A method to define agricultural robot behaviours

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***Abstract* – A new method is described that can be used to decompose human controlled agricultural operations into an autonomous tractor. Four main levels of subsumption have been identified: Operation, Task, Optimisation and Primitive Actions where each level is subsumed by the level above. Tasks were classified into two distinctive roles, deterministic tasks that can be planned and optimised before the operation begins and reactive tasks and their associated behaviours that deal with unknown conditions whilst in the field. The tasks and optimisations can be further decomposed into primitive actions, which in turn are converted into the tractor directrix. Examples of this method are given for exploring an unknown area and ploughing a field.**

I. INTRODUCTION

The word "**behaviour**" in robotics has been used in many different ways. Arkin [1] refers to behaviour as a response to a stimulus, associated only with reactive control architectures. He identified two types of behaviours. **Reactive behaviour**, which is a reactive behaviour, created by direct coupling between perception and execution; and **emergent behaviour**, which is the (desired or otherwise) consequence of the interaction of the active individual behaviours with the environment. Rzevski [2] referred to **behaviour** as a particular interaction of the machine with its environment, defined by a set of inputs and outputs, similar to what Arkin referred to as **emergent behaviour**. Pfeifer and Scheier [3] argued that **behaviour** is what an autonomous agent is observed doing, always in interaction with the environment. They referred to **emergent behaviour** as not a programmed behaviour that is derived by the interaction of the agent with the environment, but usually when many processes are assembled to derive a single behaviour. He also referred to **desired behaviour** as similar to the task that the autonomous agent would have to accomplish. Additionally, Brooks [4] argued that there are two types of behaviour, **higher-level** (macro) such as following people that control **lower-level** (micro) behaviours, such as leg lifting and force balancing. Furthermore, Gat [5] referred to **Behaviour** as a piece of code that produces a **behaviour** when it is running. He also distinguished between **primitive behaviours**, which can be composed to produce more complex **task-achieving behaviours**. Finally, Konolige and Myers [6] argued that there are another two types of behaviours: **reactive and goal-oriented behaviours**. Reactive behaviours are event-driven behaviours that exist while an unexpected event occurs, while goal-oriented behaviours are produced to satisfy individual tasks using artefacts (*a priori* information, perceptual features and user commands).

The approach, and hence the systems architecture, that has gained increased attention is the hybrid system. This hybrid approach combines both deterministic control and reactive behaviour. The deterministic control is hierarchical and is usually used for very structured and known environments (e.g. a field). The reactive behaviour is used to respond directly to a stimulus and is used for unstructured or unknown environments and conditions (e.g. a tree fallen over in a field). The advantage of reactive behaviour is that it can deal with uncertainty in perception. It need not have to recognize an unknown object or situation but be able to classify it in terms of how to react to it. This approach dramatically increases the robustness of the behaviour. On the other hand, the main disadvantage of purely reactive behaviour is that it takes into consideration only the current state of sensory information and not any overall goal-oriented targets as in deterministic control [7]. In contrast, a hybrid system combines adaptive and goal-oriented control. These hybrid approaches, based on behaviour are therefore the centre of focus for many researchers and there have been many control architectures proposed [7], [8].

II DESCRIPTION OF THE DECOMPOSITION METHODOLOGY

A method is required to define, understand and decompose the intelligent behaviour of a human in a certain context into the sensible behaviour of a machine in the same context. To achieve this, the physical actions of a person were analysed and then defined in a number of different logical representations, semantics and a lexicon. A full description can be found in Blackmore *et al* [9].

Operation is the field operation that the vehicle should carry out. (e.g. ploughing a field) Each operation can have a number of tasks.

Tasks are the main activities that the vehicle should execute while carrying out an operation. They include the main predetermined actions (e.g. ploughing) and reactions (e.g. obstacle avoidance) that the vehicle should carry out. Two task groupings have been identified: deterministic and reactive.

Deterministic tasks are those tasks that can be planned before the operation starts (e.g. route plan). Deterministic tasks can be optimised in terms of best utilising existing resources based on the prior knowledge about the tractor, field and conditions.

Reactive tasks are those tasks that are carried out when uncertainty is encountered. These tasks react in real-time to local conditions that were not known before the operation started. Reactive tasks can be defined by their behaviour to certain classes of situation (e.g. stopping when approached, obstacle avoidance).

Deterministic task optimisations are the **way** in which the deterministic task is carried out. These are a set of equations (in the form of linear programming rules) that should be optimised within the final result (e.g. .plough straight, minimize route).

