

Polymetric Sensing in Intelligent Systems

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Abstract

The authors examine the up-to-date relationship between the theory of polymetric measurements and the state of the art in intelligent system sensing. The chapter contains commentaries about: concepts and axioms of polymetric measurements theory, corresponding monitoring information systems used in different technologies and some prospects for polymetric sensing in intelligent systems and robots. The application of the described concepts in technological processes ready to be controlled by intelligent systems is illustrated.

Keywords: Polymetric signal, polymetric sensor, intelligent sensory system, control, axiomatic theory, modelling.

10.1 Topicality of Polymetric Sensing

For some time it has been widely recognized [1] that the future factory should be a smart facility where design and manufacture are strongly integrated into a single engineering process that enables ‘right first time’ every time production of products to take place. It seems completely natural to use intelligent robots and/or control systems at such factories to provide on-line, opportune and precise assessment of the quality of the production process and to guarantee the match and fit, performance and functionality of every component of the product prototype that is created.

Wide deployment of sensor-based intelligent robots at the heart of future products and technology-driven systems may substantially accelerate the

process of their technological convergence and lead to their introduction in similar processes and products.

At the same time it is well known [2] that intelligent robot creation and development is a rather fragmented task and there are different progress-restricting problems in each particular field of research. Numerous advanced research teams are doing their best to overcome these limitations for intelligent robot language, learning, reasoning, perception, planning and control.

Nowadays, a few researchers are still developing the Ideal Rational Robot, as it is quite evident that the computations necessary to reach ideal rationality in real operating environments require much more time and much more productive processors. Productivity is permanently growing but being still limited for IRR tasks. Furthermore, the robotic perception of all the necessary characteristics of real operating environments has not been sufficiently provided yet.

The number of corresponding sensors and instruments necessary for these robots is growing, but their sensing remains too complicated, expensive, time-consuming and IRR remains far from being realistic for actual application.

F.H. Simons' concept of Bounded Rationality and the concept of Asymptotic Bounded Optimality based on S.J. Russell's and D. Subramanian's approach of provably bounded-optimal agents have formed a rather pragmatic and fruitful trend for the development of optimal programs.

One has to take into account the fact that time limitations are even stricter if we are trying to overcome them for both calculation and perception tasks. While immense progress has been made in each of these subfields in the last few decades, it is still necessary to comprehend how they can be integrated to produce a really effective intelligent robot.

The introduction of the concepts of agent-based methods and systems [3, 4] including holonic environment [5] and multi-agent perceptive agencies [6] jointly with the concept of polymetric measurements [7–9] has engendered a strong incentive to evaluate all the potentialities of using polymetric sensing for intelligent robots, as this may be a precondition for generating real benefits in the field.

The matter is that obvious practical success has been achieved during the wide deployment of SADCO[®] polymetric systems for monitoring a variety of multiple quantitative and qualitative characteristics of different liquid and/or loose cargoes using a single polymetric sensor for measuring more than three characteristics of cargoes simultaneously within a single chronotopos framework. Similar information systems were also a successful tool for

the online remote control of complex technological processes of production, storage and consumption of various technological media [8].

But, as indicated above, there are very specific requirements for sensing in intelligent robots. In fact, one of the most important restrictions is connected with very limited time-consumption for the input of real-time information concerning an intelligent robot and/or multi-agent control systems operational environment.

Thus, we face an actual and urgent need to integrate and combine these advanced approaches within the calculation and perception components of intelligent robots and/or multi-agent monitoring and control system design, starting from different (nearly diametrically opposite) initial backgrounds of each component and, by means of irrefutable arguments, arriving at jointly acceptable conclusions and effective solutions.

10.2 Advanced Perception Components of Intelligent Systems or Robots

10.2.1 Comparison of the Basics of Classical and Polymetric Sensing

Classical or industrial metrology is based on the contemporary Axiomatic Theory [10, 11].

In classical industrial metrology, it is presupposed that for practical measurement processes it is necessary to have some set $\Omega = \{\sigma, \lambda, \dots\}$ of different instruments with various sensor transformation and construction systems.

But every particular instrument has a custom-made uniform scale for the assessment of the actual value of the object specific characteristic under control. Let $a_\sigma(i)$ be a numerical function of two nonnumeric variables – a physical object $i \in \aleph$ and a specific instrument, i.e.

$$a : \Omega \times \aleph \rightarrow \mathfrak{R} \text{ and } (\sigma, i) \mapsto a_\sigma(i). \quad (10.1)$$

This function is called a quantitative assessment of a physical quantity of an object.

In the general case for an industrial control system or for intelligent robot sensing process, it is necessary to have N instruments for each characteristic under monitoring at M possible locations of the components of the object under control. The more practical the application, the quicker we face the curse of multidimensionality for our control system.

Polymetric measurement in general is the process of getting simultaneous assessments of a set of object physical quantities (more than two) using one special measuring transformer (a sensor). The first successful appraisal of the corresponding prototype instruments was carried out in 1988–1992 on-board three different vessels during full-scale sea trials. After the successful tests and the recognition of the instruments by customers and the classification societies, the theoretical background was generalized and presented to the scientific community [12–14].

The latest results [7–9] seem to be prospective for intelligent robot sensing due to reduced time and financial pressure, simplified design and reduced general number of sensory components.

Summarizing the comparison of the basics of classical and polymetric measurement theories, it is essential to comment another consequence of their axioms and definitions. The introduction of the principle of the simultaneous assessment of a physical quantity and its measurement from the same polymetric signal Polymetric signal is one of the key provisions of the theory and the design practice for developing appropriate instruments. The structure of an appropriate perceptive intelligent control or monitoring system should be changed correspondingly.

10.2.2 Advanced Structure of Multi-Agent Intelligent Systems

In order for multi-agent control or monitoring systems and intelligent robots to satisfactorily fulfil the potential missions and applications envisioned for them, it is necessary to incorporate as many recent advances in the above described fields as possible within the real-time operation of the intelligent system or robot-controlled processes.

