System Design Principles: adaptation to time for long living autonomous systems

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Abstract. The article presents the *principles* of creating systems with the adaptation to the *operation time*. In the literature on systems design the adaptation mostly concerned: 1) the unknown object structure; 2) the unknown object parameters; 3) unknown parameters of input signals; 4) the unknown functions of system state dynamics; and 5) unknown environment conditions. It usually assumed that the control process is intended to achieve a certain, usually optimal state of the system, - such way the “adaptive system concept” are close to “optimal system concept”. The other approach for system design with these conditions is *robustness,* as robust control does not need a priori information about the bounds on these uncertain or time-varying parameters; robust control guarantees that if the changes are within given bounds the control law need not be changed, while adaptive control is concerned with control law changing itself. In the last 10 – 15 years there was introduced the new approach as “resilient systems”. “Resilience engineering” may look like “repairing engineering” – it is assumed that errors or malfunctions occur “for sure” and the system should respond appropriately to this.

The *system operation time*, as the cause of adaptation, was very rare considered, mostly when reliability issues are discussing. The proposed approach is new. The proposed principles should be used with known approaches of dependable system design, – these are engineering and information theory redundancy. Both approaches must be used in the design phase and are unchanged structural parameters of the system during operations. There were concerned mostly “long-living systems” and the same task of reliability.

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Proposed *principles* can be used in the development of the systems designed for continuous operation with absence of the possibility of external human intervention to restore system performance or some maintenance procedures. By «system» in this article are meant «Complex Adaptive Systems» (CAS). Currently, the proposed approach can be attributed to the development of "Artificial General Intelligence" (AGI). Examples of such systems include space-based and underwater-based robotic systems. By “Adaptability of the system to time” – in the sense of control process – it is meant a certain structural reconfiguration of the system, considering the non-stationary nature of stochastic processes of errors, damages, and system failures.

The formulation of principles is of a general declarative nature – at this stage the author gives preference to the essence of the proposal, rather than its formalization. The article does not provide specific design guidelines, but contains some examples of possible applications, mainly to highlight the essence of the proposals.

Keywords: complex system, adaptation, time, system failure, artificial general intelligence, non-stationary stochastic process.

INTRODUCTION

In the literature on adaptive systems published before the adaptation mostly concerned: 1) the unknown object structure; 2) the unknown object parameters; 3) unknown parameters of input signals; 4) the unknown functions of system state dynamics; and 5) unknown environment conditions [1]. It usually assumed that the control process is intended to achieve a certain, usually “optimal state” of the system, – such way the “adaptive system concept” are close to “optimal system concept” [2, 18]. The other approach for system design with these conditions is *robustness,* as robust control does not need a priori information about the bounds on these uncertain or time-varying parameters [3] Robust control guarantees that if the changes are within given bounds the control law need not be changed, while adaptive control is concerned with control law changing itself.

In the last 10 – 15 years there was introduced the new approach as “resilience engineering” and “resilient systems” and may look like “repairing engineering” – it is assumed that errors or malfunctions occur “for sure” and the system should respond appropriately to this [4]. This concept had been proposed on the base of two known ones: reliability and robustness. But this book was mostly concerned with organizations and social systems but very few technical issues were analyzed. In [4] it was also noted the difference of the two design philosophies: reliability design and resilient design, – is that with the concept of resilience, the system has undergone through a temporary failure or more generally, the system fails to work under a stable state say A but then changes to a new state say B to perform the function. Change of states from failure states to new states is an inherent property of these systems, which is defined as the resilience property [5]. Reliability design uses redundancy and the system after failure will try to restore the state A in operative mode.

In the article [6] it was proposed a definition of the resilient machine, a general architecture of resilient machine systems and three design principles for the resilient machine. In this article it was highlighted that resilience engineering may look like repairing engineering. However, repairing engineering uses external resources, instead of system internal resources, to heal the damaged component, so that the whole system can recover to its function. Resilience engineering focuses on own resources of the system, which are inhibited in the system, determined when the system is designed. As the definition in the article it was proposed the following: “Resilient machines are systems that have an inherent ability to change from a failure state to a new state to function”. In the books [7, 8] it were considered “rigorous development” of “complex fault-tolerant systems”.

