Synthesis of special operating decisions as part of adaptive control of a mobile robot

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Abstract

This paper presents theory behind synthesis of special operating decisions in mobile robotics. The authors have developed and implemented an experimental research methodology to substantiate the theoretical and practical significance of the proposed decision structure for incorporation of quasi-cognitive mechanisms in the process of intelligent data processing in such robotics. This paper presents research and testing of a computer model of the abstract decision-making component that analyzes the movement trajectory of a mobile object in the operational space of a mobile robotic system. This approach towards intelligent decision-making can be tested for effectiveness by whether it enables the system to detect change in the parameters of the analyzed dynamic object that are important for autonomous analysis of the environment. One finding is that using this novel operating decision structure to improve autonomy contributes to the emergence of a behavior strategy that bypasses the combinatorial methods configured during the development; this improves the system's adaptability to change in its environment.

Keywords

Artificial Intelligence, intelligent data processing, mobile robotics

1. Introduction

As applications of mobile robotics expand, such robots need improvements if novel functionality is to be implemented. For instance, a dynamic environment complicates the navigation process, as it gives rise to multiple hard-to-formalize problems that necessitate use of intelligent data processing (IDP).

Common IDP methods rely on regression of precedent data sampled in training, which contradicts the dynamic nature of the environment, where the functional dependencies fundamental to the robot's operations in its applications are very likely to change. This creates a need to make operating decisions when given inaccurate, incomplete, and inconsistent data.

Thus, there is a need for fundamental research that could lay the foundations of innovative decision-making hardware and software for use in navigation in mobile robotics, backed by a special approach to the organization of data processing that would, among other methods, incorporate quasi-cognitive mechanisms to enable the system to adapt independently to change in the environment. Practically, the existing IDP methods cannot reasonably enable such restructuring in real time.

In particular, experimental testing is needed to find the patterns to apply quasi-cognitive mechanisms to identify bifurcation points of the analyzed dynamic objects' parameters important for autonomous analysis of the environment. To that end, we herein propose a method for synthesis of special operating decisions; this method relies on the duality of data streams inside the respective sensory input processing components that generate control actions.

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2. Methods

Such a system can take two roles when interacting with the physical world: an object or a subject. When it functions as an object, it seeks to solve the applied problem it is intended to solve (which incorporates the global intended function of the system and the set of sequentially resolved local objectives that make the global function), which requires retrieval and further processing of sensory inputs from external sources. We hereinafter refer to such information retrieval as an action that triggers the system's functions. When the system is a subject, it uses the processing outputs to act on the elements of its environment. In the existing IDP paradigm, each of these two interactions is formalized by using vectors of quantitative parameters referred to as inputs and outputs, respectively. We hereinafter refer to the output as the decision. System training process consists in finding strong correlations between these vectors that must be as close as possible to reality.

This research builds upon the authors' concept of decision synthesis, the theoretical wording of which points to the fact that in a changing real environment, no decision can be written as a usual set of instructions in the form of a vector of quantitative parameters found by processing sensory inputs. In a dynamic environment, any decision made only makes sense within its specific context. To that end, we propose developing a novel decision structure where the decision makes part of the behavior strategy the system devises for itself. We assume that such a context could be obtained by applying the principle of information duality.

The principle of duality implies the existence of two independently emerging classes of information that intersect when synthesizing a decision. Class 1 constitutes a formal decision; Class 2 constitutes a strategy that stems from the unique combination of the conditions, under which such formal decision has been synthesized. This is where the proposed approach fundamentally diverts from the conventional methods of today, as the final decision is a set of conditions that uniquely determines the instruction for the robot's actuators rather than one with such properties as objectivity of existence and subjectivity of interpretation.

Let the resolution of each local objective be a discrete step towards the global goal, and let the system be in state S at each step. Let the input vector be the impulse that delivers the energy E of transition from the state S_i to a new state S_{i+1}. The state S_i is a set of data such as the magnitude of the preceding disturbance X that cancels the equilibrium state of the system plus data on how the system could be brought back to the equilibrium, i.e., how to synthesize the response Y. The energy of this transition is determined solely by the vector (as in vector algebra) in the configuration space that combines the total population of all possible states. This vector would be correctly referred to as action. Generation of such a vector is a result of information processing within the existing IDP paradigm whose methods find a strong correlation between S_i and S_{i+1}.

In other words, render the configuration space as a 2D plane as shown in Figure 1, where the system moves vertically upwards and receives at each step the energy carried by the impulse from the external environment. Since there is a probability of transition to states arising from suboptimal decisions, minimizing any parameter can be considered the objective function appropriate for the global goal.