This is the challenge for the intelligent robotics engineer, because many advanced algorithms in this field still require too much time for computation, despite improvements made in recent years in microelectronics and algorithms. Especially, it concerns the problem of intelligent robot sensing (timely and precise perception).

The well-known variability versus space (topos) and versus time (chronos) is related to similar variability of the measured data [6, 7, 10] engendering the advantages of using polymetric measurements.

That is why, in contrast to the multi-sensor perceptive agency concept [6] based on the use of several measuring transformers, each one of them being the sensing part of each particular agent within the distributed multi-sensor control system (i.e. several perceptive agents in complex perceptive agency),

the use of one equivalent polymetric transformer for an equivalent perceptive agency is proposed.

The concept of Polymetric Perceptive Agency (PPA) for intelligent system and robot sensing is schematically illustrated in Figure 10.1. Such simplified structure of PPA sub-agency of the Decision-making Agency (DMA) is designated to be used in different industries and technologies (maritime, on-shore, robotics, etc. [9, 15]).

There are some practical optimistic examples of the successful deployment and long-term (more than 15 years) operation of industrial polymetric monitoring and control systems/agencies based on polymetric measurement- Polymetric measurement technique in different fields of manufacturing and transportation [8].

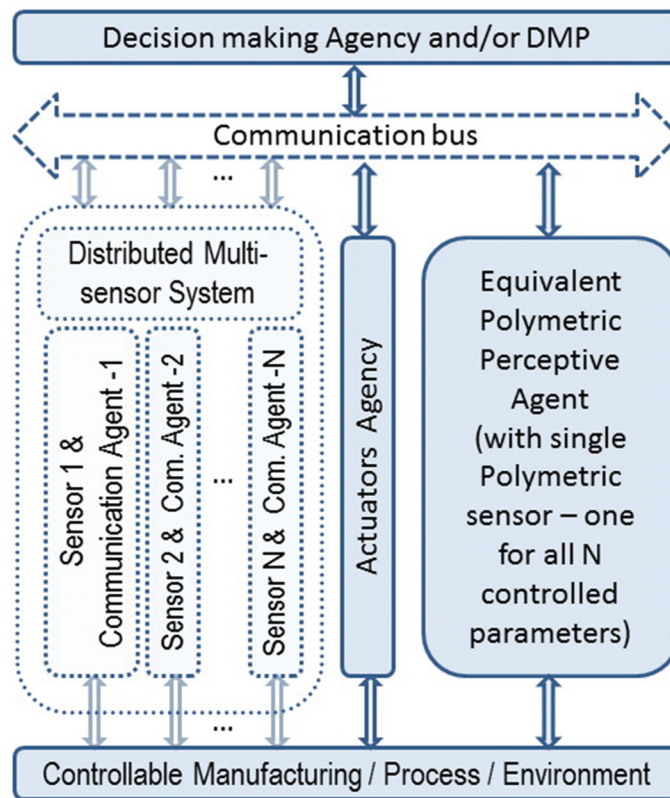


Figure 10.1 The main idea of the replacement of the distributed multi-Sensor system by a polymetric perceptive agent.

10.3 Practical Example of Polymetric Sensing

Here we describe a practical case from the research of the Polymetric Systems Laboratory at the National University of Shipbuilding and LLC AMICO (Mykolaiv, Ukraine). The practical goal is to ensure the effective and safe control of the water level in the cooling pond of nuclear power stations at the spent nuclear fuel storage during normal operation and emergency post-accident operation. There are many level sensors, which are used by the control systems in the normal operation mode: floating-type, hydrostatic, capacitive, radar, ultrasonic, etc. [16]. But there exist many problems concerning their installation and functioning under real post-accident conditions. The matter is that high pressure and extremely high temperature, saturated steam and radiation, vibration and other disturbing factors are expected in the cooling pond in emergency mode.

Thus, high reliability and radiation resistance are the most important requirements for such level-sensing equipment. One of the most suitable sensing techniques in this case is the proposed modified Time Domain Reflectometry (TDRTdr) – see Figure 10.2.

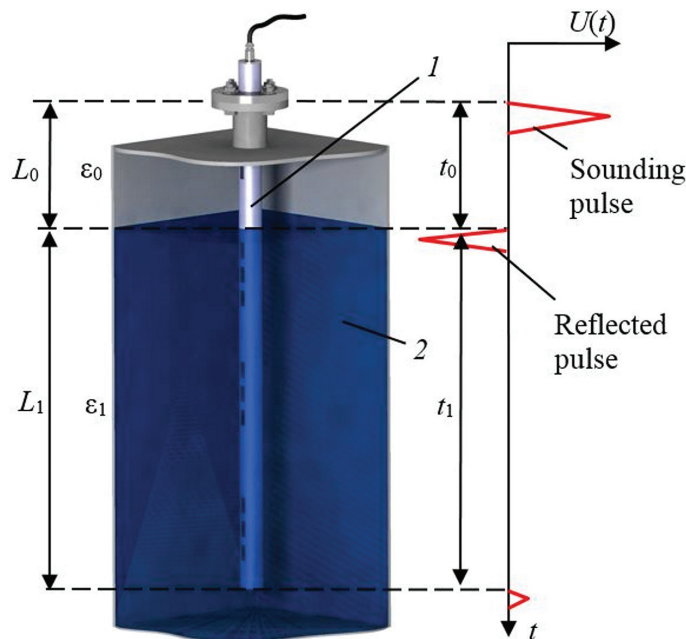


Figure 10.2 TDR Coaxial probe immersed into the liquid and the corresponding polymetric signal.

In this type of level measurement, microwave pulses are conducted along a cable or rod probe 1 partially immersed in the liquid 2 and reflected by the product surface.