Autonomous Intellectual Systems development needs to provide long and reliable operations without maintenance and repair by support staff. For example, as such tasks there can be listed robots in space and in undersea.

As Autonomous Intellectual System we mean some system with Artificial General Intelligence (AGI), – AGI-Agent or “robot”, that operates autonomously and makes the decisions on the base of interactions with the environment.

It is assumed the AGI-unit is controlled by the computer platform of “Von Neumann architecture” with operating system and application software.

Robot should test its state during the operation. In the case of AGI-concept this task is much more complex than in the case of usual technical system. If the error or system failure occurred autonomous system should take any rational activities to restore the correct operating.

Of course in many of such cases to restore full scope of features will be impossible but to keep some functions and in principle be in operative mode, – it is valuable task.

It is well known general approaches of dependable design:

- engineering redundancy - the duplication of critical components or functions of a system with the intention of increasing reliability;
- information theory redundancy – the number of bits used to transmit a message minus the number of bits of actual information in the message [9].

Both approaches must be used in the design phase and are unchanged structural parameters of the system during operations. For the first approach there are different disciplines how redundant units can be used. A lot of literature is devoted to the methods of designing high reliability systems, and the interested reader can easily find the relevant sources.

The author in this article proposes some new principles for increasing the life cycle of AGI robots, which have not been covered so far, and do not yet have specific technical implementations. These principles relate to the field of property common to all technical systems that arise during their operation: any system will fail after some time of operation. It can be confidently asserted that this property arise precisely as a result of the passage of time. In the case we will not be concerned about the question of the nature of time, which, as you know, has not yet found a fundamental answer in science.

The cause of system fail can be permanent – "system failure" – or temporary – "malfunction". Proposed principles relate to the prevention of system failures of both kinds.

As the definition of adaptation, we will use: "Adaptation is considered to be a process of modifying the parameters or the structure of the system and the control actions. The current information is used to obtain a definite (usually optimal) state of the system when the operating conditions are uncertain and time-varying [1].

Some other definition: "Adaptive control is the combination of a parameter estimator, which generates parameter estimates online, with a control law in order to control classes of plants whose parameters are completely unknown and/or could change with time in an unpredictable manner." [10].

The traditional approach to the design of adaptive systems assumes that, based on the analysis of input data and environmental parameters, the system can take actions to achieve the desired state or effect of functioning. At the same time, the traditional approach considered "time" only as an independent variable in the corresponding differential equations describing the dynamics of the system. In the case of stochastic models, the random processes underlying them, as a rule, were assumed to be stationary and ergodic. The issue of adapting to the operating time was not raised within the framework of the traditional approach to the design of adaptive control systems.

Recently, there have been works on the so-called «Time-bounded Adaptation». For example in [11] discusses the issues of dynamic adaptation of software for autonomous vehicles. It was proposed to categorize automotive systems with respect to requirements for dynamic software adaptation. They defined a taxonomy that captures various dimensions of dynamic adaptation in emerging automotive system software. In automotive systems, software adaptations must often be time-bounded since stale information could trigger improper driver reactions. For example, a driver information system should update a display within a bounded time to ensure drivers are not informed about traffic jams that no longer exist. The maps should be downloaded in time when the route needs it. Likewise, adaptations should minimize software update time to ensure that software applications and data are fully integrated into vehicles before they are used. Next-generation automotive systems differ in their need for dynamic adaptation support.

This paper [11] identifies the software adaptation requirements of the following four classes of automotive systems:

- Vehicle-centric systems;
- Driver information systems, which require the dynamic adaptation of content, as well as periodic update of vehicle software to better reflect the current environmental conditions.
- Cooperative driving systems, which adapt their behavior according to the surrounding vehicles and road conditions.
- Vehicular sharing systems, which use the processing power and data transmission of multiple vehicles to perform distribute computations.