Reactive task behaviours are the **way** in which the reactions should be carried out. These behaviours are defined in terms of reaction to stimuli and context (e.g. turn to the right when encountering an unknown obstacle)

Primitive actions are the simplest natural language descriptions of the vehicle functions (e.g. stop, go ahead, back up, turn right, turn left).

Directrix is the command of what the vehicle should do. It can be translated from the primitive actions and is machine dependant (e.g. velocity, trajectory).

Figure 1 shows a Venn diagram (or finite state diagram) depicting the relationship between the different elements and how the inner functions are nested within the outer ones.

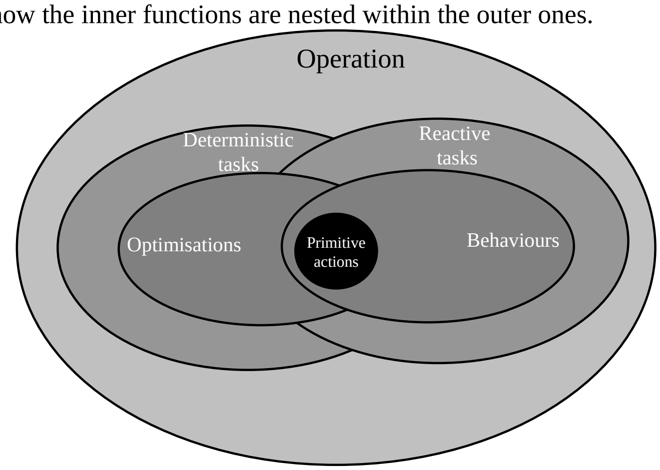


Figure 1. Generic behavioural subsumption diagram

Operation

The operation is the highest level of operational activity that the vehicle will carry out in order to realise the cultural practises of the crop system [10]. It describes the main agronomic purpose of what the vehicle will have to achieve and has an immediately intelligible; meaning to the manager. Agricultural operations that have been identified are: ploughing a field, cultivating a seedbed, seeding a field, fertilising a plot, etc.

Task

To be able to carry out the operation, some tasks will have to be performed involving relevant implements. These tasks comprise the actions and reactions that are required to make something happen. To plough a field, the tasks are to identify the resources (tractor, plough, field etc), develop a method of ploughing (direction, width etc). Both of these tasks can be optimised before the ploughing starts, so they are called deterministic tasks. There are a number of parameters that can be taken into account so that the actions can be optimised under certain conditions (minimise distance travelled, keep straight and parallel to previous rows etc). Different tasks will require different machine configurations or modes, as the tractor will have the plough in the ground while ploughing and have it raised during transport.

Some tasks cannot be planned beforehand but can be foreseen. A typical reactive task would be to avoid an unknown object. We do not know what the object is and may have difficulty in recognising it but we can decide what would be sensible behaviour in such a situation. An expert system can be used to resolve the vehicle context into a set of suitable reactions based on human behaviour.

Optimisation

A deterministic task can be optimised given a set of technical and temporal constraints as well as operational preference guidelines that should be met, maximised or minimised. This priory optimisation predetermines operational parameters like working speed, driving pattern, transport logistics, etc. The modelling approaches include simulation, linear programming, and other scheduling techniques [11], [12]. In the example of ploughing a field, we can optimise the route that the tractor should take by identifying the characteristics that we want the route to take. There are many ways to plough a field, but we can identify one particular way by giving a set of criteria such as to turn the soil opposite to the previous ploughing operation, minimise distance travelled, keep the ploughing in a straight line parallel to the previous row, etc. For example, linear programming can then suggest a route that may meet the criteria.

Behaviour

Reactive tasks can be defined by they way in which the task is carried out or the behaviour of the task. When encountering an unknown situation, it can be classified into a set reaction that exhibits a defined behaviour suitable for the context. Some contexts and their associated reactive tasks and behaviours have been identified in Blackmore *et. al.* [13] and are listed here: Avoiding, Threat, Assessing, Skid, Slip, Stuck, Sink, Tilt, Weather extreme and Theft.

