Automating Agricultural Vehicles

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Abstract

This paper describes the design and construction of TROWEL - a test bed for experimental agricultural vehicles. The vehicle will be used to explore ways of increasing the productivity of expensive agricultural mobile machinery by a) taking over some of the tasks of the operator allowing him to drive faster or for longer and b) by allowing a single operator to control several machines simultaneously. In some cases machines may be able to operate entirely autonomously without operator intervention.

Introduction

The agricultural industry has reduced its workforce and thus costs by introducing larger and more complex machinery on bigger farms and workers are now often operating machines that are on the limits of their ability to control them.

Most field tasks in agriculture can be placed in one of two categories:

1. those based on crops planted in rows or other geometric patterns that involve making a vehicle drive in straight lines, turn at row ends and activate machinery at the start and finish of each run. Examples of this are in spraying, ploughing and harvesting;
2. those that involve locating objects in an area and performing operations on them. Examples would be collecting bales or trailers.

Hitherto, when labour and tools were cheap, tasks from each category could be performed at the same time. Now they most often have to be performed consecutively. If automation could reduce the degree of attention required by operators it may be possible for a single worker to operate multiple machines simultaneously, some harvesting a crop while others package and collect it.

In a factory such automation is relatively simple but in an agricultural setting the inconsistency of the terrain, the irregularity of the product and the open nature of the working environment result in complex problems of identification, monitoring and control. Problems can include unauthorised individuals entering the working area, or ground conditions varying with the weather causing changes in wheel slip, or where the colour and shape of objects being collected is not uniform.

Background

Given the seemingly simple and repetitive vehicle paths which some farm tasks demand (e.g. ploughing) it is not surprising that over 20 years ago there were attempts to construct driver-less tractors. The limitations of the then available technology meant that most of these systems were based on the principle of following electronic guides carefully positioned in the field. The cost, inflexibility and fragility of these systems meant they never found their way from the research labs to commercial farms.

Recent technological advances have led to a resurgence of interest in automating farm vehicles. There are now:

- cost effective task-independent navigation systems (driven by the large military and civil transport markets e.g. satellite based GPS systems)
- cheap, efficient embedded vehicle computing components (spurred on by the huge production volume associated with the automobile industry e.g. CAN)
- Affordable Farm Management Software & Tools (enabled by the massive volume associated with the PC market e.g. GIS systems)
- practical robotic, telepresence & artificial intelligence methodologies (arising from fundamental computer science research and applications such as NASA space missions)

Currently some of these technologies are being applied successfully to what has come to be known as Precision Farming [Blackmore 94] for tasks such as yield mapping and spatially variable herbicide or fertiliser application [Stafford 93/96]. Indeed so successful has this area been that there are now companies such as Tera Industries in the USA offering commercial Precision Farming services. Robotics is also finding success in farm applications as diverse as digging [Seward 96], fruit picking [Bourely 90] and sheep shearing [Trevelyan 88].

Of particular interest to the authors, and the principal application of the experimental vehicle being described, is the use of machine autonomy together with teleoperation (ie remote control). By autonomy we mean the ability of machines (or machine sub-systems) that can usefully move and react to a changing (and perhaps unexpected) environment without continuous human control.

Clearly there are different degrees of autonomy. For example, a traditional tractor and trailer has no autonomy as it needs continual human control whilst the seemingly low-tech horse and trailer may need less human control and may thus have more autonomy. Ironically, we would be pleased if we obtained a similar level of autonomy in a robot tractor to the horse and cart!

Producing fully autonomous farm vehicles is a most difficult objective although there have been notable steps in this direction, such as the Aurora greenhouse robot [Mandow 96], where the environment variation and application are tightly constrained. The experimental vehicle being described in this paper is designed very much to support stepwise, incremental R&D strategies, allowing experimentation with many different computer hardware, software and control architectures [Steels 96].

Applications

The Computer "Co-Pilot"

When operating highly complex vehicles, it is usually beneficial to reduce the cognitive load on the operator. By taking over some tasks, such as maintaining correct cutter height, an "intelligent" vehicle can allow an operator to maintain higher speeds with lower stress levels both for the operator and machine. Ideally, a driver would only have to provide high level commands leaving the second-to-second management of the machine to a computer. Already we have successfully demonstrated systems [Voudouris 94] working within a laboratory that allow operators to provide a set of way points (eg such as the end points of ploughing or cutting lines) leaving path planning and obstacle avoidance to the computer

The principle question we seek to answer is "which agricultural vehicle tasks would be appropriate to delegate to a computer and which should be left to the operator?"