In the case of autonomous vehicles, it is probably incorrect to call such tasks as "time-related adaptation", because for example, the need to adapt the road context for the driver is not caused by time itself but is associated with the movement of the car and the change in the traffic situation around it. If the car is parked, for example, there is no need for "temporary adaptation", as the authors called it. Rather, in all such cases, it is about the need to reconfigure the system – in particular, to load and save some new software – when certain external events occur.

ADAPTATION TO TIME

The goal of this article is to propose new principles that can be used in the design phase to enlarge the dependability of long living autonomous systems that operate without maintenance.

The proposed approach is new. Proposed principles should be used with known approaches of dependable system design, - this is engineering and information theories of redundancy. Both approaches should be used in the design phase. There were concerned “long-living systems” and the same task of reliability.

Proposed principles can be used in the development of the systems designed for continuous operation with absence of the possibility of external human intervention to restore system performance or some maintenance procedures. By «system» in this report are meant «Complex Adaptive Systems» (CAS).

Complex adaptive systems are dynamical systems that can change their structure, their interactions, and, consequently, their dynamics as they evolve in time. Complex systems are co-evolving multilayer networks. The essence of a complex adaptive system is that the interaction networks may change and rearrange because of changes in the states of the elements. Thus, complex adaptive systems are systems whose states change because of interactions and whose interactions change concurrently as a result of states [17].

In [17] there were proposed the following ten facts about complex adaptive systems as the essence of CAS:

1. Complex systems are composed of many elements.
2. These elements interact with each other through one or more interaction types.
3. Interactions are not static but change over time.
4. Elements are characterized by states. States are not static but evolve with time.
5. Complex systems are characterized by the fact that states and interactions are often not independent but evolve together by mutually influencing each other;
states and interactions *co-evolve*.
6. The dynamics of co-evolving multilayer networks is usually highly non-linear.
7. Complex systems are context dependent.
8. Complex systems are *algorithmic*.
9. Complex systems are path-dependent and consequently often non-ergodic.
10. Complex systems often have memory.

From author point of view there should be one more fact that complex adaptive systems as opposed to simple adaptive systems: “11. Complex adaptive system should not be set in “Initial State” or as for mechanical control systems – state of x=0, where x – independent variable (usually “time”). The identification of states in complex adaptive systems is very complex task that very rare can be resolved accurately [15, 16]. In this case it is hard to predict the stability of the system even the changings occurred were small. Because of it there is substantial reason to have some mechanism to enlarge dependability of the system. As we consider “time” in classic mechanics ordinary view the proposed principles can be seen as robust approach.

Currently, the proposed in the article approach can be attributed to the development of "Artificial General Intelligence Systems" (AGI-Systems). Examples of such systems include space-based and underwater-based robotic autonomous systems [19], [20]. The proposed principles can be used in the development of Operating Systems of AGI-Applications [21].

As Complex Adaptive Systems we can consider Artificial General Intelligence Agents. In this case “the state of the system” will be mostly concern the concept “content” or “scene” – means its internal perception and model. Operation of AGI-Agent can be correct only in the case of (1) right estimation and recognition of the external environment factors;

(2) right internal model of external scene; (3) right reactions to external impacts. Proposed principles can be used for the design of AGI-Agents of long live autonomous systems.

By “Adaptability to time” – in the sense of control process – it means a certain structural and parameters reconfiguration of the system taking into account the non-stationary nature of stochastic processes of errors, damages and system failures. This non-stationary nature of the failures means that over time we see the system failure in sure! The matter is the only: it will be earlier or later…

The formulation of principles is of a general declarative nature – at this stage the author gives preference to the essence of the proposal, rather than its formalization. This article does not provide specific design guidelines, but contains some examples of possible applications, mainly to highlight the essence of the proposals.

