KNOWLEDGE ACQUISITION FOR A ROBOT EXCAVATOR

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Summary

The purpose of this paper is to describe the methods currently in use to build a knowledge base capable of intelligently controlling an autonomous robotic excavator. The current aim is that such a robot will be capable of safely and efficiently executing a range of excavation tasks with superior performance to that of the human operator. This paper surveys the measures being taken at Lancaster to provide such a knowledge base and reports on the various approaches in pursuit of this goal. The root of the problem lies in the particular difficulties concerning the externalising and making explicit of the largely implicit knowledge that at present resides in the head of the skilled operator. Whilst this work concentrates on the knowledge base required for robot excavation, the techniques and problems encountered are relevant to to the whole generic class of intelligent robots which need to be **adaptive** in response to unpredictable external factors.

Keywords

Knowledge acquisition, Knowledge ellicitation, Excavation.

1.0 Introduction

1.1 There is, as yet, no clear methodology in the realm of knowledge acquisition and so the problem needs to be attacked on many fronts, some of which will prove more successful than others. Up to now most knowledge acquisition has been carried out either by extracting information from established written work or by eliciting it from professionally qualified experts. The challenging nature of this work stems from the fact that neither of these avenues is capable of providing much of the knowledge that we require.

1.2 One of the reasons that we do not have a developed science of knowledge acquisition is that it is not clear what knowledge is. For the purposes of this paper it will be assumed that knowledge is any data which aids problem solving in the domain. However it is necessary to say more than this in order to be able to perform some useful analysis. For this purpose two basic types of knowledge can be identified; ontological and empirical.

1.3 Ontological knowledge is theoretical knowledge which conforms to the paradigm of scientific knowledge. The control of the robot can obviously be improved by an understanding of the mechanics and kinematics of large hydraulic robots. It is also conceivable that performance could be improved by increased understanding of the behaviour of soils as they are extracted and moved. This type of knowledge must be made available to the robot if it is to compete successfully with the human operator. It is obtained by the well established scientific methods of theoretical, computer and laboratory experiments. The main purpose of this paper however is to describe the approach adopted to obtain the second type of knowledge.

1.4 Empirical knowledge is that based on experience. A highly skilled excavator driver can operate his machine in such a manner that it almost becomes an extension of his own body. His senses are tuned to pick up the slightest changes in the velocity of the excavator bucket or the sound of the engine. He then uses this feedback information to make constant subtle adjustments to the controls. He also makes rapid real time decisions about techniques for digging in difficult ground or coping with boulders or tree roots. Lastly he almost instinctively plans the whole job, deciding where to place the spoil and how to maintain access for other vehicles. The knowledge is therefore at many levels and has been described in an earlier paper[1] as manual, tactical and strategic.

2.0 Sources of empirical knowledge

The following methods and sources have, or will, be used to attempt to acquire the necessary empirical knowledge:

* Elicitation by interview.
* Elicitation by observation.
* Literature.
* Mimicry.
* Physical modelling and prototyping.
* computer simulation.

Each of these will now be dealt with in some detail.

2.1 Elicitation by interview

In 1989 the mechatronics group at Lancaster University was awarded a grant by the SERC(2) to appoint a research assistant as a knowledge engineer to collect empirical knowledge on site. An engineer with fifteen years site experience was appointed and it was felt that this would assist in developing a good rapport with excavator drivers. In the previous eight months he has visited six sites and interviewed thirty experienced drivers. A considerable amount of valuable knowledge has been acquired by interview, and an example is the usefull heuristic rule:-
"In trench digging with a backhoe/loader:- to reposition the machine place the jacks on the indentation left by the front shovel".

Obviously a good deal of diplomacy was required but nevertheless the reception he received was very varied. It rapidly became obvious that several recurring problems would need to be overcome if useful knowledge was to be elicited. These problems fall into two categories - social and cognitive

2.1.1 Social problems

* **Inarticulacy** was a frequent problem encountered. The operator was unable to say how or why he does what he does. He was obviously not employed to pass on knowledge and the more subtle techniques may **never** have been articulated, therefore this is not surprising. He may have felt threatened by appearing stupid when he knows he is not. He may have been shy and uncomfortable with a university researcher.

The solution to this problem was to have the knowledge engineer spend time on site in an informal capacity encouraging a more relaxed atmosphere. It was also made clear that no-one knew the answers to these questions and that consequently their attempts were as good as anyone else's.

* **Fear of redundancy or change** is an obvious barrier. The advent of new technology is obviously seen as threat to job security and also possibly as an insult to his undoubted skills.

The solution here was to stress the very long term nature of the research and to point out the benefits of such robots in hazardous environments such as under water or near radiation or toxic chemicals.

* Some drivers were simply **uncooperative**. They either claimed to be too busy, not interested or ridiculed the project as science fiction.

The solution here was simply to find another expert.