Pursuant to the proposed concept, this system needs to be supplemented with an additional dimension to enable duality. To that end, introduce the new variable t. Let us consider a single operation to explain the meaning of this variable. An operation is defined herein as a single instance of the environment acting on the system and the synthesis of the system's decision (response). Duality implies that such an operation is not discrete in form; rather, it is analog and has a pattern. Once the variable t is introduced, we can assume that the vector of S_i to S_{i+1} transition can follow multiple different trajectories, the shape of which can be considered the qualitative class of information involved in decision synthesis.

3. Results

For experimental research, we used a computer model of the abstract decision-making component that tracks the movement trajectory of a mobile object in the operational space of a mobile robotic system. This component contributes to the autonomous navigation of the robot by collecting data on the analyzed object, applying image recognition, and sending data generated by input analysis so that the system could produce further instructions.

This computer model is a multilayer sequence-to-one LSTM recurrent neural network developed in MATLAB. Backpropagation of error was used to train the model. Training and test sets were made of the coordinates of seven latest points in the movement trajectory of the analyzed object; speed vector served as the output. Duality principles described above were incorporated in the model during the experiment.

The authors have developed and implemented an experimental research methodology to substantiate the theoretical and practical significance of the proposed decision structure for incorporation of quasi-cognitive mechanisms in the process of intelligent data processing in decision-making components. The goal of this methodology was to practically confirm the possibility of detecting change in the object's environment by synthesizing a novel decision on the principles of information duality.

Step 1 was to use a simulation model of the analyzed moving object whose trajectory contained four timepoints where the mathematical model of the process changed. All four timepoints contained an image of convergence with the robot with a high risk of crossing the trajectory. Figure 1 illustrates the inputs of experimental conditions.

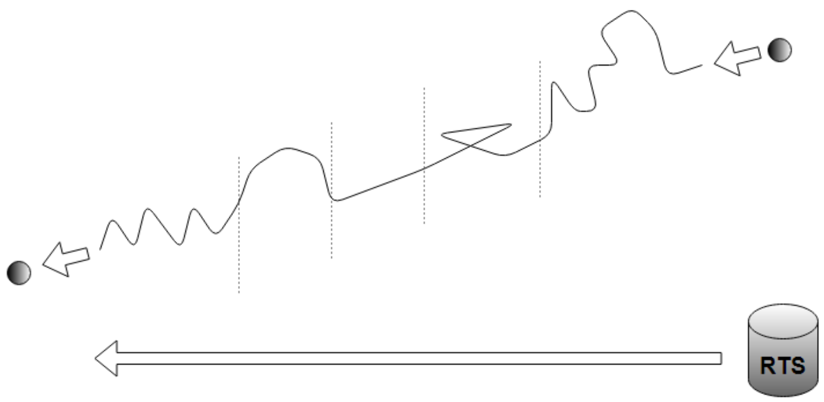

Figure 1: Initial data for the first experiment

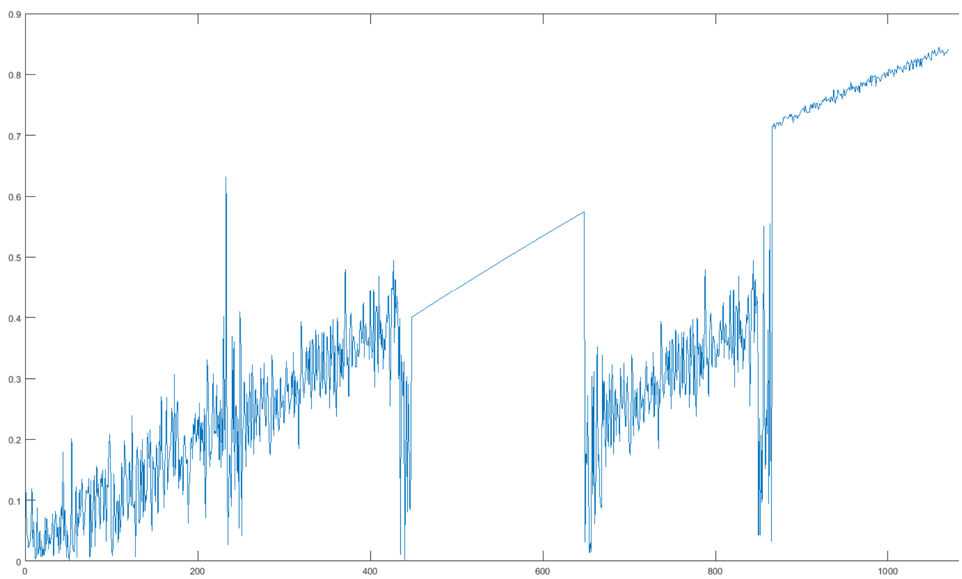

Figure 2: The results obtained during the first experiment (dependence of the amplitude of cognitive activity on the system at each discrete moment of the considered time interval)

Figure 2 shows output curves. These curves show surges in the activity of the contextual information stream, which in all cases match the timepoints of change in the mathematical models of the analyzed object's movement trajectory.