Sounding and reflected pulses are detected by the transducer. The transit time of the pulse t_0 is a function of the distance from the level sensor to the surface of the liquid L_0 . This time is measured and then the distance from the level sensor to the surface of the liquid is calculated according to the calibration function:

$$L_0 = f(t_0), \quad (10.2)$$

which is usually presented as a linear function:

$$L_0 = b_0 t_0 + b_1, \quad (10.3)$$

where b_0 and b_1 – coefficients which are obtained during a calibration procedure.

From the physical point of view, the slope of this function stands for the speed of the electromagnetic wave which propagates forward from the generator on the pcb-board, along the cable and the specially designed measuring probe, and back to the generator. It can be defined as:

$$b_0 = \frac{c}{2\sqrt{\varepsilon_0}}, \quad (10.4)$$

where c – speed of light in vacuum; ε_0 – dielectric constant of the material through which the electromagnetic pulse propagates (it is close to 1 for air); the coefficient of $1/2$ stands for the fact that the electromagnetic pulse propagates along double the length of the probe (forward and backward).

The fact of the presence and the value of the intercept b_1 are caused by many reasons. One of them is that the electromagnetic pulse actually passes the distance greater than the measuring probe length. In the general case, the real calibration function is not linear [8].

10.3.1 Adding the Time Scale

In this practical case, the basic approaches for constructing the polymetric signal are described based on the TDR technique. The concept of forming an informative pulse polymetric signal includes the following: generation of short pulses and sending them to a special measuring probe, receiving the reflected pulses and signal pre-processing for its final interpretation. It is worth mentioning that in terms of polymetrics, each of these steps is specially designed to increase the informativity and interpretability of the resulting signal.

Therefore, to calculate the distance from the sensor to the surface of the liquid, it is necessary to carry out the calibration procedure. The level-sensing procedure can be simplified by adding additional information to the initial «classic» signal to obtain the time scale of this signal. A stroboscopic transformation of the real signal is one of the necessary signal pre-processing stages during the level measurement procedure.

This transformation is required to produce an expanded time sampled signal for its future conversion to digital form. This transformation can be carried out with the help of a stroboscopic transformer based on two oscillators with frequencies f_1 (the frequency of input signal) and f_2 (the local oscillator frequency) that are offset by a small value $\Delta f = f_1 - f_2$ [17]. The duration of the input signal is:

$$T_1 = \frac{1}{f_1}. \quad (10.5)$$

As a result of this transformation, we have expanded signal duration:

$$T_{TS} = \frac{1}{\Delta f} = \frac{1}{f_1 - f_2}. \quad (10.6)$$

In this case, the relationship between the duration of transformed and the original signal is expressed by the stroboscopic transformation ratio:

$$K_{TS} = \frac{T_{TS}}{T_1} = \frac{f_1}{f_1 - f_2}. \quad (10.7)$$

The next processing step of the transformed signal is the conversion of this inherently analog signal to digital form with the help of the analog-to-digital converter (ADC).

The time scale and delays during analog-to-digital conversion are known. Therefore, it is possible to count ADC conversion cycles and to calculate the time scale of the converted signal. It is not convenient because conversion cycle duration is connected with the ADC parameters, clock frequency value and stability, etc. In order to exclude the use of the conversion cycles number and ADC parameters, it is possible to «add» the additional information about the time scale of the converted signal.

In this case, we can add a special marker which helps to measure the reference time interval – see Figure 10.3.

The main idea is that ADC conversion time T_{ADC} must be greater than the duration of the signal from the output of the stroboscopic transformer T_{TS} to obtain at least 2 sounding pulses in the resulting digitized signal. It is necessary

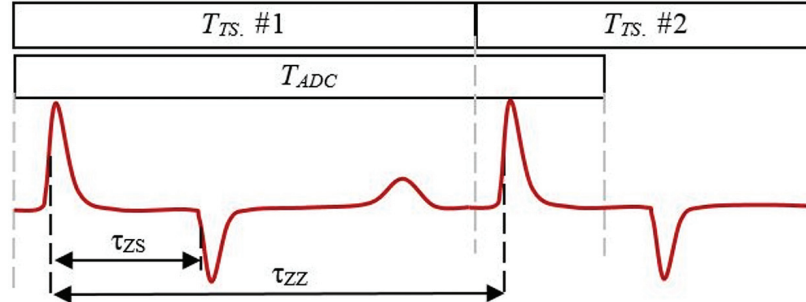


Figure 10.3 Time diagrams for polymetric signal formation using additional reference time intervals.

to count the delays between two sounding pulses τ_{ZZ} and between the first sounding pulse and the reflected pulse τ_{ZS} (in terms of the number of ADC readings).

The delay τ_{ZZ} , expressed in ADC readings count, corresponds to the time delay T_{TS} (in seconds). The next equation should be used to calculate the time scale of the transformed and digitized signal:

$$K_{DT} = \frac{T_{TS}}{\tau_{ZZ}} \text{ s/reading.} \quad (10.8)$$

It is possible to calculate the time value of the delay between the pulses t_0 (see Figure 10.2):

$$t_0 = \frac{K_{DT}\tau_{ZS}}{K_{TS}} = \frac{\tau_{ZS}}{f_1\tau_{ZZ}} \text{ s.} \quad (10.9)$$

Finally, to calculate the distance to the surface of the liquid, it is necessary to use the equation:

$$L_0 = \frac{c}{2\sqrt{\varepsilon_0}} \frac{\tau_{ZS}}{f_1\tau_{ZZ}} + b_1, \quad (10.10)$$

where b_1 (zero shift) is calculated using information on the PCB layout and generator parameters or during a simple calibration procedure.

10.3.2 Adding the Information about the Velocity of the Electromagnetic Wave

In the previous paragraph, a special marker was added to the signal to obtain the time scale of the signal and to easily calculate the distance to the surface of the liquid in normal operating mode.

