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# DEVELOPMENT OF A DETERMINISTIC AUTONOMOUS TRACTOR

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## ABSTRACT

An automatic steered tractor capable of following a predefined route plan was developed as part of ongoing research into identifying the requirements of autonomous agricultural machines. A small grounds tractor was retrofitted with steering, throttle and continuously variable transmission actuators controlled by a proprietary automatic steering system. In addition, the three point linkage and power take off, could also be controlled. The resulting system showed that it could follow predefined instructions in a deterministic way by itself with reasonable accuracy but was found not to be a practical tool until it can be made to react to unknown obstacles and situations.

## INTRODUCTION

The purpose of this research was to establish the operational requirements of an autonomous tractor. It was felt important to keep the research in an agricultural context but also to explore new ways of understanding of what we do in crop production. In setting up this equipment we used as many commercially available components as possible. This project was part of the Autonomous Platform and Instrumentation system (API) project in collaboration with the Danish Institute of Agricultural Science and Aalborg University.

In our studies so far, all the tasks and actions within an agricultural operation can be classified into three groups; deterministic tasks, reactive behaviours and reflexive responses.

A **deterministic task** is one that can be defined before the task starts. It is well understood and can even be optimised to allow efficient use of resources. One such task would be to cover a whole field with an agricultural operation (e.g. seeding, weeding, fertiliser, spray etc.). Knowing the tractor and implement characteristics as well as the field and crop structure, an efficient route plan can be devised before the tractor enters the field.

**Reactive behaviours** occur when the tractor meets an unknown situation (e.g. an unknown obstacle in its path). The tractor should react in a sensible manner given the sensed conditions. If the tractor came across a fallen tree, then a sensible response would be to go around the tree and carry on with its task.

**Reflexive responses** are those actions that need no deliberation. They are usually closed loop feedback systems that minimise errors. An example would be to change the steering angle to go to the next waypoint or adjust the flow of fertiliser on a VRT spreader.

In practice, all of these actions need to be combined into a hybrid system that can switch between deterministic and reactive responses whilst running many reflexive responses

concurrently. A more complete description of this approach can be found in Blackmore *et. al.* (2004a)

Two autonomous platforms are being used in this research, one purely deterministic automatic steered tractor and one purely reactive research robot. The first is described in this paper, the second is introduced in (Vougioukas et al. 2004). A description of the behavioural decomposition method used can be found in (Blackmore et al. 2004b)

## METHODS

### **Hardware**

The tractor was a 27 horse power, 3 cylinder diesel, Hakotrac 3000 grounds tractor supplied on loan from Hako-Werke GmbH (2001). It has both front and rear hydraulic linkages and a continuously variable transmission (CVT) instead of a gearbox. This tractor was chosen as it was one of the smallest conventional tractors that can carry out traditional agricultural tasks as well as it having many electro-hydraulic interfaces and actuators. This allowed easier computer interfacing. The standard tractor can be seen in Figure 1.



**Figure 1. The original Hakotrac 3000**

The automated controller fitted to the tractor was an AgroNav GT2000 from GEOTEC (now bankrupt) is shown in the top of Figure 2. It is essentially an embedded PC with a flat screen and soft keys around the screen. It operates under Microsoft Windows 2000 and runs the navigation program as an application. It can interface to a USB keyboard and route plans are transferred via a memory stick. The RTK GPS outputs data to the GT2000 via a standard RS232 interface. A Control Area Network (CAN) bus is used to communicate between the GT2000 and the dedicated ESX job computer (Sensor-Technik Wiedemann).

The directrix data is transferred into the ESX for interpretation and implementation. The ESX is interfaced to the set points for the three primary control loops of steering, engine speed, and CVT. Engine speed and the CVT were both fitted with linear actuators and had

dedicated Proportional Integral and Derivative (PID) electronic positional controllers. The steering was retrofitted with electro-hydraulic proportional flow valves (PGV32) by Sauer-Danfoss as part of the API project. Sensors were fitted to give feedback of tractor speed (inductive proximity switch on the front prop shaft) and steering angle (resistive potentiometer mounted over the king pins). A third CPU was fitted to coordinate the different safety aspects, interlocks and operating modes.



