount of data without any real time requirements in the further processing.

Wireless transmission to base station

Specifications for the desired crop and weed mapping are send from the farmer/base station to the platform. The amount of data requires a high transmission line capacity. There is no hard real time requirements.

Map information must fit the ACKO-Dronningborg Fieldstar concept.

3.1 Electrical layout

As seen from the previous the embedded system onboard the platform has to handle several different

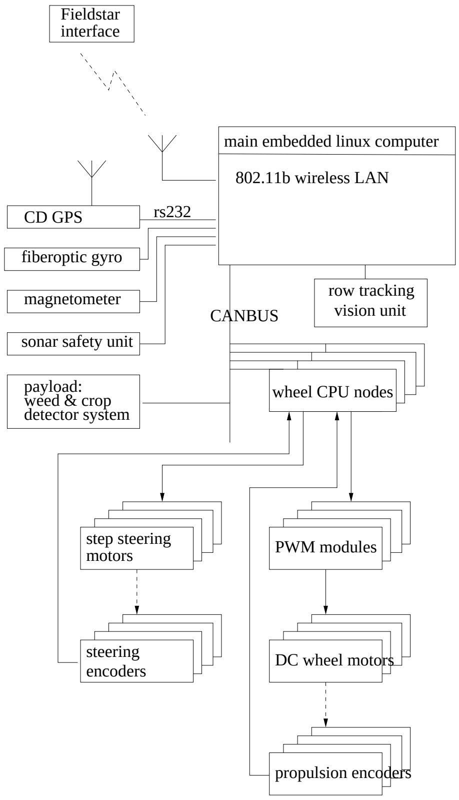

Figure 3: Sketch of electrical layout

types of data transmitted with several different time requirements.

The electrical layout reflects the above mentioned functionallities as illustrated in figure 3. The intended use of the platform nessecitates robust equipment, additionally compability to agricultural standards is taken into account.

The vehicle is equipped with a PC-104 for control purposes and on-board data communication is established

An agricultural controller from LH-AGRO has been selected as the WHC hardware platform. It is based on Infinion C167 CPU series and do support CAN-BUS, RS232, digital and analog I/O, high speed counters and PWM controllers for Four-Quadrant control and DC motors.

3.2 Time requirements within the Communication

An intuitive way to structure and decompose a real time system is by timing requirements, here the different time requirements can be used for a hierarchical design. Observations on the API control system functionality leads to the following decomposition based on timing analysis.

1. Propulsion and steering control of the wheels - (1/100 of seconds)
2. Motion control of the vehicle - (1/10 of seconds)
3. Traversing singular path arcs between way points - FPC(seconds)
4. Traversing a field and taking single crop/weed photographing (minutes-hours)
5. Task planinng (hours - days)

The traversing and mapping fields poses time depend on platform velocity. 10 km/hour is a compromise between high speed and accuracy in movement on rough surfaces. The platform may be able to move in the rows between crops.

Recognition of weed and crop requires a high quality pictures. The pictures taken with a rate of 1-2 pr second is the dominant network traffic and demands a link capacity in the area of 1MB/second.

Traversing a path between two way points imply time constants in the range of 1 second or lower demanding a 1 Hz level of real time in the control system in combination with a "near real time" external communication system.

Steering and internal wheel control have the primarily real time demands. Steering loop control is in the area of 10 Hz and the wheel control loops is 30-100 Hz.

4 Control, Reliability and Safety Issues

Safety is of major importance due to the fact that the platform has to move autonomous in an open environment where unknown obstacles (eg. animals and human beings) potentially can be in the vehicle moving direction. This necessitates a high and reliable platform-self-control solution.

Safety and reliability are defined as real time predictable behavior in the presence of faults and failures as well as under normal conditions.

It is important to note that safety and timing requirements not necessarily are related. In a system there may be components with similar control loop frequency but very different safety levels (e.g. behavior in case of faults).

Using this approach the design of the control system is based on a inside out concept, where the innermost level has the highest degree of safety and often the highest control loop frequency.

At the API the inner safety level includes the control of the four platform wheels. Since each wheel is independently motorized, it has been chosen to use one controller for each wheel. This supports the timing and safety strategy. Each of the four local controllers has to meet the demands of high speed sampling of wheel rotation and corresponding electrical current to obtain torque measurements, high speed sampling of wheel orientation, control of propulsion and orientation, retrieval and delivery of set point and control loop states to the superior controller and safety supervision of the local system (internal algorithms, communication and I/O).

The wheel controllers are under synchronized control of an outer layer with the purpose to steer the platform from way point to way point. This layer combines way points, platform position and movement measurements through sensor fusion in combination with differential GPS, gyro, compass, wheel velocities etc. Based on path tracking algorithms, this layer generates reference values for the four wheel controllers. The magnitude of sampling frequencies is an order of magnitude lower than in the wheel controllers. Although safety is of high importance at this layer, it should be noted that the reliability of the wheel controllers must be higher, meaning that direct control of the wheels is the last safety guardian for the entire system.

Using this method the design of the platform control has four safety levels. The lowest level handles two high speed control algorithms for propulsion and steering. It is localized on each wheel node controller(hereafter WNC). The second level is the four WNC's including their common connectivity (CAN network). It can be accepted for shorter period of time to loose contact to the platform controller (hereafter PFC) if all wheel nodes can interchange time critical information. The third level includes the platform controller and the fourth level is the station controller (hereafter STC) which is located outside the platform.

It should be noted that the third safety level which is wheel controllers and CAN-BUS must be under supervision from the level two due to the lack of controllers at this level.

External safety aspects is partly based on ultra sonic sensors, it is part of the PFC, but not explicit handled in this paper.