But, as it was mentioned above, the emergency operating mode can be characterized by high temperatures and pressure, the presence of saturated steam in the cooling pond. Steam under high pressure and temperature will slow down the propagation speed of a radar signal which can cause an additional measurement error. It is possible to add the additional information to the signal for automated correction of measurement. A special reflector or several reflectors are to be used in this case [8]. Almost any step of wave impedance discontinuities can be used as a required reflector (probes with stepwise change of the impedance, fixing elements, etc.). The reflector is placed at a fixed and known distance L_R from the generator and the receiver of short electromagnetic pulses GR in the vapour dielectric – presented in Figure 10.4.

If there is vapour in the tank, the pulses reflected from the special reflector and from the surface of the liquid are shifted according to the change of the dielectric constant of vapour (as compared to the situation when there is no vapour in the tank).

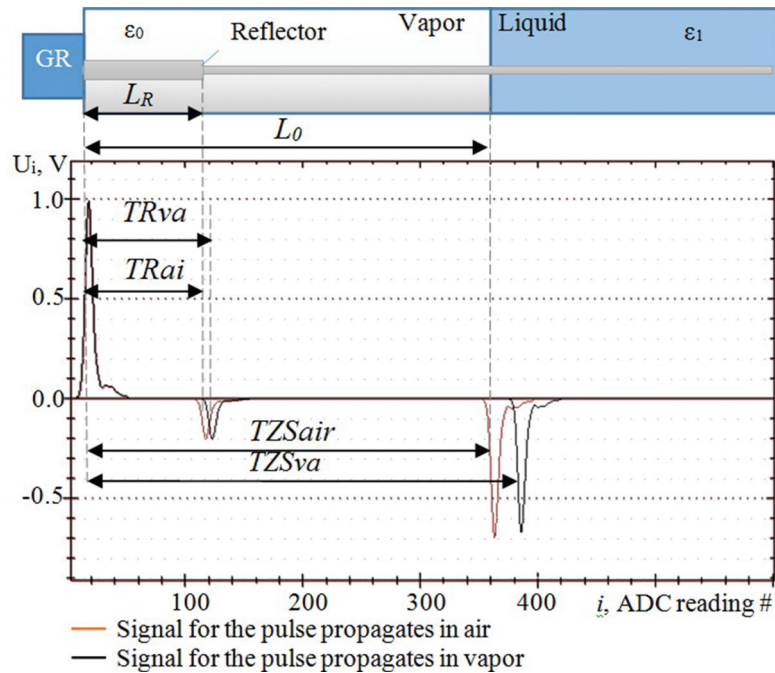


Figure 10.4 Disposition of the measuring probe in the tank, position of the reflector and corresponding signals for the cases with air and vapour.

The delays between the sounding pulse and the pulse reflected from the special reflector τ_R and between the sounding pulse and the pulse reflected from the surface of the liquid τ_{ZS} for cases with air and vapour are different.

The dielectric constant ε_0 can be calculated using the known distance L_R . Therefore, the distance to the surface of the liquid L_0 can be calculated using the corrected dielectric constant value:

$$L_0 = \frac{(L_R - b_1)\tau_{ZS}}{\tau_{ZR}} + b_1. \quad (10.11)$$

As it can be seen from the equation, the result of the measurement depends on the time intervals between the sounding and reflected pulses and the reference distance between the generator and the reflector.

The above-described example of polymetric signal formation showed that a single signal carries information about the time scale of this signal, the velocity of propagation of electromagnetic waves in dielectrics and the linear dimensions of these layers. This list of measurable parameters can be easily continued by using additional information in the existing signals and building new «hyper-signals» [9] for measuring some other characteristics of controllable objects (e.g. on the basis of the spectral analysis of these signals the controllable liquid can be classified and some quality characteristics of the liquid can be calculated).

10.4 Efficiency of Industrial Polymetric Systems

10.4.1 Naval Application

One of the first polymetric sensory systems was designated for on-board loading and safety control (LASCOS) of tankers, fishing, offshore, supply and research vessels. The prototypes of these systems were developed, industrialized and tested during full-scale sea trials in the early 90-es of the last century [18]. These systems have more developed polymetric sensing subsystems (from the “*topos-chronos*” compatibility and accuracy points of view). That is why they are also successfully providing commercial control of cargo handling operations.

The structure of the hardware part of LASCOS for a typical offshore supply vessel is presented in Figure 10.5. It consists of the following: operator workplace (1); a radar antenna (2); an on-board anemometer (3); the radar display and a keyboard (4); a set of sensors for ship draft monitoring (5); a set of polymetric sensors for fuel-oil, ballast water and other liquid