Figure 2. Hako tractor showing some of the retrofitted electronic components

### **Operation of the tractor**

The tractor had three main operational modes. ‘Standby’ was the first mode entered after applying power to the circuits. This mode allowed the CPUs to boot and carry out their self check programs. A sub mode called ‘start’ was used to check that all systems were correct (Safety circuit reset, throttle set to idle, CVT in neutral) before allowing the operator to start the engine. The second mode was called ‘Remote’ which allowed the operator to control the engine speed, CVT and steering angle from a remote hard wired handset. The third mode was ‘Automatic’ where the relevant CPUs would take control of the tractor. Both Remote and Automatic modes had sub modes called ‘neutral’ where all the circuits are functional but the tractors are all in neutral i.e. the tractor does not move.

The ESX was also interfaced to the three point linkage as well as the power take off.

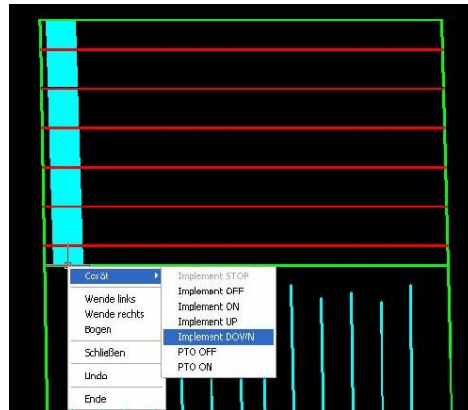
### **Safety**

Safety has always been a primary concern during the design and operation of this vehicle. The irony is that while developing a driverless tractor we now need two people to operate it! One person is designated as the operator and deals with all the issues of starting and running the tractor. The other person is designated the safety operator who holds the ‘dead man’s handle’ which when released stops sending a radio signal to the tractor safety circuit which then shuts down the tractor. The role of the safety officer is none other than to look for any condition that may seem unsafe. Four hard wired emergency stop switches were also fitted on each corner of the tractor. When tested at full speed, the tractor would stop within 2m after the emergency stop switch was released. This short distance was primarily due to stopping the engine and the large braking effect from the CVT.

## **Software**

To define the route and actions the tractor should carry out, AgroNav Plan by GEOTEC was used. This software was a plug-in for AutoCAD that comprises of a number of scripts and tools to generate the final route plan. AgroNAV Drive, was the software written by GEOTEC that ran on the GT2000 to control the actions of the tractor.

The process starts by defining the tractor and equipment to be used and identifying the field boundary and existing structures in WGS84 or UTM coordinates. This can come from existing digital maps or can be obtained by driving the tractor around the field and logging the points. Next, the working direction is chosen, usually parallel to a long edge of the field. AgroNAV Plan can then offer a set of suggested guidelines for the body of the field and the headlands (based on the working width and desired overlap of the implement) that the tractor could follow. These points can then be selected, one at a time by clicking the mouse, until the plan has been completed. If the user tried to define a route that cannot be achieved by the tractor, (e.g. defining a turning circle that is too tight) the software will alert the user. Operations or treatments can also be defined in the route plan as AgroNAV Drive also has control over the three point linkage as well as implement on and off and the PTO. See Figure 3. The final route plan (job file) is then stored as a text file that can be transferred to the tractor on a USB memory stick.



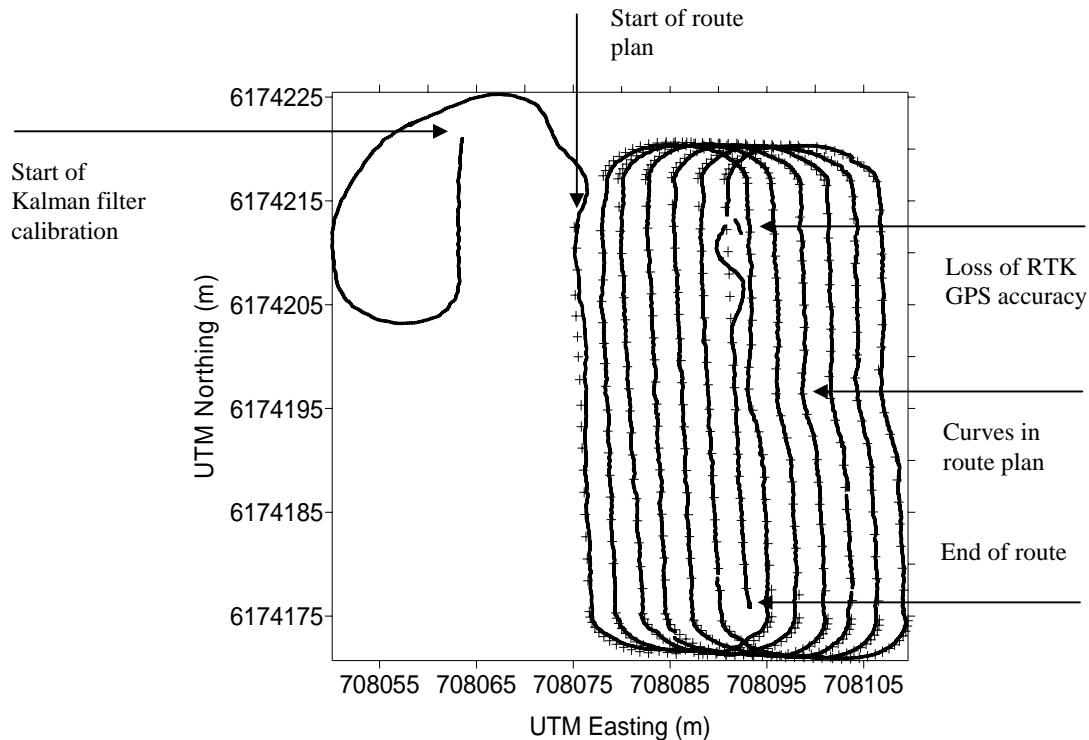
**Figure 3. Screen shot from part of the route planning process showing the field boundary (green), headland guidelines (red), crop rows (thin blue lines), first part of the route (thick blue line) and defining the point where the implement should be lowered.**

