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ADVANCED NAVAL OPERATIONS UNDER SPATIAL GRASP TECHNOLOGY

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Анотація. *У статті обговорюється організація великих розподілених морських систем на базі мережевої технології високого рівня, яка дозволяє отримувати інтегровані, холістські вирішення складних проблем у швидкозмінюваних та непередбачуваних середовищах. Матеріал частково доповідався на міжнародній конференції по Військово-морських бойових системах, яка відбулася в Лондоні, Великобританія, 28–29 липня 2015 року.*
Ключові слова: *військово-морський флот, глобальна координація, технологія просторового захоплення, мобільный інтелект, динамічні операційні інфраструктури, атака роботичним свормом, протиракетний захист.*

Аннотация. *В статье обсуждается организация больших распределенных морских систем на базе высокоуровневой сетевой технологии, позволяющей получать интегрированные, холистские решения сложных проблем в быстроменяющихся и непредсказуемых средах. Материал был частично доложен на международной конференции по Военно-морским боевым системам, проходившей в Лондоне, Великобритания, 28–29 июля 2015 года.*
Ключевые слова: *военно-морской флот, глобальная координация, технология пространственного захвата, мобильный интеллект, динамические операционные инфраструктуры, атака роботическим свормом, противоракетная защита.*

Abstract. *The paper discusses organization of large distributed maritime systems with the help of high level networking technology allowing for integral, holistic solutions of complex problems in rapidly changing and unpredictable environments. This material was partially reported at the international conference on Naval Combat Systems, 28–29 July, Park Plaza Victoria, London, United Kingdom.*
Keywords: *naval fleet, global coordination, spatial grasp technology, mobile intelligence, dynamic operational infrastructures, robotic swarm attack, missile defence.*

1. Introduction

1.1. The World Naval Fleet, History and Development Tendencies

For thousands of years, strength at sea has been one of the defining military factors of any world power [1]. Naval strength is used to respond to territorial disputes as well as enforce maritime borders and protect national interests. Today's navies are often required to operate thousands of miles away from homeports with combat not necessarily requiring line-of-sight.



a *b* *c*

Fig. 1. Modern fleet examples: a) aircraft carrier; b) navy cruiser; c) multinational fleet

The battle force ships are made up of aircraft carriers, frigates, destroyers, corvettes, torpedo boats, patrol boats, amphibious support craft, and landing craft (see Fig.1 for some examples). Auxiliary vessels are also included.

The latest tendency in the world fleet development shows that small boats are rapidly increasing in numbers. Most of the world's navy's and related coast guards and other sea services plan to add hundreds of new small boats and craft to their fleets over the next 20 years [2], see Fig. 2. These types of small and fast craft and their unmanned surface vessel counterparts are especially suited for massive distributed operations, which are dominating in new military doctrines, strategies, and tactics.

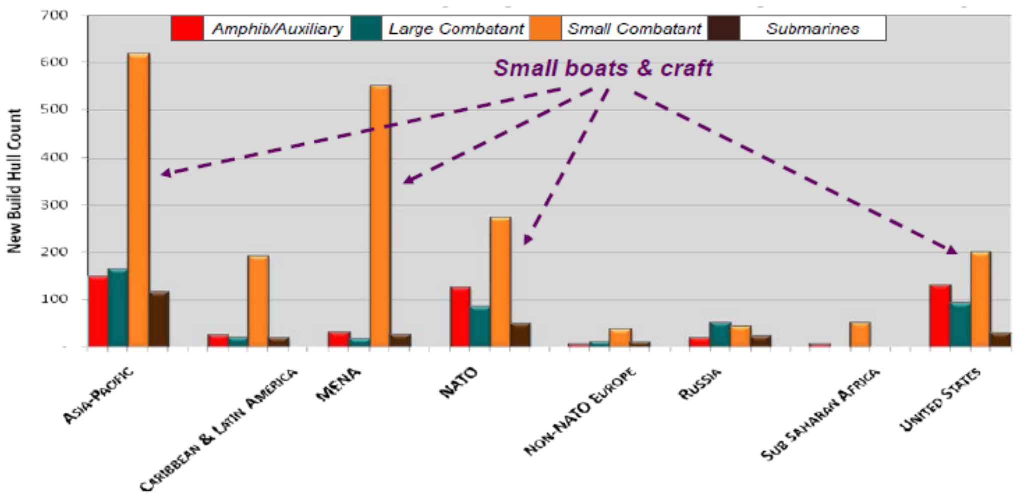
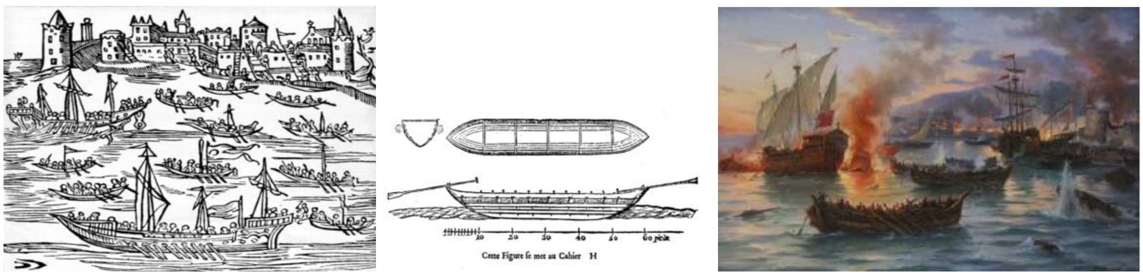