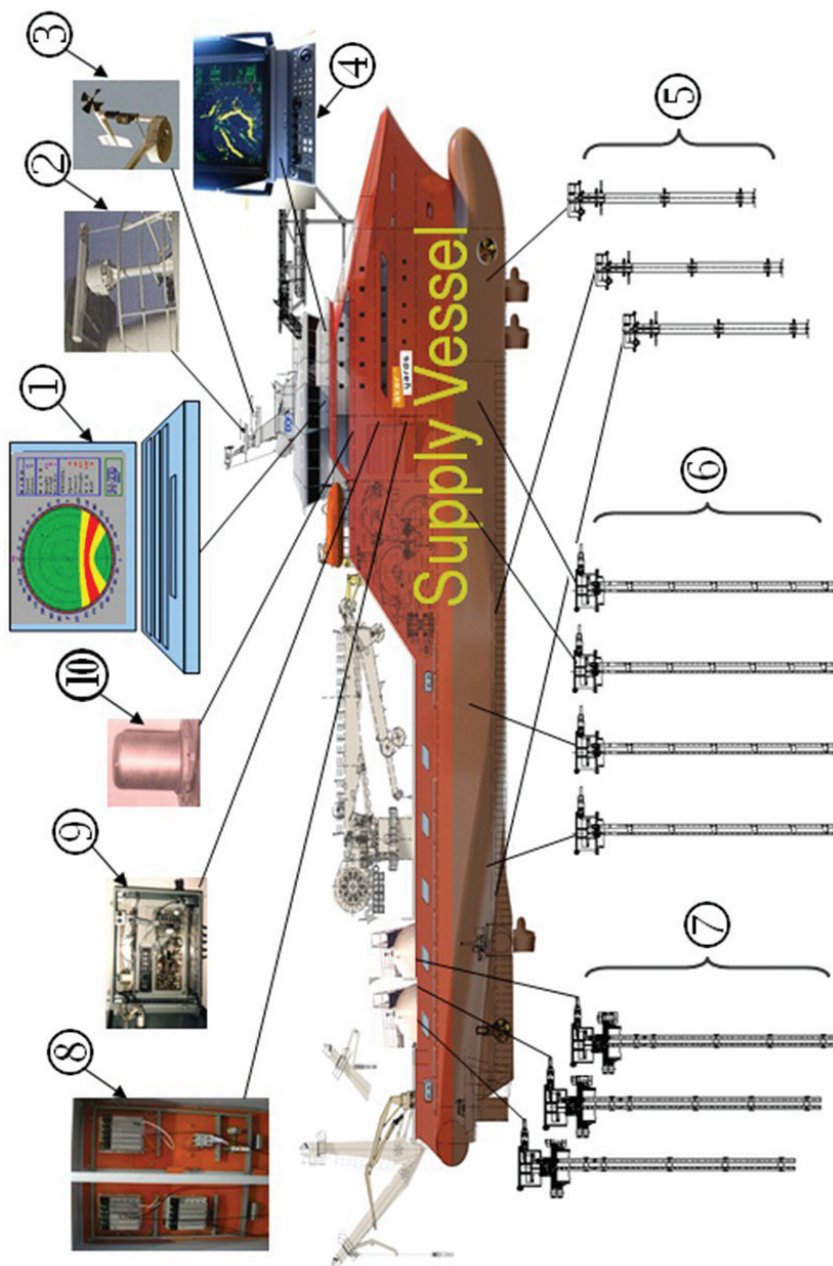


Figure 10.5 Example of the general structure of lascos hardware components and elements.

cargo quantity and quality monitoring and control (6); a set of polymetric sensors for liquefied LPG or LNG cargo quantity and quality monitoring and control (7); switchboards of the subsystem for actuating devices and operating mechanisms control (8); a basic electronic block of the subsystem for liquid, liquefied and loose cargo monitoring and control (9); a block with the sensors for real-time monitoring of ship dynamic parameters (10).

The structure of the software part of the typical sensory intelligent LASCOS is presented in Figure 10.6.

It consists of three main elements: a sensory monitoring agency (SMA) which includes three other sensory monitoring agencies – SSM (sea state, e.g. wind and wave model parameters), SPM (ship parameters) and NEM (navigation environment parameters); an information environment agency (INE) including fuzzy holonic models of ship state (VSM) and weather conditions (WCM), and also data (DB) and knowledge (KB) bases; and last but not least – an operator interface agency (OPIA) which provides the decision-making person (DMP) with necessary visual and digital information.

Unfortunately, until now, the above-mentioned challenges have not been combined together in an integrated model, which applies cutting-edge and novel simulating techniques. Agent-based computations are adaptive to information changes and disruptions, exhibit intelligence and are inherently distributed [4]. Holonic agents inherently may help design and operational

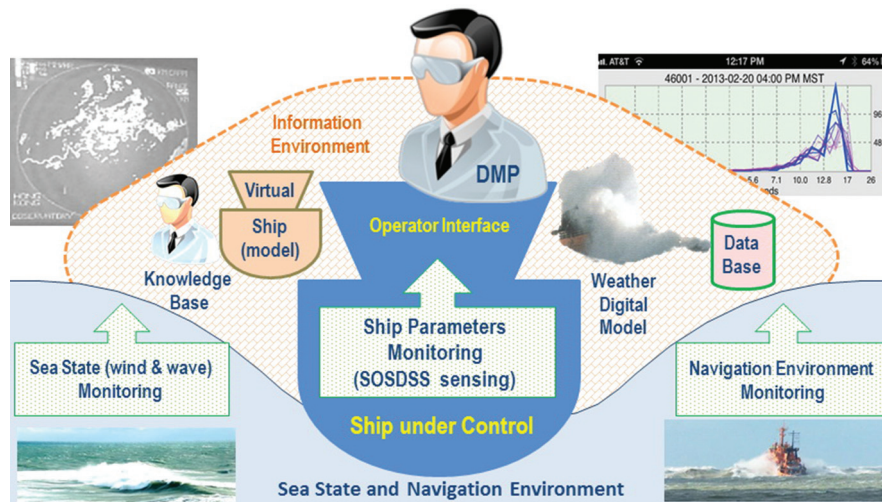


Figure 10.6 The general structure of lascos software elements and functions.

control processes in self-recovery and react to environmental real-time perturbations.

The agents are vital in a ship operations monitoring and control context, as ship safety refers to the inherently distributed and stochastic perturbation of its own state parameters and external weather excitations. Agents are welcome in the on-board LASCOS system design because they provide properties such as autonomy, responsiveness, distributiveness, openness and redundancy [15]. They can be designed to deal with uncertain and/or incomplete information and knowledge and this is extremely topical for fuzzy LASCOS as a whole. On the other hand, the problem of their sensing has never been under systematic consideration yet.

10.4.1.1 Sensory monitoring agency SMA

As mentioned above, all initial real-time information for the LASCOS as well as the sensory system is provided to DMP by the holonic agent-based sensory monitoring agency (SMA) which includes three other sensory monitoring agencies – SSM, SPM and NEM (see Figure 10.7).

The simultaneous functioning of all the structures presented in Figure 10.5, Figure 10.6 and Figure 10.7, i.e. hardware, logic and process algorithms, the corresponding software components and elements of LASCOS provide online forming of information environment for the system operator or seafarer – the decision-maker.

The polymetric sensing of the computer-aided control and monitoring system for cargo and ballast tanks is designed to ensure effective and safe control of ship operations in remote mode. This system is one of the most critical systems on-board a ship or any other ocean-floating vehicle. The operation of the system must be finely adjusted with the requirements of the marine industry. The polymetric system is a high-tech solution for the task of on-line monitoring and control of the ship liquid cargoes and ballast water tanks state. These systems are also designated for ship safety parameter monitoring and for docking operations control.

