Scientific methods in mobile robotics?!

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1 Introduction

"Scientific methods in mobile robotics" is the main theme of TIMR '97 — but what are these scientific methods?

This position paper argues that at the foundation of any science is a common language, that is, first a set of concepts that have meaning, and secondly agreement within a scientific community what that meaning is. In physics, identifying concepts and giving them meaning has been achieved through measurement of properties (such as mass, velocity, *etc.*) of the object under investigation. The scientific language has thus become objective, in that experimental conditions and results can be described quantitatively.

In mobile robotics, due to the complexity of the function that governs agent-environment interaction, this is not (yet) possible. This paper argues, therefore, that in order to develop the science of mobile robotics, a scientific language of identifiable concepts with agreed meaning has to be developed first.

Glimpses at philosophy of science will set prepare the ground for setting some goals for that foundational language of an empirical science of mobile robotics.

2 What would be a science of mobile robotics?

To answer this question adequately, even remotely, is beyond the scope of this paper, and all we can attempt is to highlight some issues, and point to relevant literature. Much of the following argument is based on [Chalmers 82].

2.1 Inductivism

Naive inductivism purports that through faithful observation scientific laws and theories can be derived. "Science is a structure built upon facts" ([Davies 68]), and the careful assimilation of faithful observation will lead to a body of "proven " knowledge.

According to the inductivist's view of science, legitimate derivations of universal laws can be achieved through

1. Taking many observations,
2. repeating experiments under different experimental conditions, and
3. not encountering any conflicts with theory in the process.

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The *principle of induction*, then, says that if a large number of As have been observed under a variety of conditions, and all of those As possess the property B, then all As have the property B.

Through inductive reasoning a finite list of singular statements (faithful observations) give justification of a universal statement, and through subsequent deductive reasoning predictions and explanations of observed events can be obtained.

There are various objections to this point of view. Firstly, it is possible for an inductive inference with true premises to lead to a false conclusion. For example,we may have observed a large number of exclusively black ravens, and finally conclude that all ravens are black (inductive principle). However, a pink raven would falsify that statement, and yet not pose a logical contradiction to the original proposition. Secondly, the principle of induction cannot be proven on logical grounds, because the chain of reasoning "Induction worked successfully in situation x, the principle of induction worked successfully in situation y, etc., therefore it always works" is an induction in itself (this is usually called the problem of induction).

Most importantly, however, there is the objection that "faithful observations" are not independent from the observers past experience, expectations and knowledge. Furthermore, observation statements have to be made in the language of some theory (example: stating that a white cylindrical object near a blackboard is a piece of chalk is based on the theory that chalk is white and cylindrical, and usually found near blackboards). Therefore, theory must preced observation, in other words: to establish the validity of an observation statement one needs to appeal to theory. There is no ultimate scientific law against which all theories can be evaluated, or, as Popper ([Popper 68, p. 111]) puts it: Science has no solid bedrock, but is built on piles that are driven further and further into the ground.

2.2 Falsificationism

Falsificationism offers an alternative view of science, taking into account some of the objections made against inductivism. Its fundamental beliefs are that

- Observations are indeed guided by theory,
- theories are merely speculative and tentative conjectures,
- theories that fail to stand up to observational and experimental tests must be eliminated, so that the "fittest" theories survive, and
- theories can be falsified and rejected, but never be established as true or probably true.

It follows that a theory that is to say anything about the world has to be falsifiable, independently testable (Popper). An unfalsifiable theory says nothing about the world. This furthermore implies that the "quality" of a scientific theory can be judged by the degree of falsifiability it offers: a theory replacing an old theory must be more falsifiable than the original one, in order to improve scientific knowledge (example: a theory concerning the motion of *all* planets has a higher degree of falsifiability than one about the orbit of Mars, and is therefore preferable). This, in turn, necessitates that theories are expressed clearly and precisely.

In summary, the falsificationist view is that science starts with problems, not observations, and that theories can only be falsified, not proven to be correct. Significant advances in science are marked by the confirmation of bold conjectures or the falsification of cautious conjectures (the falsification of a bold conjecture simply means that yet another crazy idea has been discarded, and the confirmation of a cautious conjecture is merely the application of an already known law to another problem).

While the inductivist believes that a theory is the stronger supported, the more confirming observations are made ("keep watching falling stones"), the falsificationist believes that the significance of observations depends on the (historic) context in which they are made.

There is one major objection to the falsificationist's statement that, based on faithful observation, theory acceptance is always tentative, while theory rejection can be decisive: this belief assumes that perfectly secure observations are possible. However, as discussed in subsection 2.1, this is not the case! Conclusive falsifications of theories are not achievable, because the falsifying observations may be falsified themselves later. Poppers reply to this argument is that observation statements are accepted as the result of decision or agreement, and to that extent they are conventions.