When the GT2000 was started it booted up as a normal Windows 2000 PC. AgroNAV Drive was started and the job file could be loaded. If all the hardware was functioning properly then the operator drove in a straight line for about 10m to calibrate the Kalman filter and positioned the tractor at the indicated starting point and orientation for the route plan. The operator left the tractor cab and the mode switch was turned to Automatic and AgroNAV Drive could be started.

The tractor would then attempt to follow the predetermined route and actions.

## RESULTS

Figure 4 shows the desired and actual indicated route plans from the tractor under automatic control. The desired route is indicated as points and the indicated route is denoted as a black line. The route taken to calibrate the Kalman filter can be seen on the left and the deliberate curves in the route plan to judge the response of the tractor can be seen on the right.



**Figure 4. Points showing desired route plan overlaid with indicated RTK GPS track**

Although the tractor does follow the desired route, it can be seen that there is an absolute positional error of about a meter in the first run. This is indicative of problems with the RTK GPS which also arose later by indicating a jump in position to the East in the centre of the trial. Most of the remaining errors are less than 10cm.

## DISCUSSION

It is obvious that any errors in the primary guidance instrument (the RTK GPS) will have a significant effect on the positional accuracy of the tractor. Reliability of access to 'visible' satellites seems to be a problem at such high latitudes (as Denmark) especially combined with occasional low dilution of precision due to satellite geometry. We cannot do much about these problems but we can improve the accuracy and reliability by adding other sensors. Accuracy can be improved, especially over rough ground, by adding an inclinometer to measure the inclination of the tractor as it pitches and rolls over uneven surfaces. This is particularly important when the antenna is mounted relatively high on the roof of a small narrow wheelbase tractor. Secondly the Kalman filter uses both the RTK GPS and the steering potentiometers to improve the reliability of the positional data. The use of the

potentiometers could be replaced by an Inertial Measurement Unit (IMU) that, although expensive, would improve the reliability.

Although this test has shown the positional accuracy of the tractor, it is often the implement mounted on the tractor that must have the highest accuracy. For that reason it is envisioned to use a soil engaging disc coulter to steady or dampen the lateral movement of the implement on the three point linkage relative to the tractor. When this was tried, distances between consecutive slots were only a few centimetres, indicating that many of the errors are symmetrical and can be smoothed out. A further refinement can be to fit a second RTK GPS to the implement and control its lateral position by adding a powered side shift.

These tests were conducted under strict research conditions and hence required two people to operate the tractor in a purely deterministic way. It was found that although the tractor did what was intended it is not yet a practical tool until we can build sensible reactive behaviours into the control system.

## CONCLUSIONS

These tests have shown that an automatic steered tractor can be programmed to follow a predetermined route to within a few centimetres. This route plan can be optimised to minimise the distance the tractor travels, based on the implement size and field shape, before the tractor starts. This deterministic approach helps with efficiency and optimisation but can not react to unknown situations and obstacles. So, as such, it is an incomplete system and needs reactive capabilities brought together in a hybrid system before it could be used in a practical way

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