Time still is undefine concept in physics. There are approaches to formulate mechanics without time as the factor, for example by Julian Barbour [12]. The author belongs to the scientists that think that “time” is an illusion. But the existence of time as the real physics factor does not concern the principles proposed here because of the principles’ definitions use not “time” directly but non-stationarity of stochastic processes of errors and failures in the systems.

For the simplicity we will consider the systems with discrete internal states.

What is the “state” of the system?

If we consider the dynamic systems that is the coordinates, velocities, and forces [10]. To introduce the meaning of “right state” in this case is out of reason because the “state” in this case also included the environment parameters that are external for the system.

If we consider the If we consider the finite state machine (sometimes called a finite state automaton) a “state” means the discrete vector of all states of memories’ cells (triggers) [13]. In this case a “right state” means correct operating conditions of automata and absence of occasional errors.

But with Artificial General Intelligence Systems (AGI-Systems) – also discrete as the base a “right state” means not only operating conditions but also the correspondence and relevance of internal model of the environment in AGI-System (robot) and real external situation [14].

Let AGI-System has the number of states N. Let us see $P_i(t)$ is the probability of the state i ∈ 1,…N in the moment of time t. Thus

$P_i(t)=1 - \sum_{(1\ldots(i-1),(i+1,)\ldots N)} P_i(t)$.

When t=0 the system is in the initial state and $P_1(0)=1$ – we consider the system in operating mode, thus $\sum_{(2\ldots N)} P_i(0)=0$.

When t increases the states will be changed according to the environment impact and the laws of functioning. But in every moment t only one state will be the “proper” one. If that be not right for some kind of system we can consider the set of right states as one entity and the rule will be executed.

Let us see $P_r(t)$ as the probability of right state “r” in the moment t. As the experience shows when t increased substantially $P_r(t)<1$ and it decreases permanently when t increases

and $\sum_{(\text{all other states without r})} P_i(0)>0$ – this sum increases permanently when t increases

and $P_r(t)+\sum_{(\text{other states without r})} P_i(0)=1$ in any moment t as for complete group of events.

The goal of proposed *systems design principles* is to increase $P_r(t)$ in any moment t.

The systems design principles of adaptation to time.

Principle 1 – “Functional scope reduction over time”: the system should decrease the number of functions supported over time.

Comments: In complex systems there are main functions and axillary functions. In main functions set also usually can be assigned the priorities – and with the time the number of active functions can be decreased – as the result the probability of right set $P_r(t)$ will be correspondingly increased. Of course, in every case the special analysis should be undertaken.

Principle 2 – “Operating area reduction over time” – the system should decrease the area of operation over time.

Comments: Every system has limited resources/features. These resources/features should serve some area of operations. If with increasing time the area of operations will be decreased the probability of right state $P_r(t)$ will be increased.

Principle 3 – «Defocusing attention over time» or «mutual compensation of the errors»" – the system should reduce the accuracy of maintaining the state over time.

Comments: Most systems try to keep the "right state" taking into account the impact of external environment and noise. But when the state had been changed improperly from right one to some incorrect one – as the result of error or noise impact, - the stability of this incorrect state leads to error functioning of the system in time and as stronger would be the accuracy of keeping the current state as more time the system would be incorrect. If we weaken the accuracy of state saving over time, then we increase the probability of finding the system in the correct state $P_r(t)$ as a result.

Non-stationary nature of stochastic processes of errors, damages and system failures means that the total probability of the set of incorrect states will be permanently increasing and correspondingly the probability of correct state will be decreasing.

If we use Principles 1 and 2 in the design of the system, the probability of keeping of correct state over time will be increased in comparison.

Principle 3 use the possibility of "compensation of the errors" – if the system is in incorrect state the accuracy of maintaining of this state is harmful and when we decrease this accuracy, we correspondingly increase the probability of correct state.