The solution provides safe and reliable operations in real-life harsh conditions, reduces risks for vessels and generates both operational and financial benefits for customers providing:

- The manual, automated or automatic remote control of cargo handling operations;

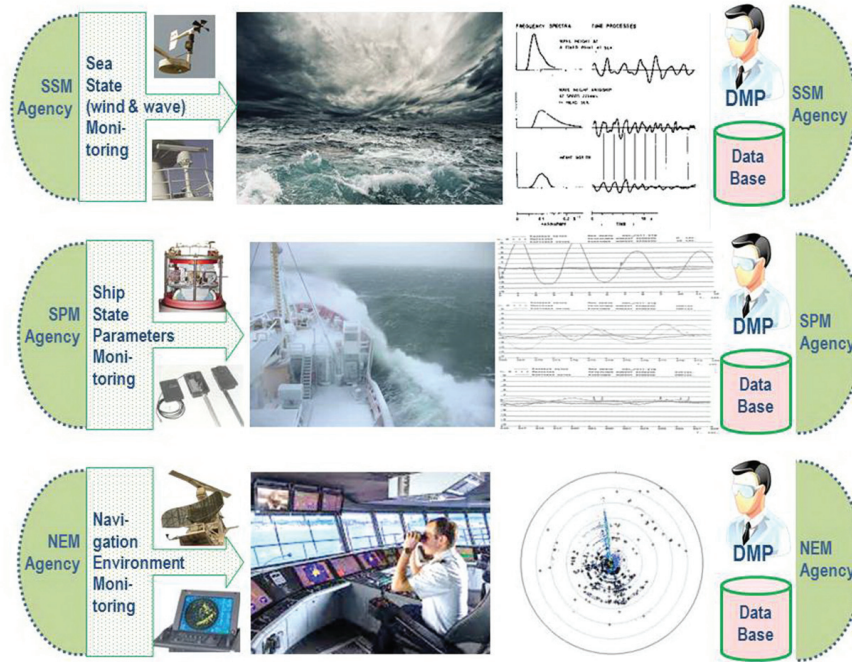


Figure 10.7 The General Structure of LASCOS Holonic agencies functions.

- The on-line monitoring of level, volume, temperature, mass, centre of mass for liquid, loose cargo or ballast water in all tanks;
- The monitoring and control of list and trim, draft line, bending and sagging lines;
- The monitoring of the vessel position during operation or docking; level indication and alarm of all monitored tanks;
- The remote control of cargo valves and pumps according to the actual operational conditions; the feeding of control signals to actuators, valves and pumps; the monitoring of hermetic dryness of dry tanks and conditions of water ingress in the possible damage conditions;
- The audible and visual warning about risky process parameters deviation from the stipulated values;
- The registration and storage of retrospective information on operations process parameters, equipment state and operator actions (“Black Box” functions);

- Comprehensive data and knowledge bases management;
- The testing and the diagnostics of all equipment operability.

10.4.1.2 Information Environment Agency INE

The information environment agency (INE) includes the fuzzy holonic models of ship state (VSM), the weather conditions model (WCM), and also data (DB) and knowledge (KB) bases. The central processor of the LASCOS system processes all the necessary initial information concerning ship design and structure in all possible loading conditions using the digital virtual ship model (VSM).

The information concerning the actual distribution of liquid and loose cargoes (including their masses and centres of gravity) are provided by the sensory monitoring agency (SMA). This information is combined with the information concerning actual weather and navigation environment details that are converted into the actual weather condition model (WCM). The information, permanently refreshable by SMA, is stored in the database and it is used in real-time mode by the VSM and WCM models [18].

10.4.1.3 Operator Interface Agency OPI

The operator interface agency (OPI) of the LASCOS system provides the decision-maker with all the necessary visual and digital information in the most convenient way for decision-making support on quality, efficiency and timeliness. Examples of some of these interfaces are presented in Figure 10.8 and Figure 10.9.

One of the functions of the LASCOS system is to predict safe combinations of ship speed and course in rough sea actual weather conditions. On the safe-storming diagram, the seafarer may see three coloured zones of “speed-course” combinations: the green zone of completely safe ship speed and course combination (grey zone in Figure 10.8); the dangerous red zone with “speed-course” combinations leading to ship capsizing with up to more than 95% probability (the black zone in Figure 10.8); and the yellow zone with “speed-course” combinations with intensive ship motions, preventing normal navigation and other operational activities (the white zone in Figure 10.8).

The centralized monitoring and control of ship’s operational processes is performed via the operator interface from the main LASCOS system processor screen located in the wheelhouse. The advanced operator interface is playing an increasingly important role in the light of the visual management concept. The proposed operator interface for LASCOS provides all traditional man-machine control functionality. Moreover, this interface is clearly structured,

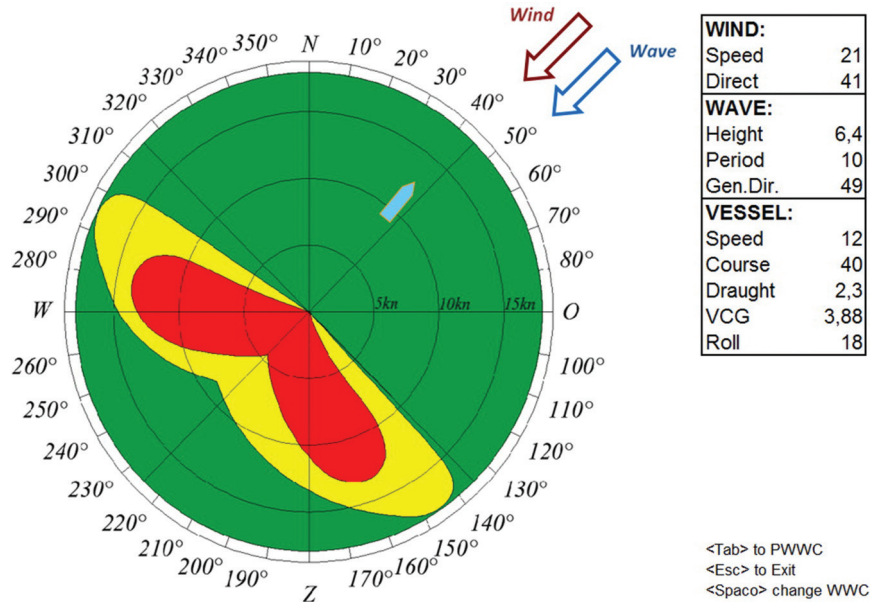


Figure 10.8 Safe Storming Diagram Interface of LASCOS.