Further experiments were carried out with the analyzed object moving away from the robot. This trajectory also contained four arbitrary changes in its mathematical models, see Figure 3.

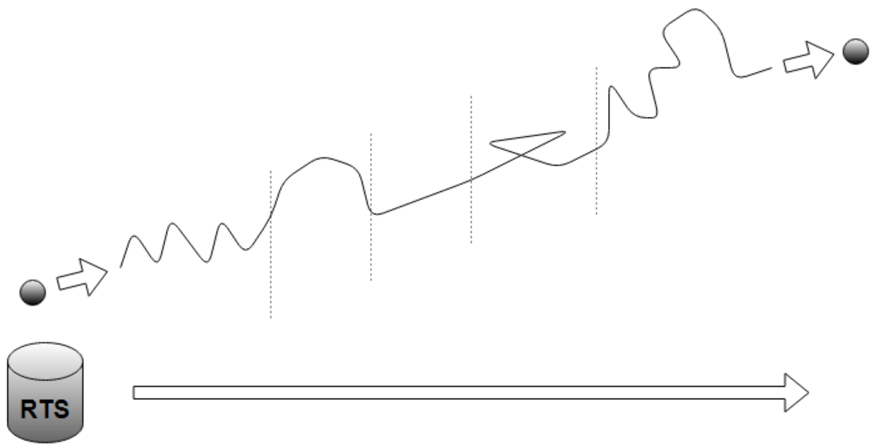

Figure 3: Initial data for the second experiment

Figure 4 shows curves of the contextual information stream outputs that have the same surges of activity matching the timepoints of the mathematical model of the analyzed object's movement trajectory.

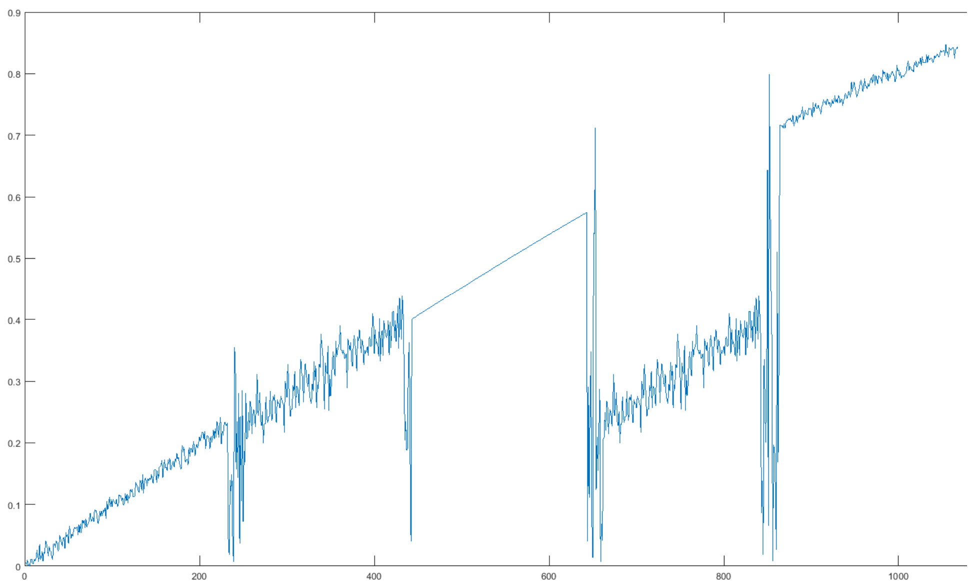

Figure 4: The results obtained during the second experiment (dependence of the amplitude of cognitive activity on the system at each discrete moment of the considered time interval)

A third scenario of the object's behavior consists in variating the mathematical models of its trajectory to contain convergence, distancing, and escorting vectors. The tested combination of timepoints of trajectory change is shown in Figure 5.

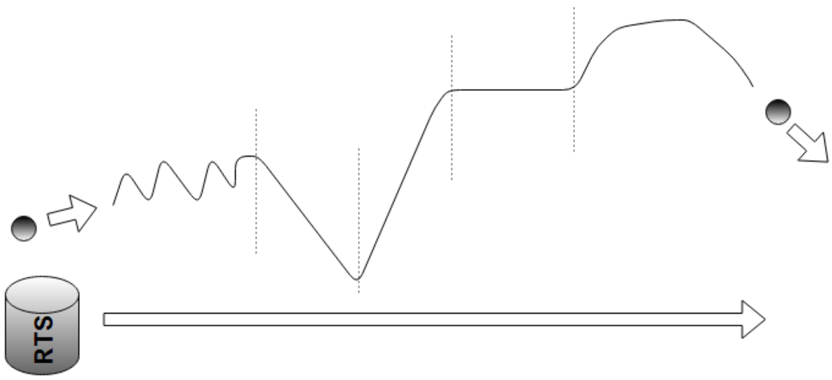

Figure 5: Initial data for the third experiment

Figure 6 proves the system's response to the events of interest.