Fig. 2. Naval global market prediction

Small boats were massively and effectively used in the past too, like, for example, by Zaporozhian Cossacks (their boats called "chaikas") [3], while destroying the Turkish fleet and capturing Caffa in 1616, see Fig. 3 *a–b*. In 1635, the Cossacks fleet of chaikas was also able to defeat the Swedish fleet on Baltics, which became one of the biggest victories of Poland (Fig. 3 *c*).



a *b* *c*

Fig. 3. Some history of massive use of small boats: a) by Zaporozhian Cossacks defeating Turks; b) the "Chaika" vessel; c) victory of Poland over Swedish fleet

Massive naval operations by small vessels are increasing in popularity in modern times, see Fig. 4. For example, Iranian fast boats were used for scattered attacks during the Iran-Iraq war (See Fig. 4 *a*), and war games have been conducted recently in the Strait of Hormuz with small boats too [4], Fig. 4 *b–c*. An attack of 100 fast boats would be extremely hard to defend against (some published numbers even mentioned 10000! [5]).

a *b* *c*

Fig. 4. Small boats application: a) during the Iran-Iraq war; b) – c) war games in the Strait of Hormuz

These trends of massive use of small boats are now moving into the robotics field too. The tests on Virginia's James River (Fig. 5) are the first large-scale military demonstration of a swarm of autonomous boats designed to overwhelm enemies [6]. The boats operated without any direct human control.

Fig. 5. Massive use of small robotic boats

1.2. High Integration and Coordination Needed

Naval units, surface & submersible, manned and unmanned may be in huge numbers and spread over vast areas. How to organize them operate altogether in an integral, seamless, and global-goal-driven way, fulfilling complex objectives of the 21st century?

To cope with the increasingly diverse air and surface threats, modern platforms, either operating in a single ship configuration or within a (joint and/or combined) task group/force, will require their sensor suite and weapon arsenal to be efficiently managed. The coordination and tight integration of these resources will also be required. The following are some examples of existing efforts in this direction.

Anti-Submarine Warfare (ASW) [7] will remain a core mission area for the United States Navy. All efforts will be coordinated by FORCEnet, which integrates warriors, sensors, platforms and weapons into a networked, distributed combat force applicable across all levels of ASW. Such systems will provide pervasive awareness by way of hundreds, even thousands, of small sensing and computing devices that permeate the operating environment, yielding unprecedented situational awareness and highly detailed pictures of the battlespace.

The Persistent Littoral Undersea Surveillance Network (PLUSNet) project [8] is a program funded by the Office of Naval Research (ONR) and seeking to apply innovative and emerging technologies to demonstrate new methods for conducting naval surveillance. It incorporates mobile and persistent surveillance using new undersea vehicles and deployment techniques, improved directional sensitivity using innovative undersea sensors, adaptive feedback using adaptive ocean sampling, modelling, and forecasting, as well as autonomous detection, classification, localization and tracking of underwater signals with minimal human input.

In the rest of this paper we will describe in brief the high-level networking technology being developed for the last four decades and tested in different countries, which allows us to obtain integral, gestalt-related solutions in distributed spaces, and investigate its appropriateness for effective coordination of large naval systems.

