Autonomous Decentralized System and Its Strategic Approach for Research and Development

SUMMARY Autonomous Decentralized System (ADS) has been making progress in these 31 years since it was proposed in 1977. During these long years in the rapidly advancing computer and communication technologies, the ADS concept has not been changed but its technologies have been growing in accordance with the change and diversity of the social, economical and personal requirements and through the globalization of the market and the restructuring organizations. The ADS technologies are systematized to cover all processes of system design, operation, maintenance and modification. This paper reviews the work done in fields of ADS in past 31 years from not only technological perspectives, but it also encompasses users requirements and value, system design, industrial activity, academic activity and standardization [1]–[26]. Moreover the new directions of the ADS are suggested.

key words: autonomous decentralized system, distributed system, assurance, strategic approach, standardization

2. Technology Trend

The novel concept of ADS is proposed to achieve the clear objectives, which cannot be satisfied by the conventional technologies based on the centralized, hierarchical and functionally distributed systems concepts. As the system becomes large/complex; and socially/economically influential purposes, the system is required to achieve the on-line property consisting of on-line expansion, on-line maintenance and fault tolerance not to at stop totally system operation during the construction/expansion, the maintenance/test and partial failures in the system. The ADS has the objectives to resolve this on-line property when its research started in 1970’s. Even now, this on-line property has been more and more important.

2.1 Concept

The ADS is proposed on the basis of the molecular biological analogy. The living thing has three basic properties:

(1) Uniformity:
The living thing consists of the uniform cells, each of which has the same genetic DNA (Deoxyribonucleic Acid).

(2) Equality:
Each cell has the equal power to the others in function.

(3) Locality:
Each cell basically utilizes the local information around itself.

These characteristics are the basis of growth (on-line expansion), metabolism (fault tolerance) and immunity (on-line maintenance).

The ADS concept asserts that a system is grasped by viewpoints:

(1) a system consists of subsystems.

(2) a system almost always includes the incomplete subsystems.

That is, at first the subsystem is clarified and then a system exists as the result of the integration of subsystems. Here it is assumed that the totality of the structure, objectives and information cannot be previously specified for system, as well as the living thing and the real world’s large scale and complex system. Moreover almost always, the system includes the incomplete subsystems with the failures/additions/modifications/repairs.

The ADS concept suggests that the system is changing its structure and the functions but it keeps its operation...
Based on this ADS concept, the ADS system is defined under two properties: autonomous controllability and autonomous coordinability.

(1) Autonomous controllability
The autonomous controllability means that the subsystem can control itself to achieve its mission under any other subsystem is incomplete because of their failure, maintenance and construction/modification.

(2) Autonomous coordinability
The autonomous coordinability is described that, even if any subsystem is in incomplete situation, the other subsystems can coordinate their objectives among them.

The ADS concept does not have the view of the absolutism which means that all power, values and truth are given to one ruler, but of the relativism which insists that they are relative to subsystems.

This innovative concept has made it possible to create the new technologies which are completely different from the conventional system concepts of the centralized, hierarchical and functional distributed systems in the fields of computing, communication and control. Then the new systemized technologies are deduced.

2.2 System Architecture

The ADS system is that each subsystem has its own intelligence to control itself for autonomous controllability and to coordinate through communicating with the others for autonomous coordinability even under the evolving situations in the system.

Under these situations, Data Field (DF) System Architecture is proposed. Here each subsystem has its own management operation system, ACP (Autonomous decentralized Control Processor) for autonomously controlling itself. The subsystem communicates the data through the DF for autonomously coordinating with the others, where each subsystem judges whether or not to receive the data. Under the DF architecture, each ACP realizes the autonomous control and coordination by its functions of the data-driven management and the content code communication technologies.

(1) Content code communication
Content code communication makes it possible to realize each subsystem's autonomy for the coordination. In this communication, the subsystem broadcasts the data attaching its content code, corresponding to the meaning of the data, without its destination into the DF. While, the other subsystems select to receive the necessary data by their own judgment on the basis of the content code. The sender need not know the total system structure and the relation between the senders and receivers for the communication.

At the conventional communication, the sender has to specify the receiver's address and then the receiver has to receive it. That is, the communication mechanism is based on the previously fixed master-slave relationship. Then it is difficult for the subsystem to keep the communication, without stopping under the evolving situation where the system structure and the functions are changing unexpectedly and then the relation between the senders and the receivers changes.