There is a second objection to falsificationism: A theory cannot be conclusively falsified, because the possibility that some (e.g. experimental) aspect other than the theory itself is responsible for the erroneous prediction cannot be ruled out. This can lead to a situation where the "culprit" is always identified as something other than the theory under investigation ([Lakatos 74, pp. 100f]).

2.3 Scientific revolutions

Aiming to explain the historical observations of the progress of science (which is in contradiction to traditional accounts of science) Kuhn ([Kuhn 70] offers a different view of scientific progress. According to him, science progresses from a pre-science state to a state of normal science (invovling detailed attempts at matching a paradigm with nature), until a crisis is encountered (e.g. an increasing number of serious anomalies). At this stage science is in turmoil[1], until a revolution sets in, which lead to new normal science, and onwards to a new crisis, and so on. Kuhn likens the scientific revolution to a political one.

A mature science, according to Kuhn, then is a science exhibiting a lack of disagreement over fundamentals, as opposed to pre-science, where total disagreement and constant debate over fundamentals are the norm. Science must have a paradigm capable of supporting a normal science tradition.

3 Implications for mobile robotics

3.1 What is a good theory?

Much of the above was written with the laws of physics in mind, but if we postulate that universal laws (so far unknown to us) govern the behaviour of robot, performing a specific task (i.e. running a specific control program), in a specific environment, then these considerations have implications for robotics.

As observations are preceded by theory (subsection 2.2), and as "science" must have a paradigm capable of supporting normal science tradition (see section 2.3), theories of robot behaviour are needed foremost[2].

What are the requirements of a good theory? According to Lakatos ([Lakatos 74]) a good theory

- should offer a research programme,
- should contain only modifications to its protective belt (of conditions) that are independently testable, and
- should contain no modifications that violate the hard core of the theory.

By maintaining the inviolability of the hard core of the research programme order is maintained, whereas in the falsificationist's view there is the risk of unmethodical chaos in trying to locate the source of contradictions (which could be due to anything, not just the theory in question).

The paradigm must be capable of supporting normal science tradition (Kuhn), and independently testable (Popper).

Finally, it is impossible to establish the superiority of one paradigm over another, because this requires *agreed* premises (which typically do not exist). And: no rivalling paradigm can ever be judged to be superior, because a major breakthrough may just be round the corner.

3.2 Mobile robotics as an empirical science

Lelas ([Lelas 93]) argues that

- Science is not only about what is, but also about what can be,
- science is as genuinely technology as it is ontology,
- implementation has a peculiar and important cognitive role, and

[1] Pauli wrote to a friend in 1924:"At the moment, physics is again terribly confused. In any case, it is too difficult for me, and I wish I had been a movie comedian or something of that sort and had never heard of physics."

[2] There are indeed (emerging) paradigms within mobile robotics that show those characteristics ([Malcolm *et al.* 89]). Behaviour-based task decomposition versus functional task decomposition is one major aspect of that new paradigm.

- creating phenomena in artificial devices, explaining them by hypotheses, testing the hypotheses, and building apparatuses is a single process.

Following this argument, the process of building mobile robots, running specific control software on them and observing the resultant behaviour in a specific environment, is scientific investigation, aiming to elucidate the universal law that governs robot-environment interaction. The robot is an instrument that is used to make phenomena visible that are otherwise invisible (like eye glasses).

"To transform the invisible into the visible ... requires skill" ([Lelas 93]), which in the case of mobile robotics research is the skill to build robots that through their design support the testing of hypotheses without introducing artefacts (a robot, for instance, which lacks a sensor necessary to conduct a particular experiment, and uses a simulated sensor instead, is an example of an unsuitable instrument). Like a telescope is used to make celestial artefacts visible, a mobile robot is used to reveal universal laws of agent-environment interaction.

Paradigms (theories), as well as experimental procedure (in the widest sense) form the basis of a science of mobile robotics. To express these, a common language is required, and we believe that in the mobile robotics community we are still at an early stage of establishing that language. In particular, few attempts have been made yet to characterise robots, environments or robot-environment interaction quantitatively. Exceptions are the work by Smithers ([Smithers 95]), Lee and Recce ([Lee & Recce 94]) and Duckett and Nehmzow ([Duckett & Nehmzow 97]).

In summary, we believe that a science of mobile robotics requires a common language, which in turn requires

- Quantitative characterisation of mobile robot behaviour,
- quantitative characterisations of environments, agents and their interaction,
- characterisations of experimental procedures to facilitate replication of experiments,
- actual replication of experiments and validation of results, and
- comparative methods, e.g. for comparison between two robots, or comparison between a robot and its simulation.

This would give us the precise language required to conduct mobile robotics as the empirical science it is.

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