Part IV Conclusion & Appendix

Chapter 13

Conclusion

This section will summarize the major investigations presented in this thesis. First, the set of methods and techniques, which are presented for the first time are mentioned briefly. The achieved results (including the drawbacks) are discussed at an abstract level. Finally, a perspective is given by a short introduction of one further research line.

13.1. What was new?

The central philosophy all introduced methods are based on is the preservation of as many degrees of freedom as possible and reasonable concerning the world modelling process of a mobile robot in unknown, unreliably, or dynamic environments. Beyond the general aspect of adaptability, the question of variance in the set of behaviours of a mobile robot, dedicated to real world scenes (i.e. scenes containing unforeseeable constraints), opens up the general discussion about a reasonable relation of pre-programming and learning in mobile robots[1] interacting extensively with their environments.

SPIN

The *SPIN* system has shown up an almost model-free method of generating stable, geometric 3-d symbols out of current working environments (☞ chapter 7). In the course of development, some new and specific techniques were introduced and investigated – some of them even relevant outside the focus of geometric abstractions or visual steering.

The shown visual search methods are especially dedicated to highly focused devices. This field is prevailingly unexplored, due to the fact, that visual search is mainly motivated by physiological investigations concerning visual cortexes (mainly in cats and monkeys), which are also focused, but always offer a possibility of gathering blurred information from immediate surroundings simultaneously. Therefore the steering methods from the literature are based on "parallel" vision systems, instead of serial sensor readings, as assumed in the *SPIN* system. The orders of magnitude between the realtime information bandwidth in both configurations has forced, beside other constraints, new methods, introduced in this thesis (☞ chapter 8).

Motivated by the need of a-priori knowledge during a kind of bootstrap in the abstraction pipeline of *SPIN*, a new neural fuzzy decision method (*SPIN-NFDS*) was introduced and proven applicable in the given context, even in general terms (☞ chapter 3).

The classification of 3-d surfaces through dynamic self-organising maps was not a completely new approach, but extends the methods given in the literature by some important features ensuring lifelong learning abilities (☞ chapter 4).

1. *also denoted animats, critters, creatures, etc.*

Finally the *SPIN* system has introduced a complete pipeline of sub-symbolic, adaptive, geometric abstraction components, not yet investigated in this complexity (☞ references in chapter 7).

ALICE

ALICE is currently the only mobile robot (to the knowledge of the author), able to build up a dynamic, self-organized map of sensor-situations in one exploration phase (☞ chapter 4). Additionally this was performed under hard realtime constraints. Qualitative modelling for mobile robots was introduced before, but the methods are limited to off-line training, or have (for good reason) never left the simulations.

In order to show the navigation abilities that can be established based on the qualitative topologic mapping, a new, adaptive path execution process was introduced, modelling a set of phenomena (the robot's kinematics, drifts and systematic sensor disturbances, local manoeuvres constraints, etc.) by one mapping step from the robot's current situation to proposed actuator settings (☞ chapter 5).

ALBATROSS (communication)

The introduced realtime communication scheme for asynchronous running processors, assuring blocking free access to communication ports with constant delays, was introduced due to the need of a communication system, fulfilling hard realtime constraints (☞ chapter 5).

13.2. What could not be shown?

The major drawback of this thesis is the lack of a proof of practical relevance concerning the sub-symbolic geometric abstraction project *SPIN*. A range finder of adequate speed and precision could not be employed during experiments with the introduced methods. Therefore a steering and control mechanism for such a range finder could be investigated on the base of simulations only.

The complexities of employed algorithms in the *SPIN*-components allow realtime configurations in principle, i.e. the actual realtime abilities have still to be proven, including real-world implementations. But the total amount of computational power (accumulating all *SPIN*-components), assuming SISD computers, is very large and handicaps implementations on moving machines at the current state of the art in computer architecture.

13.3. What has been shown?

Assuming environments containing enough descriptive edges and a range finder with adequate features, the *SPIN* system has demonstrated a possibility achieving stable, geometric symbols from previously unknown environments. The decomposition into the necessary components is complete and ensures a working overall system, although the system was never tested (due to limited computational power) with all components running in parallel.

Visual steering concerning highly focused devises was investigated for the first time and could therefore not be compared to existing systems. Nevertheless, principal improvements regarding simulated environments and compared to elementary recursive edge-following could be shown.

A neural-fuzzy method, employing fuzzy rules, pre-structuring a five layer network together with standard neural adaptation methods for refinements according to the actual context, was introduced and proven a major improvement in comparison to fuzzy logic or standard connectionist methods applied individually. The comparison to existing neural-fuzzy controllers has turned out some significant new features.

The geometric classifications in order to generate stable symbolic representations could be performed ensuring some stability, generalization as well as lifelong learning abilities, and resulting in reasonable symbols. All applied algorithms (dynamic self-organizing maps respectively Adaptive Resonance Theory) have complexities allowing realtime implementations.

The *ALBATROSS* operating system kernel includes a communication scheme, especially adapted to the demands of asynchronous realtime transfers, and applied to a couple of mobile platforms in the meanwhile.

Finally, the *ALICE* project as a first step towards the idea of simple, but adaptive robots of practical relevance, has proven stable real world abilities even under extremely worse conditions (regarding drift, sensors, systematic errors, and limited computational power). The ability of realtime world modelling with

lifelong flexibility running in parallel to the robot's self-localization is a unique feature. The generated models are of qualitative, topological character, and applicable for a wide range of tasks.

13.4. Perspectives

The number of potential new directions, continuing and completing the investigated research fields appears rather large, but in order not to become too speculative here, the author would like to limit this final section to one aspect.

The prevailing tests with the mobile platform *ALICE* have shown promising results with respect to real world applications, especially if constraints regarding weight, stability, and reliability have to be considered. A currently not satisfying aspect (comparing *ALICE* to any primitive biological creature) is the large number of performed movements. This drawback is the straight result of the applied sensor devises. On the other hand the employment of range finding sensors is not uncritical, if the elementary *ALICE* feature of being small and light weighted should remain untouched (as intended by the author). Additionally the "perspective-problem" (situations appearing significantly different from specific perspectives) introduces a new stage of sensor pre-processing and forces modifications in the qualitative, topologic world modelling as introduced in this thesis. Nevertheless, *ALICE* (respectively her younger sister) will be equipped with special range finders, where the biological plausibility as well as other *ALICE* assumptions will be still considered.

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