Remote Control (teleoperation)

Vehicles can be remotely controlled either from positions sufficiently close to the vehicle to see and safely control them or at a distance where transmission of CCTV images is required. An example of the former might be a farmer locally controlling one or more vehicles in a field (maybe keeping at a safe distance for spraying) whilst an example of the latter might be observation of a field (and tractor-robots) from a remote farmhouse.
Even though this research is concerned with systems that retain a human in the control loop, it is evident that it is advantageous for such systems to possess a high degree of autonomy (of a similar type to the co-driver system). In the case of remotely operated vehicles the remote operator often has a restricted view of the vehicle's environment, there is often significant latency, temporal indeterminacy and low bandwidth in the communications links. It is vital for remotely controlled, expensive and maybe dangerous vehicles to be able to protect themselves and their environment without operator intervention.

In order to support experimentation along these lines the vehicle is equipped with radio modems that can communicate with a portable PC over a distance of up to several kilometres.
We have already successfully demonstrated remote control of robots over low-bandwidth, high latency networks [BT 95, Heron 97] and will be using the University's VASE Laboratory (Virtual Reality) together with the experimental vehicle to extend this to agricultural environments.

Find, Fetch and Carry.

Locating and collecting objects from fields is a common task in farming (eg collecting boxes of fruit/vegetables, hay/straw bales). One of the first goals for the experimental vehicle is to produce a demonstration of the vehicle locating and collecting hay bales. There are a number of possible approaches to solving this problem such as utilising GPS information from Harvesters as they drop bales to identify their approximate location and then plan a route to most effectively visit and collect the bales.

Most applications in this category rely in some part on machine vision systems. Thus, most of the work completed at Essex to date has focused on machine vision [Freeman 94] and the recognition of objects in their natural environment. Currently, single 120Mhz processor machines are being used to identify a set of bales in static images. This work will be extended to deal with dynamic images and to these ends the vehicle is equipped with VME racks that can house many high performance processor boards. We have also developed hardware to perform some of the simpler, but computationaly intensive vision processing operations, such as frame differencing and compression for transmission over low bandwidth links.

Multi-Vehicle Co-operation

There are persuasive arguments made in favour of replacing large expensive machines by numerous cheaper machines. This startegy promises increasing reliability - the system continues to function despite one machine failing - and scaleability - large farms would simply have more mini farm-robots than a smaller farm (but the small farmer would still benefit from the economy of scale associated with the overall market). Ideas and work are still at a rudimentary stage but initial simple applications could include the creation of “driverless trailers" that would form themselves up in to loose "trains" and follow a lead tractor while getting themselves through narrow gates, avoiding low bridges, passing ramblers and errant sheep. Other possibility is the use of a large number of relatively simple and cheap "browsers" to perform some task like root vegetable picking or mowing while being "supervised" by a small number of more intelligent "herders”.

Computational and Control Issues

The work planned for this vehicle builds or R&D that originated from earlier laboratory based mobile robot work [Callaghan 95].

Levels of Autonomy

We do not aim to produce fully autonomous agricultural vehicles from the start. Starting from straightforward remote control via the radio link our strategy will be to incrementally add autonomous sub-systems, such as heading and speed control and obstacle avoidance. Having identified a subsystem that can operate autonomously, it is likely that it will also be possible to perform this computation on a separate processor. The issue of autonomous sub-systems is thus closely related to the issues of distribution described in the next section.

Distribution of Control

TROWEL will allow experimentation with different degrees of control distribution. As will be explained below it is provided with a rich set of media for interconnecting processors. Distribution of control functions provides greater tolerance to vehicle damage. It is possible to build 'damage containment' into the distributed system that prevents that spread of damage from one part of the system to another. Something that may not be possible with a centralised system. Distribution also enables the processing to be sized cost effectively across a range of vehicle applications (e.g. processing power is added in proportion to sensor quantity and type).

Distribution can also reduce the amount of interconnection that is required between sensors, actuators and controllers and thus reduce the wiring complexity. As the control system is now part of the device it is in theory possible to reduce the interconnection to a single 'command' connection that interconnects all devices. This is the concept behind the CANbus (described below) developed for the automotive industry.

On the other hand we expect to find that some tasks (such “mission management”) will need to be placed in central control of many other systems. Nevertheless we retain a view that distribution provides cheapness, robustness and speed.

Vehicle Co-operation

For some tasks it may be worth the investigating the use of collections of smaller vehicles working together instead of a single large vehicle, although this could be considered as an extreme case of distributed control. One such example is grass cutting. Large gang-mowers are used to minimise the cutting time required, but these are difficult to manoeuvre around trees and in confined spaces. A co-operating group of smaller mowers could follow a lead mower in formation to create the effect of a gang-mower, but could then break up into smaller or single units to operate in confined areas.

Although we have only built one TROWEL vehicle one other is on the drawing board, we have four laboratory vehicles and are planning 10 more. We also have a simulator that models our vehicles reasonably closely on which we can experiment with very large numbers of vehicles [Chernett 97].