5 The on board structure

In the following the implementation of the hierarchal control architecture is discussed.

5.1 The wheel Node Controllers - WNC

The main reason for individual WNC is the ability of the autonomous controllers to act on detection of platform behavior or degradation and at the same time to execute the high speed control loops. In combination with an almost verifiable number of rather non-complex applications in terms of perspective and algorithmic complexity a highly reliable system is ensured. The WNC handles the following tasks:

- Steering control loop designed to facilitate set points transferred from the PFC.
- Propulsion control loop
- Communication with PFC and the other three WNC's
- Integrated monitoring and safety control

The main objective is to be in control in as many situations as possible. The timed communication on the field-bus includes set points and commands from the PFC, observation of the communication traffic from the other WNC's for state analysis, observation of ALERT/ALARM communication (like emergency stop), supervision of propulsion and steering motors and general supervision of the communication.

The observations are used by the control tasks to determine the control state to be executed. Based on this the WNC's has the following basic states:

1. Normal running
2. No contact to PFC
3. No contact to one or more WNC's
4. 2 & 3 together
5. Propulsion engine malfunction

Besides an autonomous supervision of the control tasks and the information exchange is carried out to obtain a more reliable and safe system.

The software is standard multi threaded design, and driven by a preemptive- real-time kernel [9] . Cycle times is 20Hz but can differ when testing alternative control algorithms.

5.2 Platform infrastructure

The backbone system onboard the platform consists of four LH-Agro controllers and one PC-104 based platform controller implemented on an embedded Linux. The quality of connectivity between these nodes are of high importance because the second timing level control are carried out via the network. In the network the following demands must be fulfilled:

- Robust predictable real time behavior
- Control via the network in the range of 10-500 Hz
- Very short error notice time
- Standard low level protocols

In agricultural vehicles CAN-BUS is the most common field bus while it is selected for the platform. Until now an European and an American standard has been used as well as several non specified company "standards". At the API the European Agriculture 11 bit identifier CAN BUS running at 125 kbit/sec is selected.

5.3 The Platform Controller - PFC

The PFC is the control and information handler of the platform. The PFC is of much higher complexity than the WHC. The major tasks for the FPC can be summarized as follows:

- Superior control system for the individual wheel controllers
- Interfacing crop row camera for navigation
- Interfacing differential GPS navigation system
- Interfacing flux gate compass and gyro meter
- Interfacing accelerometer
- Interfacing state information from the four WHC's
- Interfacing payload guest application like Vision system for crop and weed identification

Sensor fusion techniques are used to obtain and maintain the highest quality of position and velocity estimation for the superior control algorithms.

Allthough international standardization for communication has been ongoing for decades the PFC must implement several different communication protocols to interface the above mentioned intelligent sensors and actuators which has complicated the design and implementation of the PFC.

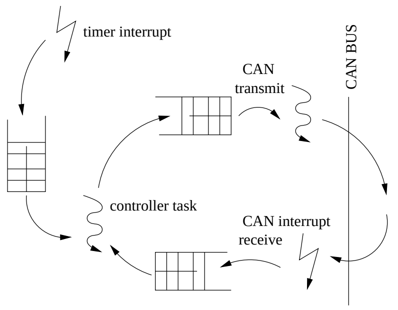

Figure 4: Schematic structure of WNC program

The overall strategy for the design of the applications is to use simple master-slave protocols, decoupling of applications to the highest degree and grouping of applications and their interfaces according to timing and safety.

The PFC is implemented on a 233 MHz PC-104 "PC" running Linux . It is equipped with CAN, WLAN (802.11b) and rs232/485 interfaces to the above mentioned items. The highest loop frequencies is in the interval [1..10] Hz which is possible on a standard Linux. All coding is in C.

5.4 The Station Controller - STC

The STC is the coordinating controller. Due to the loose connectivity to the API the timing demands is very low as temporary breakdown must be predicted as explained in previous sections. The STC must transfer new way points to the PFC when needed. For these reasons the STC is not regarded as a part of the safety system but as a reference provider. The STC is a standard linux PC with all applications coded in java.

6 Implementation and selected results

Figure 4 shows the design of the WNC control loop SW. It is rather simple. However in the main thread - the controller task - safety and supervision is an integrated part. The CAN network interface is "isolated" from the control task. A safety supervisor task is running in parallel.

The behavior for the timing critical communication on the CAN BUS is an important indicator for the quality of the system. Figure 5 from [11] shows repetitive measurements on the 125 Kbit/sec CAN BUS

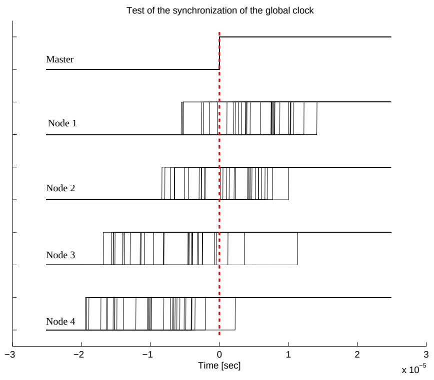

Figure 5: can timing

of the four WNC's control loop timing. The WNC's deviate max 20 μ-seconds which compared to control frequency below 100 Hz (10 m-seconds) is negligible. Due to the priority based access protocol the CAN network shows excellent behavior for control purposes. The fact that CAN communication tasks is low prioritized compared to the control task on the WNC gives an indication of a well functioning system meeting the mentioned demands.

7 Summary

In this paper a design concept for a hierarchal control system based on time and safety analysis is developed and used on board an autonomous platform for crop and weed inspection. The use of the methods results in design of a well functioning control system including distributed computer system and adherent information exchange. The system is implemented and tested on the platform.

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