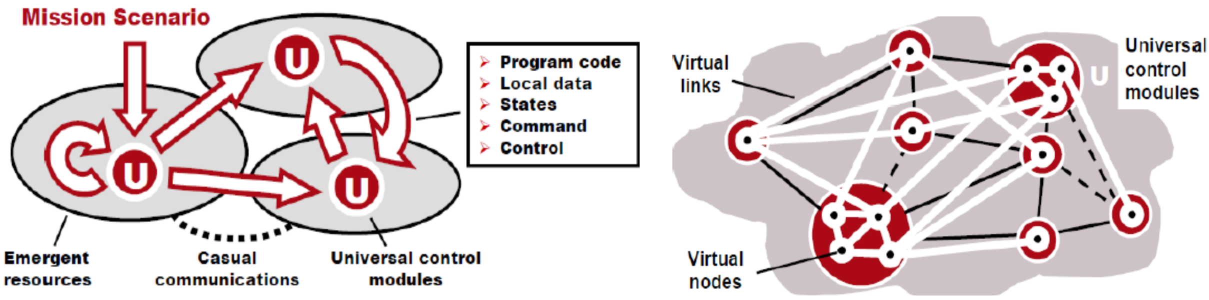
2. Spatial Grasp Technology (SGT)

SGT [9–11, also 15–20] provides full domination and control over large spaces of different natures using organized distributed sensor & effector networks. It is conceptually based on feedback-controlled seamless grasp of distributed worlds (see Fig. 6 for the main idea) versus traditional interaction of parts (agents), also of what is called “interoperability”. It has strong psychological and philosophical background, reflecting how humans mentally plan, comprehend and control operations in complex environments.

a *b*

Fig. 6. SGT main idea: a) controlled parallel grasp of distributed spaces; b) symbolic physical analogy

The technology practically operates as follows. A network of universal control modules U embedded into key system points (humans, robots, sensors, mobile phones) collectively interprets high-level mission scenarios in Spatial Grasp Language (SGL), see Fig. 7 *a*. Capable of representing any parallel and distributed algorithms, these scenarios can start from any node, covering at runtime the whole system or its parts needed with operations and control.

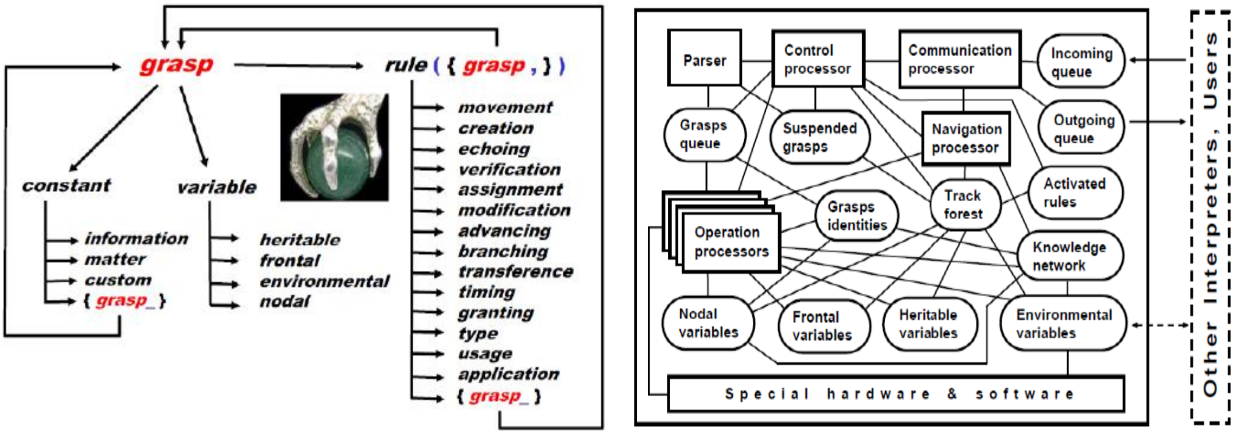


a *b*

Fig. 7. How SGT operates: a) collective interpretation of spatial scenarios,
b) creating spatial infrastructures

The spreading scenarios can create knowledge infrastructures arbitrarily distributed between system components (robots, sensors, humans), as in Fig. 7 *b*. Navigated by same or other scenarios, these can effectively support distributed databases, C2, situation awareness, and autonomous decisions. Also simulate any other existing or hypothetic computational and/or control models.