(2) Data-driven management
Data-driven management makes it possible to achieve the subsystem's autonomy for control, in which the subsystem determines to start its execution when it receives all of the necessary content code data from the DF. Then all of the subsystems asynchronously start their execution without previously specifying the execution sequences among the subsystems and directing the others' execution. Each subsystem need not know who generates the received data and, when the sender sends it. The subsystem only registers the content code, necessary for its own application software, in its ACP.

Conventionally the data-driven mechanism was proposed where the subsystem can start its execution under the direction by the dispatcher who collects the data. This conventional data-driven mechanism is not autonomous but hierarchical between the dispatcher and the other subsystems. This conventional data-driven mechanism is not flexible for the evolving situation.

2.3 Technologies

The ADS concept has been applied in the network, controller/sensor, database and so on.

(1) Network
The network is one of the appropriate fields to apply the ADS concept. As the system has been constructed in the distributed manner in 1980's, several networks called LAN (Local Area Network) were proposed. At that time, the network's requirements of reliability and performance has not been sufficient due to its utilization in the large, complex and mission critical systems, but the requirements of fault tolerance and expandability have been increased. Moreover the fiber optical cables, appeared in the market in the late 1970's, made it possible to easily resolve the conventional requirements. Then the ADS technologies have been proposed to realize the on-line properties not to stop the communication under the partial failures, expansion and maintenance of nodes and links in the network. One of the ADS networks, ADL (Autonomous Decentralized Loop network) has been successfully applied in the mission critical systems. In the ADL, each network node has its autonomous network management and they are mutually connected by utilizing the content code communication.

But in 1980's, the standardization of the networks such as Token Ring and Ethernet has been promoted and then the proprietary network such as ADL had not been utilized except some specific area. Therefore the content code communication technology has been tried to be realized on the standard transmission protocol of UDP (User Datagram Protocol) on the standard networks such as Ethernet, FDDI (Fiber Distributed Data Interface) and so on.

The researchers in the US took keen interest to em-
ploy the ADS network management technology for the Internet research. They had researched it as the post ARPA (Advanced Research Projects Agency) Network, which was developed by DARPA (The Defense Advanced Research Projects Agency) and managed by the centralized manner. And in 1980’s, the Internet has been designed to apply the ADS network management where each node has its autonomous routing and fault detection/recovery mechanism. In 2000’s, the functionality of the autonomous decentralized management has been applied in the wireless network.

Recently in wireless sensor network as one of the most active research fields, the ADS technologies have been applied not only for the network management and the energy consumption management but also for the routing management under the unstable wireless communication environment.

(2) Controller/Sensor

In the production processes of the factories, many controllers such as PLC (Programmable Logic Controller) and intelligent sensors are connected through the network and the on-line property for these manufacturing systems become inevitable. In these fields, the autonomous devices have been studied and developed not only for the on-line property under the bad environment in the factory but also for the life-cycle cost reduction. Recently these autonomous intelligent devices have been realized as system LSI which includes the functionality of sensing, control and communication.

(3) Data Base

As the memory disk (HDD: Hard Disk Drive) has been miniaturized, many disks are integrated by the RAID (Redundant Arrays of Inexpensive Disks) technology. For improving the reliability and speed of RAID, the disk controller is designed to be autonomous for managing the disks. Moreover in the storage systems connecting many disks, each disk controller has the autonomous functionality for the fault detection/recovery/test and management.

Recently, several storages, each of which attaches the processors, are connected directly to the network called SAN (Storage Area Network). Here this networked-DB system has the autonomous DB management functions for sharing the load and achieving the back-up among the DBs.

3. Value and Its Evaluation

Under the evolving situation in the technology, society and market, not only the system but also its value change. Then the system has to be evaluated not in the fixed and static situation but in the variable and dynamic situation. The new values are pursued for the ADS.

(1) Functional Reliability

The objective of the ADS is the on-line property. However, the value of the conventional system is statistically evaluated by reliability and availability. Their measures are the failure and recovery rates from its complete situation to the system failure and vice versa. The ADS tries not to totally stop the system operation by each subsystem’s auton-

omy even against any other subsystems’ mal-functionality. Then even if some subsystems fail, the functionality of the other remaining operational subsystems has to be evaluated. The functional reliability has been proposed to evaluate the operational functionality of the subsystems under partial incomplete situation in the system.