powerful, ergonomic and easy to understand; it also makes the immediate forecast of ship behaviour under the control action chosen by the operator, thus preventing too risky and unsafe decisions. It also ensures all control processes rules and requirements consolidating all the controllable factors for better efficiency of operations to exclude human factor influence on decision-making. The interface also ensures system security via personal password profiles for nominated responsible and thoroughly trained persons to prevent the incorrect usage of equipment and to avoid the unsafe conditions of ship operations.

10.4.1.4 Advantages of the polymetric sensing

The described example of a sensory system for typical offshore supply vessel (presented in Figure 10.5) can be used for the demonstration of the polymetric sensing advantages.

The structure of the typical cargo sensory system for the offshore supply vessel consists of the following parts: a set of the sensors for the fuel-oil, liquefied LPG or LNG, ballast/drinking water and other liquid cargo quantity and quality monitoring; a set of sensors for the bulk cargo quantity and quality monitoring.

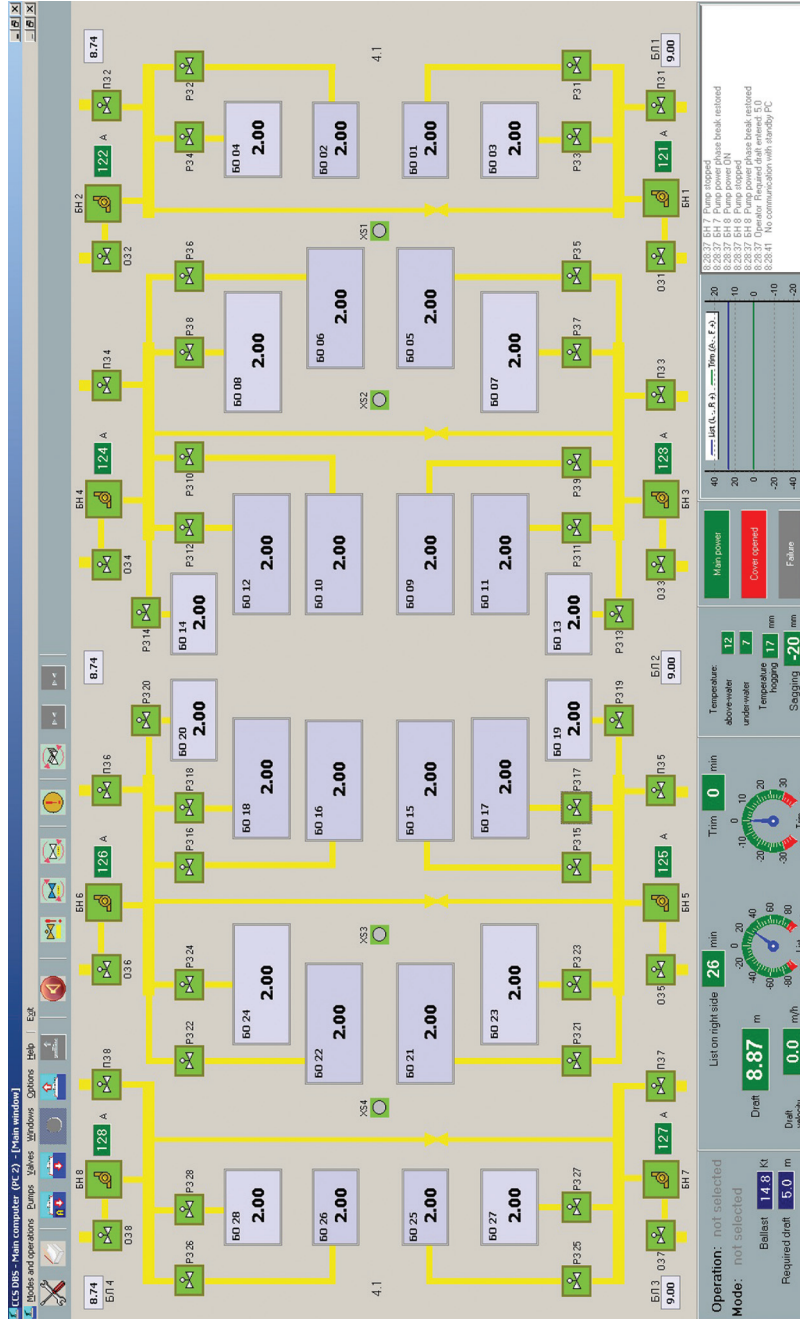


Figure 10.9 The Main Window of Ballast System Operations Interface.

Each tank is designated for the particular cargo type and equipped with the required sensors. For example, for the measurement of the diesel oil parameters, the corresponding tanks are equipped with the level sensors (level sensors with the separation level measurement feature) and temperature sensors. The total number of the tanks, corresponding sensors for the tanks of a typical supply vessel, are shown in Table 10.1 (in case of the traditional sensory system).

All the information acquired from the sensors must be pre-processed for the final calculation of the required cargo and ship parameters in the computing system. Each of the sensors requires power and communication lines, acquisition devices and/or interface transformers (e.g. current loop into RS-485 MODBUS) and so on.