Thus, the results of the three experiments confirm that duality-based decision synthesis can indeed detect change in the environment of the mobile robot and implement elements of adaptive control and autonomous navigation.

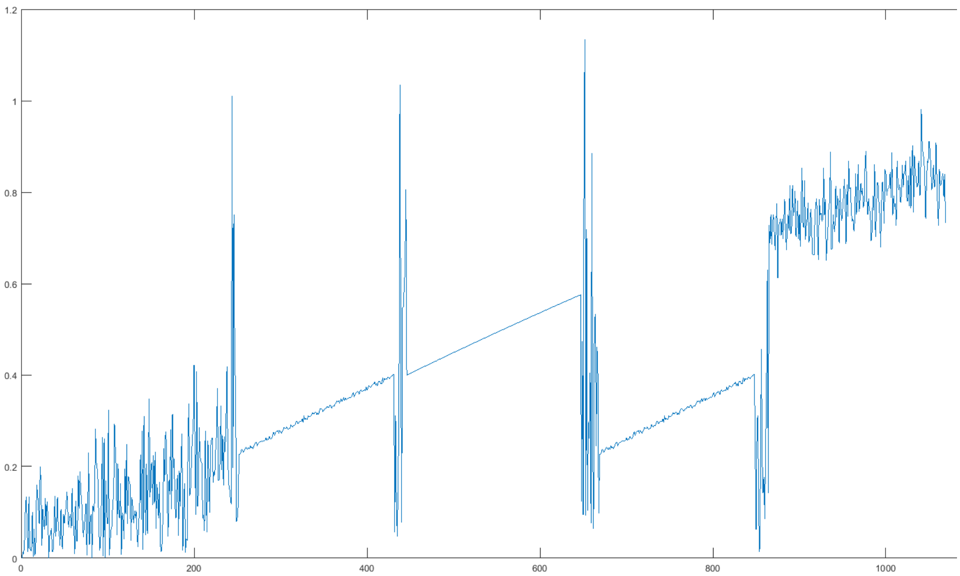

Figure 6: The results obtained during the third experiment (dependence of the amplitude of cognitive activity on the system at each discrete moment of the considered time interval)

4. Conclusions

The conclusion hereof is that novel quasi-cognitive mechanisms could be implemented within the decision-making components of an autonomous mobile robot, which can produce special decisions to establish an associative link between the robot and its environment. To implement this process with maximum efficiency, natural cognitive semantics shall be developed, as well as an analog and not algorithmically described method shall be developed for the existence of a decision synthesis mechanism capable of finding its hardware implementation when implementing the considered systems as applied devices based on modern electronic components [9, 10].

5. Acknowledgements

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6. References

[1] G. Meyer, G. Adomavicius (Eds.), A Machine Learning Approach to Improving Dynamic Decision Making, Information Systems Research 25(2) (2014) 239-263.

[2] B. Daachi, T. Madani, Adaptive Neural Networks and Robots Intelligent Control in Direct or Indirect Interaction with Humans, Elsevier, Amsterdam, 2019, p. 120.

[3] H. Brink, J. Richards, M. Fetherolf, Real-World Machine Learning – Manning 427 (2016).

[4] H. Lu (Eds.), Artificial Intelligence and Robotics, Springer, Berlin, 2018, p. 326.

[5] S. Emel'yanov, D. Makarov, A. I. Panov, K. Yakovlev, Multilayer cognitive architecture for UAV control, Cognitive Systems Research (2016). doi:10.1016/j.cogsys.2015.12.008.

[6] A. I. Panov, K. Yakovlev, Behavior and Path Planning for the Coalition of Cognitive Robots in Smart Relocation Tasks, Robot Intelligence Technology and Applications 4 3-20 (2015).

[7] S. N. Danilin, M. V. Makarov, S. A. Shchanikov, Design of artificial neural networks with a specified quality of functioning, IEEE International Conference on Engineering and Telecommunication, MIPT, Moscow/Dolgoprudny, 2014, pp. 67-71.

[8] S. N. Danilin, M. V. Makarov, S. A. Shchanikov, Numerical simulation of neural network components of controlling and measuring systems, Applied Mechanics and Materials (2015).

[9] S. Shchanikov (Eds.), Designing a bidirectional, adaptive neural interface incorporating machine learning capabilities and memristor-enhanced hardware, Solitons & Fractals, Chaos, 2021.

[10] I. A. Surazhevsky (Eds.), Noise-assisted persistence and recovery of memory state in a memristive spiking neuromorphic network, Solitons & Fractals, Chaos 146 110890.