SGL language. SGL, see Fig. 8 *a*, allows us directly move through, observe, and make any actions and decisions in fully distributed environments (physical, virtual, executive, or combined). It has universal recursive structure capable of representing any parallel and distributed algorithms operating over spatially scattered data.



a *b*

Fig. 8. SGT basics: a) SGL language; b) SGL networked interpreter architecture

SGL interpreter. The interpreter, see Fig. 8 *b*, consists of a number of specialized modules handling & sharing specific data structures. The whole network of the interpreters can be mobile and open, changing the number of nodes and communication structure between them at runtime. A backbone of the distributed interpreter is its spatial track system providing global awareness and automatic C2 over multiple distributed processes.

3. Dynamic Creation of Distributed Infrastructures in SGT

SGL can create and manage at runtime a variety of active distributed infrastructures effectively providing global awareness and automatic C2 for the large naval systems.

3.1. Hierarchical Operational Infrastructure

An example of hierarchical infrastructure is shown in Fig. 9, starting from a supposed to be command centre and covering all other units, with set up infrastructure links based on closeness of units with each other.

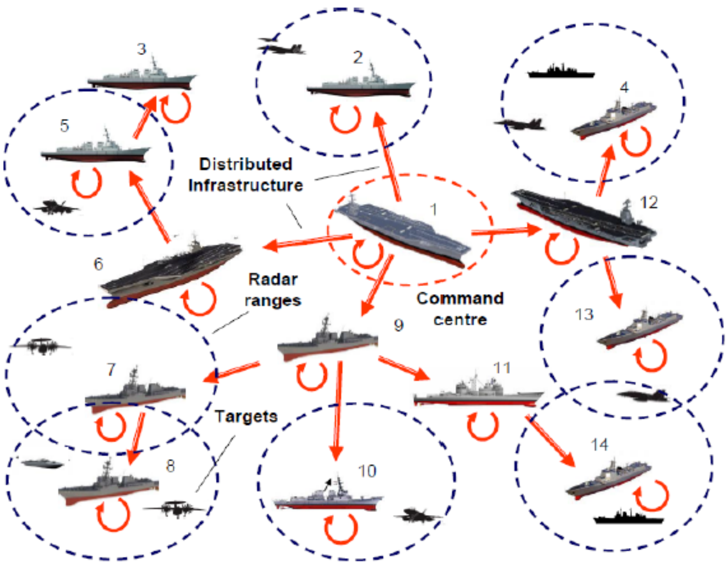


Fig. 9. Hierarchical operational infrastructure example

Distributed hierarchical infrastructure creation & operation scenario in SGL may be as shown in Fig. 10.

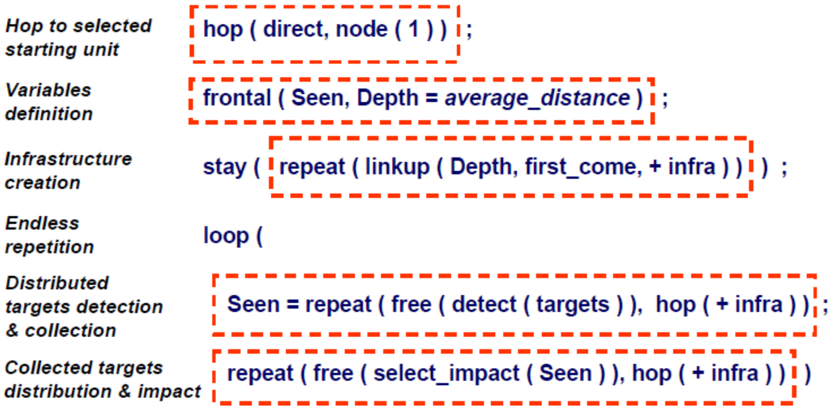


Fig. 10. Hierarchical infrastructure creation & operation in SGL

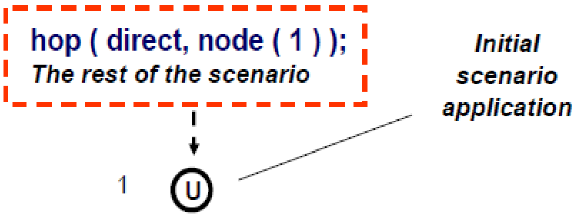


Fig. 11. Initial scenario injection

This self-evolving spatial scenario, starting from the component selected as top of the hierarchy (Fig. 11), first creates persistent hierarchical infrastructure covering all nodes (Fig. 12). It then repeatedly uses this infrastructure to collect targets throughout the whole region (Fig. 13) and disseminate them back to the units for possible individual attacks (Fig. 14).