This measure is effective for one computer system. But recently, several different computer systems are mutually connected and then so many participants are involved as the users and/or providers. Then the assurance is proposed under the heterogeneous environment.

(2) Assurance

In the heterogeneous environment with the different users and providers, the different multilevel requirements coexist. Moreover, recently the requirements of the users and providers for the system have been rapidly and unexpectedly changed as the users’ preferences and the market competitiveness have varied. The value of the system cannot be evaluated for single requirement at the statistic and specific situation but for the heterogeneous requirements under the dynamic and unpredictable situation.

The assurance of the system is defined as ability to keep its operation while adapting to the heterogeneous requirements. This assurance value has been required in Japanese market in 1980’s, and this assurance has been gradually requested in the US in the later 1990’s.

The adaptability for changing situation and the multiplicity for requirements is nicely achieved by the subsystems autonomy in the ADS with the on-line property including the on-line expansion, on-line maintenance and fault tolerance. But still the multilevel requirements cannot coexist and be satisfied in the ADS. The assurance property is one of the remaining problems to be resolved by the ADS.

In 1997, the assurance technology conference, HASE (High Assurance System Engineering symposium) sponsored by IEEE was founded in cooperation with the DOD (Department of Defense, US) and the ADS group. Since then, the assurance research interest group has been established in IEICE Japan.

4. Design

The ADS concept has the standpoint that at first a subsystem exists and the system is constructed by their integration. That is, the design of the ADS is not the top-down manner but the bottom-up approach.

(1) Bottom-up design

As the system becomes large and/or complex, the totality of the system structure, functions and objectives can not be clarified from the beginning. In the realistic situation for the economy and market, the system has to start from the small scale construction and then to be grown up while the already constructed parts should not be modified. The bottom-up design is effective when it is difficult to clearly and previously define the total system.

Moreover, nowadays the field engineers try to design the computer application software by their PC because they
know well the real application jobs and the software development tools. The IT (Information Technology) investment of the users is largely for the operation, modification and maintenance of the system once it has been constructed. After its construction the investment ratio has almost reached to 70% of the total IT investment. As the modification and addition of the system occur more frequently, the system design should be adaptive according to the evolving situation.

Therefore recently the bottom-up system design of the ADS has been much more important not only by the computer specialists but also by the field engineers.

(2) Uni-interface design

In the ADS, each software module in the subsystem has uni-interface only with the Data field and the software module starts to execute after it receive its necessary content code data. The software module has no internal data within it. The software module is defined by the input-output content code data. Then the software module can be designed without clarifying the interfaces with the other software nodules.

This ADS bottom-up and uni-interfaces design approaches proposed in 1980’s have been accelerated in the various fields of the object-oriented design, SOA (Service Oriented Architecture) and web-based design.

5. Industrial Activity

In Japan, the applications of the ADS have been initiated in the control industry fields of the manufacturing and the train operation, which have the global competitiveness in the production and the service. After that, the implementation of the ADS technologies have been expanded to the information service systems, the satellite computer systems, the communication systems and recently the control-information integrated systems such as the SUICA (Super Urban Intelligent Card) by JR East (East Japan Railway Company) for fare collection and e-commerce. These ADS technologies have been successfully applied and been well-operated.

The reason to apply the new technologies in the strongly competitive industry is that these companies have the severe requirements and they can evaluate the technologies from various aspects through these developments and then the technologies can be improved and advanced. The diffusion of the technologies cannot be achieved without any success at the influential companies or organizations in the market.

In the US and Europe, the organizations have focused to apply the ADS in the computer and communication fields respectively. IBM has started the 21st century strategic project, “Autonomic Computing”, which has the same approach on the basis of the biological analogy as the ADS. But the autonomic computing project target is the policy base and/or schedule base technology for cooperating among the subsystems under the slowly changing situation. This approach is very effective in the information application area such as the computational resources management in the data center with the large data bases.

In the Asian countries, especially China, the research activity about the ADS has been accelerated in these years and the development of the ADS has been experimentally tried in the railways.

6. Academic Activity

At first, the ADS has been evaluated outside Japan in 1980’s and thereafter the research and development in Japan have been activated.