III TESTING AND VALIDATION

This method was applied to one of the simplest basic operations for a mobile robot of being able to explore its (unknown) environment. The operation was to explore an unknown closed boundary or object with a number of different obstacles. Explore is made up of one deterministic task called Straight ahead and three reactive tasks called Follow boundary, Too close and Much too close. An ATRV – jr from iRobot was used for the experiment (see Fig 2)

Figure 2. ATRV-jr from iRobot used in the tests

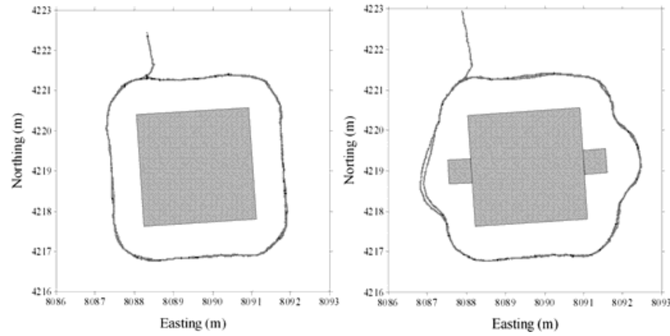
Descriptive English was used to describe the tasks and behaviours. Drive straight ahead was self defined (at a constant speed). Follow boundary was defined as 'Follow around the obstacle at a safe distance keeping it to the left'. Too close was defined as 'If an object is too close to the front then back up'. Much too close was defined as 'If an object is much too close to the vehicle then stop and wait until it goes away'.

Structured English was then used to define the primitive actions.

- Deterministic task: Initial drive ahead
  Straight ahead
- Reactive task: Too close
  IF 0.25 < Front_Dist < 0.5 m THEN Back up
- Reactive task: Much too close
  IF Min_Dist < 0.25 m THEN Stop
- Reactive task: Follow boundary
  IF 0.25<Front_Dist<0.9 m, THEN Turn Right
  IF Left_Dist = 0.9 m THEN Straight Ahead
  IF Left_Dist > 0.9 m THEN Turn Left
  IF Left_Dist < 0.9 m THEN Turn Right

The primitive actions were then further decomposed into machine directrixes.

Figure 3 shows the results of this method. The coordinates are UTM zone 32 and the track is from an RTK GPS.



(a) (b)

Figure 3. Results from Explore.
(a) Following the boundary of a frame.
(b) Following the boundary of a frame with two extra obstacles

A simple deterministic task called Goto was also tested. Four waypoints were established and visited twice in turn. Figure 4 show the route taken. Note that even when a purely deterministic task is programmed into the robot, stochastic influences can result in emergent behaviour (the two different routes on the West side).

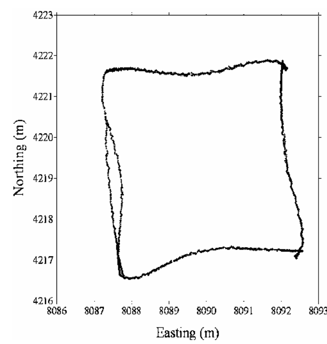
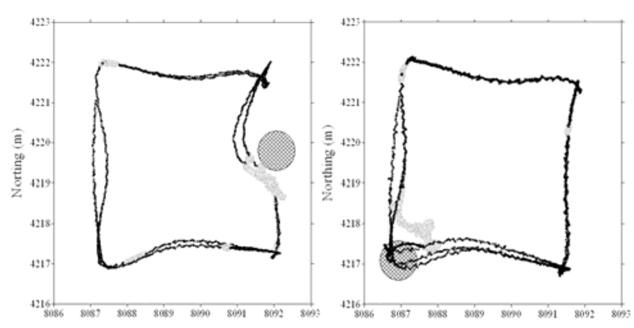


Figure 4. Results from the deterministic task Goto.

A hybrid control system that used both the deterministic task of Goto and combined it with the reactive task Explore was developed and called Navigate. Static objects were placed on different parts of the route to test the reaction and the resulting course is shown in Figure 5. Grey points denote when the robot was in object avoidance mode. A full description of this method that was implemented using potential fields, is given in Vougioukas *et al.* [14].



(a) (b)

Figure 5. Results from Navigate.
(a) Navigating to the four waypoints with a static object on a side.
(b) Navigating around the waypoints with a static object on a corner

IV CONCLUSION

The separation of deterministic and reactive tasks, inside a rational framework significantly helps to define the behavioural requirements of an autonomous machine. Tests have shown that they can be combined successfully into a hybrid control system that can optimise deterministic tasks based on prior knowledge as well as react sensibly to unknown input stimuli. This method should allow the possibility to construct a more detailed control system that can deal with the real world complexities but also be simple enough for people to understand based on our own understanding and perception.

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