In contrast to the classical systems, the polymetric sensory system requires only one sensor for the measurement of all required cargo parameters in the tank. Therefore, if we assume that traditional and polymetric sensory systems are equivalent in the measurement information quality and reliability (systems are interchangeable without any loss of measurement information quality), it is obvious that polymetric system has the advantage in the measurement channels number.

The cost criterion can be used for the comparison of the efficiency of traditional and polymetric sensory systems. Denoting the cost of one

Table 10.1 Quantity and Sensor Types for the Traditional Cargo Sensory System (Example)

Cargo Type	Measureable Parameters	Tanks Number	Sensors Number/Tank	Total Sensors Number
Diesel oil	Level in the tank, presence of water in the tank, temperature	6	3	18
LPG	Level in the tank, quantity of the liquid and vapor gas, temperature	1	3	3
Ballast water	Level in the tank	6	1	6
Drinking water	Level in the tank, presence of other liquids in the tank	6	2	12
Bulk cargo	Level in the tank, quality parameter (e.g. moisture content)	2	2	4
Total		21		43

measurement channel (the sensor + communication/power supply lines + transformers/transmitters) as C_{TMS} and C_{PMS} , the cost of the processing complex as C_{TPC} and C_{PPC} , the costs of the sensory systems for traditional sensory system C_{TSS} and for polymetric sensory system C_{PSS} can be estimated:

$$\begin{aligned} C_{TSS} &= C_{TPC} + N_{TSS} \cdot C_{TMS}, \\ C_{PSS} &= C_{PPC} + N_{PSS} \cdot C_{PMS}, \end{aligned}$$

where N_{TSS} , N_{PSS} – the numbers of sensors used in the traditional and polymetric sensory system correspondingly.

Assuming that

$$C_{TPC} \approx C_{PPC} \approx C_{TMS} \approx C_{PMS},$$

the efficiency comparison of the polymetric and traditional sensory system $E_{TSS/PSS}$ can be roughly estimated using the costs of the equivalent sensory systems [8]:

$$E_{TSS/PSS} = C_{TSS}/C_{PSS} = \frac{N_{TSS} + 1}{N_{PSS} + 1}.$$

As can be seen from the above-described supply vessel example, the polymetric sensory system efficiency is two times greater than the efficiency of the traditional sensory system ($E_{TSS/PSS} = 44/22 = 2$). It is worth mentioning that this comparison of the system efficiency is very rough and it is used only for the demonstration of the main advantage of the polymetric sensory system.

10.4.1.5 Floating dock operation control system

Another example of naval polymetric sensory systems is a computer-aided floating dock ballasting process control and monitoring system (CCS DBS) with the main interface window presented in Figure 10.9.

These systems were designated to ensure effective and safe control of docking operations in the automatic remote mode. The ballast system is one of the most critical systems on the floating dock. The operation must be finely coordinated with the requirements of the marine industry. The polymetric system enables to take high-tech solutions to support safe control and monitoring of the dock ballast system. This solution provides the safe and reliable operations of dock facilities in real-life harsh conditions, reduces risks for vessels and generates both operational and financial benefits to customers.

The main system interface window (see Figure 10.9) contains the technological equipment layout and displays the actual status of a rudder, valves,

pumps, etc. The main window consists of the main menu, the toolbar, the information panel and also the technological layout containing control elements.

It is possible to start, change parameters or stop technological processes by clicking a particular control element. The user interface enables the operator to efficiently supervise and control every detail of any technological process. All information concerning ship safety and operation monitoring and control, event and alarm management, database management or message control is structured in functional windows.

10.4.1.6 Onshore applications

Another example of the successful polymetric sensing of computer-aided control and monitoring systems is connected with different marine terminals (crude oil, light and low-volatility fuel, diesel, liquefied petroleum gas, grain) and even with bilge water cleaning shops. Such sensing allows simultaneous monitoring of practically all the necessary parameters using one sensor for each tank, silo or other reservoir.

Namely, a set of the following characteristics is taken by a single polymetric sensor:

- The level, separation level of the non-mixed media and the online control of upper/lower critical levels and volume of the corresponding cargo in each tank;
- The temperature field in the media, the temperature of the product at particular points;
- Density, octane/cetane number of a fuel, propane-butane proportion in petroleum gas, presence and percentage of water in any mixture or solution (including aggressive chemicals – acids, alkalis, etc.);

As a result, a considerable increase of the measuring performance factor $E_{TSS/PSS}$ was achieved in each application system (up to 4–6 times [8]) with the essential concurrent reduction of number of instruments and measuring channels of the monitoring system. All the customers (more than 50 objects in Ukraine, Russia, Uzbekistan, etc.) reported commercial benefits after serial SADCOTM systems deployment.

10.4.1.7 Special applications

Special applications of polymetric sensing of control and monitoring systems were developed for the following: real-time remote monitoring of motor lubrication oil production process (quantitative and qualitative control of the

components depending on time and real temperature deviation during the production process); real-time remote control of aggressive chemicals at a nuclear power station water purification shop (quantitative and qualitative control of the components depending on time and real temperature deviation during the production process); water parameters control in the primary coolant circuit at a nuclear power station in normal and post-emergency operation state (fluidized bed-level control, pressure and temperature monitoring – all in the conditions of increased radioactivity).

10.5 Conclusions

This paper has been intended as a general presentation of a rapidly developing area of the promising transition from traditional on-board monitoring systems to intelligent sensory decision support and control systems based on neoteric polymetric measuring, data mining and holonic agent techniques. The area is especially attractive to those researchers who are attempting to develop the most effective intelligent systems by squeezing the maximum information from the simplest and most reliable sensors by means of sophisticated and effective algorithms.

In order for monitoring and control systems to become intelligent, not only for exhibition demonstrations and show presentations, but for real industrial applications, one needs to implement the leading-edge solutions for each and every component of such a system.

Combining polymetric sensing, data mining and holonic agencies techniques into one incorporated approach seems to be rather prospective if more and more research will develop appropriate theory models and integrate them into the practice as well.

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