The Experimental Vehicle

The experiment vehicles (left - an electric vehicle, right - a diesel powered vehicle)

The Mechanical Hardware

The robotic vehicle (see photo) has an unmodified U-channel-section chassis with a twin cylinder air-cooled Lister diesel engine providing the drive to an hydrostatic transmission system as shown in Figure 1. Originally, the axial piston pump, P, from Sauer Sundstrand had a mechanically-controlled swash plate but adapting the mechanism for computer control proved to be less satisfactory than a servo system, so the pump control has recently been adapted to electro-hydraulic servo operation. It has also been fitted with an auxiliary gear pump to provide hydraulic power for other services such as steering.

The steering mechanism of the tractor has been adapted to take a small double-acting but single rod hydraulic cylinder. Although this gives differing characteristics on left and right turns, the feedback control mechanism has been designed to compensate for this. Flow control is via a Bucher proportional hydraulic valve.

The hydraulic motor, M, is a fixed displacement gear motor, sized to give the vehicle a maximum speed of 1.5m/s via the tractor's standard rear axle transmission. This low maximum speed is adequate for initial development but it is anticipated that the motor will be replaced with a smaller displacement unit when more speed is required. Contamination of the oil is always a concern in applications such as this and design features to reduce contamination are included.

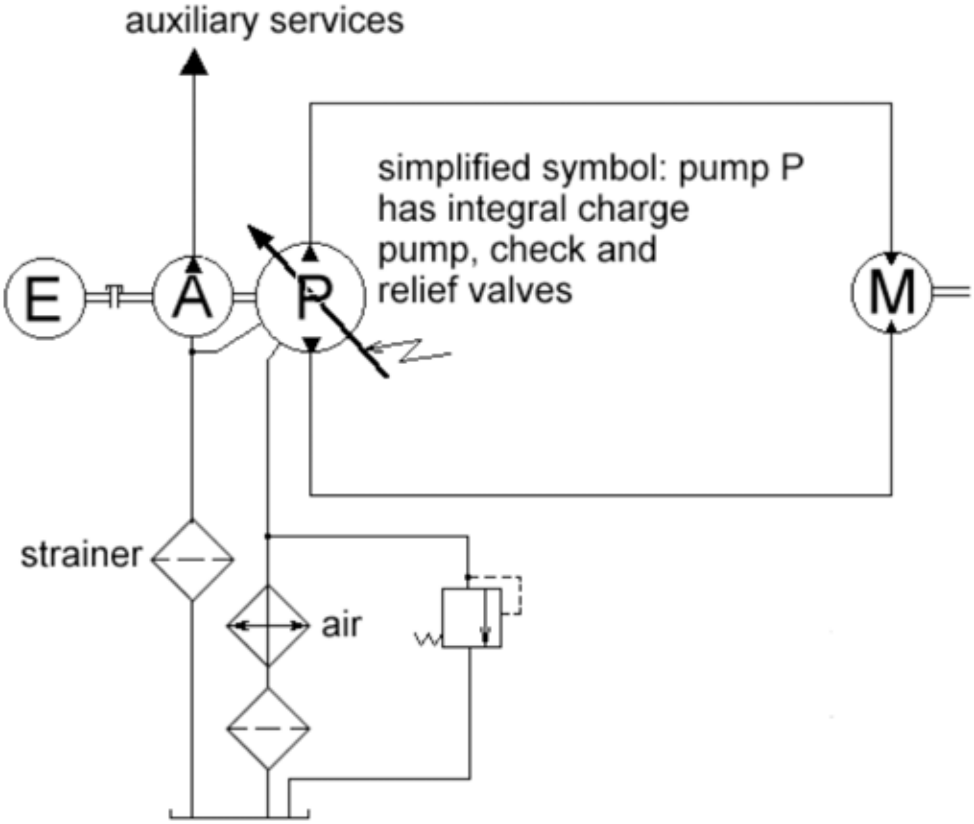

Figure 1 - Simplified hydraulic circuit for the tractor

The Computer hardware.

As discussed earlier, the purpose of the vehicle is to provide a platform capable of supporting an ongoing series of differing experimental approaches by various research groupings. Thus the nature of the project demands a flexible and modular approach to the computational framework, and the current design is influenced largely by requirements for both parallel and distributed processing in a real-time environment. There are two main components, which will be described in turn.