If and when we could assign some *measure* to the "states" and by such way to define some "distances" between *states* we could define one more principle of adaptation to time, namely: "over time the system should decrease the distances between the states", – taking into account that with these *distances* the power to go from one state to another can be tied thus the power to return to the "right state" from any other can be minimized. But now the author cannot define the *measure* for the *states* and that will be for future research.

CONCLUSION

In the article there was proposed new approach of system design principles that can enlarge dependability of the systems in long period of time. Despite the author has not seen such principles published before it is hardly be said that all of them are unknown. In the design of cabins of modern aircrafts there was used Principle 1. Principle 2 is used in some tasks of radio location. But the formulation of this principles, as author can see, is new. Author only cannot find the proper example for using of Principle 3 – may be, it was not only formulated but invented.

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Принципы системного проектирования: адаптация ко времени для долгоживущих автономных систем

Сергей Корнеев

Аннотация. Представлены принципы создания систем с адаптацией к времени работы. В качестве системам в данном случае рассматриваются Сложные адаптивные системы, например, интеллектуальные автономные системы, относящиеся к концепции «Искусственного интеллекта общего типа» (Artificial General Intelligence, AGI). В литературе по проектированию систем в основном речь идет о: 1) неизвестной структуре объекта; 2) неизвестным параметрам объекта; 3) неизвестным параметрам входных сигналов; 4) неизвестным функциям динамики состояния системы и 5) неизвестным условиям окружающей среды. Обычно предполагается, что процесс управления предназначен для достижения определенного, обычно оптимального состояния системы, – таким образом «концепция адаптивной системы» близка к «концепции оптимальной системы».

Другим подходом к проектированию систем с этими условиями является *робастность*. Робастное управление не требует априорной информации о границах этих неопределенных или изменяющихся во времени параметров, – *робастное управление* гарантирует, что если изменения находятся в заданных пределах, закон управления не нуждается в изменении, в то время как адаптивный контроль связан с изменением самого закона управления. В последние 10 – 15 лет был внедрен новый подход «устойчивых систем». «Инженерия устойчивости» может выглядеть как «ремонтная инженерия» – предполагается, что ошибки или неисправности происходят «наверняка» и система должна соответствующим образом реагировать на это. *Время работы* системы, как причина адаптации, рассматривалось очень редко – в основном, когда обсуждались вопросы надежности.

Предлагаемый подход является новым. Такие принципы должны быть использованы с известными подходами надежного проектирования систем, – это избыточность конструктивная и информационная. Оба подхода должны использоваться на этапе проектирования, при этом и структурная организация системы, и ее параметры остаются неизменными в процессе эксплуатации.

Рассматриваются «долгоживущие системы» и задача надежности. Предложенные принципы могут быть использованы при разработке систем, предназначенных для непрерывной работы с отсутствием возможности внешнего вмешательства человека для восстановления работоспособности системы или некоторых процедур технического обслуживания. Под «системой» подразумеваются «сложные адаптивные системы» (CAS). В настоящее время этот подход можно отнести к разработке

«Искусственного интеллекта общего типа» (Artificial General Intelligence, AGI). Примеры таких систем включают роботизированные системы космического и подводного базирования. Под «адаптивностью системы ко времени», в смысле процесса управления, подразумевается определенная структурная перенастройка системы с учетом нестационарного характера стохастических процессов ошибок, повреждений и сбоев системы.

Формулировка принципов носит общий декларативный характер – на данном этапе автор отдает предпочтение сути предложения, а не его формализации. В статье не приводятся конкретные рекомендации по проектированию, но содержатся некоторые примеры возможных применений, главным образом для освещения сути предложений. Принцип 1 – сокращение объема функциональности во времени. Принцип 2 – сокращение обслуживаемого пространства со временем. Принцип 3 – снижение точности выдерживания состояний системы со временем.

Ключевые слова: сложная система, адаптация, время, сбой, отказ, искусственный интеллект, нестационарный стохастический процесс.