The international symposium on ADS sponsored by IEEE and the Japanese three societies of IEICE, IPSJ (Information Processing Society of Japan) and SICE (Society of Instrument and Control Engineers, Japan) was founded in 1993 and the first ISADS (International Symposium on Autonomous Decentralized Systems) was held in Kawasaki, Japan. Taken it started from Japan, the ISAD has been held successfully every two years in the world.

The project of the ADS started under the sponsorship of the Japanese Ministry of Education from 1990 to 1993. This project included the topics of control theory, neural network, robotics, manufacturing management and so on with more theoretical emphasis. The research of the ADS in computer and communication have been progressed in the US and Europe. In the Europe, some of the major computer industries have been defeated by the US companies. But the European telecom industry has been competitive, and it financially funds the research and development of ADS technologies for agent, service engineering, CSCW (Computer Supported Cooperative Work), mobile communication. In the US, the research area on the ADS has been focused on the computing. In China, the ADS research has been more theoretical in the fields of the control and artificial intelligence at the universities, and it has been gradually activated toward the computing fields.

7. Standardization

In the computing and communicating technologies, their standardization is important for spreading and advancing technologies in the world. The standardization can contribute not only to expand the technology application area but also to accelerate the technology research and development through the collaboration between the academia and universities. As the area of the application expands, the new requirements can be found and the technologies may advance.

The ADS technologies have been standardized in several areas. At first, the technologies have been approved as the de-facto standard by the consortium of ODVA (Open DeviceNet Association) [28], where the ADS communication and processing technologies are applied on DeviceNet with the protocol of local area network; CAN (Common Area Net). The CAN is the de-facto standard for the car vehicle network and therefore it is expected to be applied in the other various application areas. The ODVA was founded
in the US and it started with only ten companies but the ODVA members reached to more than two hundred control related companies in the world. One of the conformance test provider is located at ASTEM RI (Advanced Software Technology & Mechatronics Research Institute) in Japan. This activity has stimulated the Japanese societies of the manufacturing and Building Automation industries. They made their ADS standard, MSTC/JOP 1101-1999/09/30 for the Factory automation system at MSTC (Manufacturing Science and Technology Center) [29] and the ADS standard IEIEJ/p-0003-2000 for the building automation system at the IEIEJ (Institute of Electrical Installation Engineers of Japan) [30].

Moreover in the information processing area, the OMG (Object Management Group) consortium has discussed one of the ADS technologies in its standard OMG Document ADS/99-10-01 [31]. The ADS system architecture is fitted to the CORBA (Common Object Request Broker Architecture) where the data bus corresponds to the DF and the ADS communication and processing technologies are approved as the recommendation to the standard.

Nowadays, China is trying to make the standard ADS technologies for the application area such as the train transport operating system. The trains would be operated in China and across the countries in Asia and Europe. Recently the necessity of the train systems has been rapidly increasing because of the environment problem. Then the standard of the train, signal and transport operation technologies have been more required.

8. **Education**

The ADS has been educated in the various fields of control, communication, robotics, and manufacturing in Japan and gradually in the world, especially in China. Moreover the ADS research and development activities have been utilized in the Management of Technology (MOT) course to educate the strategic approach for technology and business. The ADS research is an appropriate case study while its research and development have been continued through the successful and failed processes, and the concept-oriented approach has reached to the applicable technologies.

In Japan and most of the countries, so many excellent researchers and engineers have created the technologies but unfortunately some of them have not been successfully applied and commercialized. Therefore the MOT education has been much more required not only by the academia but also by the industry and government. The case study on the ADS research and development at the MOT course in Japan and China have been expected more to contribute the education for the Japanese style strategic management of technology including the concept creation, technologies invention, commercialization, patent and standard in the long term.

9. **Conclusions**

In this paper, we have overviewed the ADS with respect to the concept, technologies, value, application, standards and education perspectives. The ADS research and development has the features of the consistent and sustainable approach from concept to technology, applications to standards, and research to management of technology. These evolution has been taken in the world.

In these processes from 1970's to 2000's, the forces of the technology innovation have been gradually driven from the manufacturer to the user. The trend of the ADS technologies has been changing from control, computer and communication to their integration, which has been utilized more for each person's comfortable life than for the society's majority convenience and economy.

The ADS is expected to be growing more in accordance with the changing society and value.

**References**

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