2.1.2 Cognitive problems

* **Implicit knowledge** has implicit problems. It is sometimes referred to as tacit or deep knowledge or even instinct. It may be confused with inarticulacy when first encountered. Implicit knowledge is the meat and drink of knowledge engineering. This knowledge is very difficult to get hold of and formalise and may be impossible to verify. When interviewing expert drivers one can often be met by replies such as " It's obvious", "I just do it" or "I don't think about it". If we fall into the trap of calling this inarticulacy we are accusing the expert digger driver of being unable to answer questions that a cognitive scientist cannot answer. We are signally ignorant of what constitutes common-sense reasoning yet we are attempting to find out what common-sense reasoning is involved in the excavation process.

One solution to this problem is for the knowledge engineer to apply his own powers of rational analysis to the items raised by the operator. In other words if the operator performs a particular action but cannot explain why, the knowledge engineer himself must attempt to give the action meaning, with the operator helping where he can. This obviously requires the knowledge engineer to develop a familiarity and understanding of the domain.

* **Spurious answering** occurs when the expert wants to please the interrogator while at the same time needing to appear rational. This phenomenon may appear in reverse form where the knowledge engineer hears what he thinks he requires.

Obviously this must be guarded against by rigorous evaluation of the rationality of the knowledge.

2.2 Elicitation by observation

The above problems encountered with interviews highlight the need for other methods of elicitation and an obvious one is passive observation. This is essentially a behaviourist approach with the knowledge engineer simply

observing how the operator solves problems. An example of knowledge elicited by this method is:-
"Drivers always claim that they fill the bucket on each cycle but observation reveals that this is often not the case when visibility is a problem. They implicitly make an economic assessment of the value of emptying the half bucketfull rather than returning to fill it."

Much use has been made of still photography and the next stage is to move on to video recording. It is anticipated that this will be particularly useful for recording and understanding subtle manual behaviour. A video camcorder with the facility to display elapsed time will be used.

2.3 Literature

Among the literature we include learned journals and papers[3], books[4], civil engineering and contractors plant journals and drivers manuals. Not a great deal of information was gained in this way but it was of some use when viewed alongside other knowledge sources.

2.4 Mimicry.

This refers specifically to the researcher attending a backhoe/digger operators course sponsored by the construction industry. The reason for this was to see if he could get hold of the notion that skilled operators call "feel", presumably something akin to "autopilot" or "flying by the seat of your pants". It can also be conceived as "muscular memory". The course was of some use in that it contained general information about the machine - how to operate it , how to service it and what the maintenance considerations were. More useful however was the instruction concerning the various digging strategies. Again, attending this course was seen as an additional string to the bow rather than a pivotal knowledge source.

2.5 Physical modelling and prototyping.

This involves developing and verifying digging techniques using a 1/5 scale model backhoe excavator at present nearing completion in the mechatronics section at Lancaster. The intention is to test the expert system on this device. It will be particularly valuable in evaluating the real-time capabilities of the control system. It will allow the performance of unconventional "machine friendly" strategies to be compared with the human approach. In other words the heuristics and strategic knowledge acquired from the expert, may not be the optimal strategy for a machine.

2.6 Computer simulation

The robot simulation package GRASP is being used as a means of optimising digging strategies by evaluating cycle times. It contains the facility to create original robot models and one for a backhoe excavator arm has been created - see figure 1. Individual joint accelerations and velocities can be defined and the times for particular cycles summed.

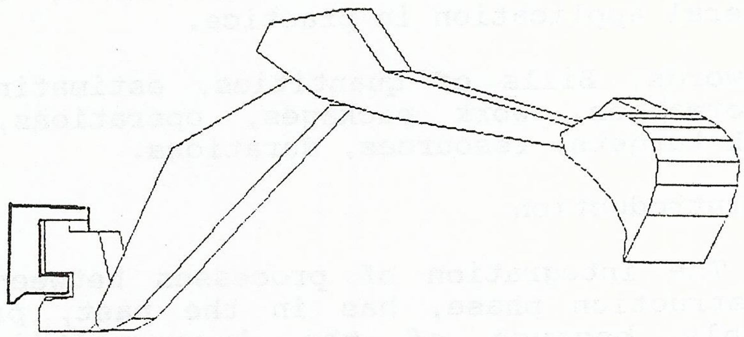

Figure 1

3.0 Competing knowledge

An obvious problem which can arise is that different sources can provide conflicting knowledge. As far as this project is concerned there are two types of conflict. Firstly that which arises between two or more sources who simply disagree about the best manual approach to a problem, and secondly that conflict which arises between the manual approach and theoretical considerations of an automated robotic approach.

The first of these can be illustrated by considering the basic recommended digging style for trenching work:-

* The literature (ref. 4) recommends short deep digging motions to minimise time and reduce bucket wear.

* Observation indicates that skilled drivers use long inclined passes which slope up towards the boom pivot point, because this produces a fast rythmic motion with high excavating power and good vision.

* The digger operators course recommended long horizontal passes which produces a flat bottomed trench throughout for easy depth checking.

By contrast the robot can adopt a flexible strategy to minimise cycle time without risk of overdigging.

4.0 Conclusions

This paper has pointed out the difficulties of acquiring the knowledge of skilled manual workwers, and has shown how a wide range of acquisition methods must be used in order to capture it.

It was also pointed out how a robot has inferior senses but superior calculating ability to a human operator, and that this can influence the fundamental approach to problems. Each must play to their own strengths.

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