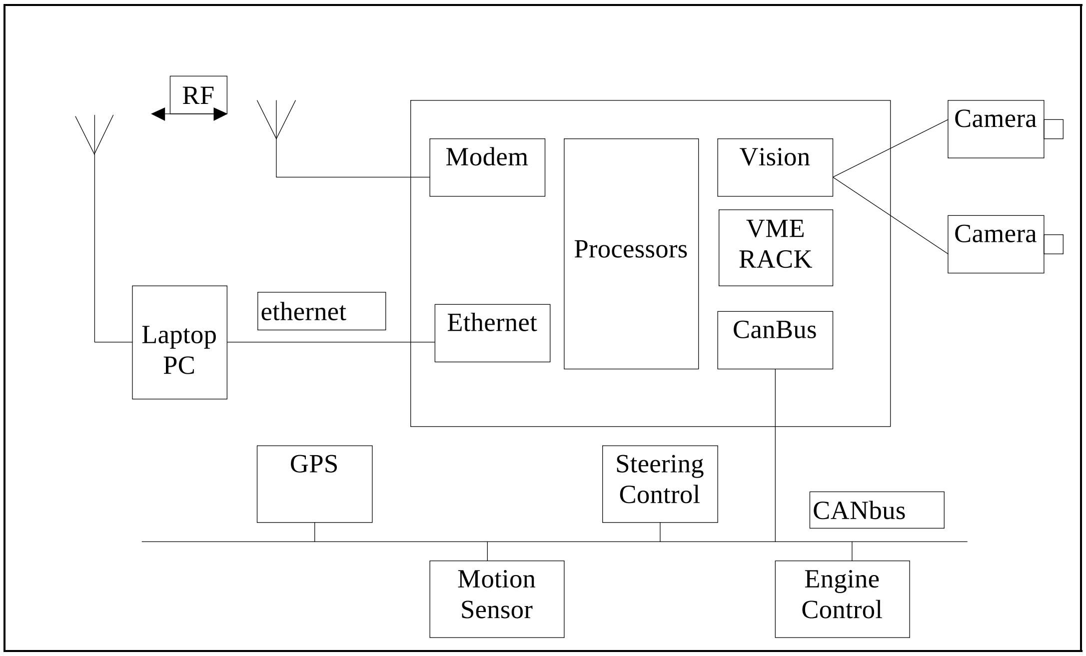

Figure 2 - Simplified Diagram of Computer System

The VME BUS system.

We have several Motorola MVME167 boards each with an MC68040 processor and up to 8MB of RAM for the use on the experimental vehicle. The processor boards communicate with each other and with the CAN bus via an HM CAN01 board and the VME bus. Each processor runs VxWorks as the real-time kernel running the target application code. Radio modems form a link via serial ports to a remote PC for teleoperation.

CAN network

CAN (Controller Area Network) is a serial fieldbus protocol originating from the automotive industry. It was designed for use in a noisy environment and has numerous error-detection and correction facilities. Being bus-based, nodes are simply connected to the bus, obviating the need for a traditional wiring harness. A bitwise arbitration scheme ensures bus access priority for the highest priority message, which combined with an upper time bound on message latency, provides for a potential real-time response at any node. Each node in our system has local intelligence, and consists of sensors and/or actuators connected to an I/O port. The system can support multiple CAN buses.

The Software and Program Development Tools

The Wind River Tornado program cross-development system is deployed across both hosts and targets, with VxWorks as the real-time kernel running the target application code. Programs developed on PC can be compiled and transparently downloaded, run and debugged on any target (ie robot) connected to it via a network, bus or other port (ie targets may be remotely located). In outdoor operation of the actual vehicle, code changes can be made by download from a laptop to the system using a wireless modem link.

This project has accumulated over the years an extensive set of library programs which provide functions such as obstacle avoidance, object tracking, map generation, path planning and image. The control architectures employed to date have included a behaviour based fuzzy hierarchical control architecture and an associated programming language which was developed within the department [Voudouris 94/95] and other traditional AI methods using the CLIPS [Clips] production system and prolog logic programming language [Sicstus]. Many modules have used straightforward ANSI C.

Closing Remarks

This article has outlined the design of a flexible experimental platform which it is hoped will act as a catalyst in the progressive development of autonomous farm vehicles. The general motor vehicle market is massive being estimated at some $2billion dollars [Reade 97] for only the embedded computing and electronics. In many respects farm vehicles with onboard computers, data-networks (eg CAN) and navigation (eg GPS) are at the forefront of this revolution. The increasing presence of electronics and computing on vehicles combined with the pressure to increase cost effectiveness of farming will inevitably to lead to an increase in automation on farm vehicles. Whilst general purpose fully autonomous farm robotic vehicles are some time off, current technology is already enabling farm machinery vendors to offer new functionality (eg recording crop yield) and provide some simple levels of automation. It is likely that this trend will be a progressive process leading to much higher levels of farm vehicle autonomy. These trends combined with advances in embedded computing and artificial intelligence techniques promise an exciting era for those involved in farm machinery.

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Acknowledgments:

The authors are pleased to acknowledge the generous support from Wind River Computer Inc, HM Computing Ltd, University College Writtle and Essex University which has funded the current work