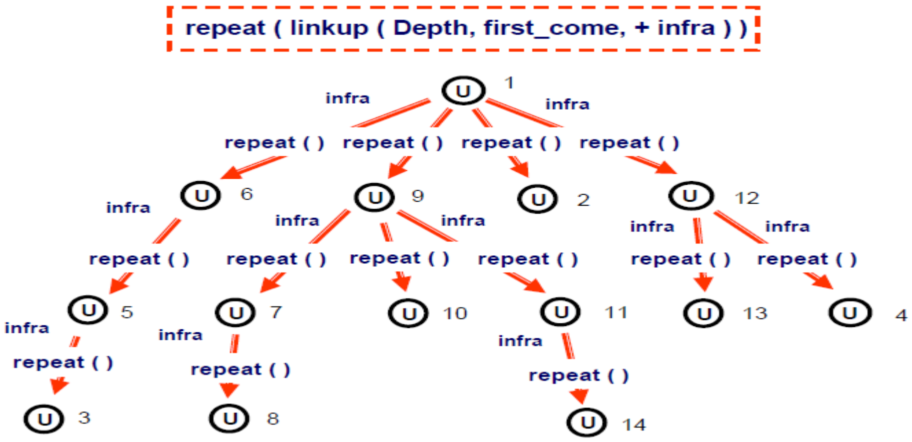


Fig. 12. Stepwise infrastructure creation

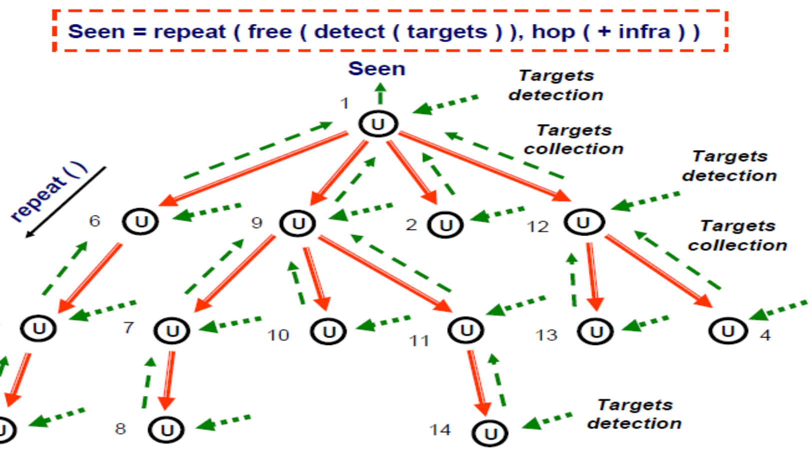


Fig. 13. Simultaneous infrastructure navigation, targets detection & collection

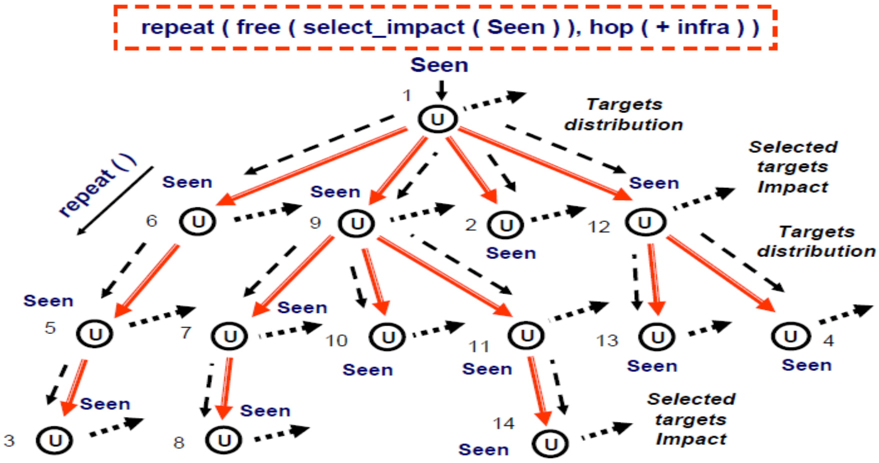


Fig. 14. Simultaneous targets distribution, selection & impact

3.2. Active Peripheral, Ring Infrastructure

An example of peripheral, or ring, infrastructure (dedicated, say, for defending the whole distributed fleet against external, outside targets) is shown in Fig. 16, and its creation & operation – by the following SGL scenario.

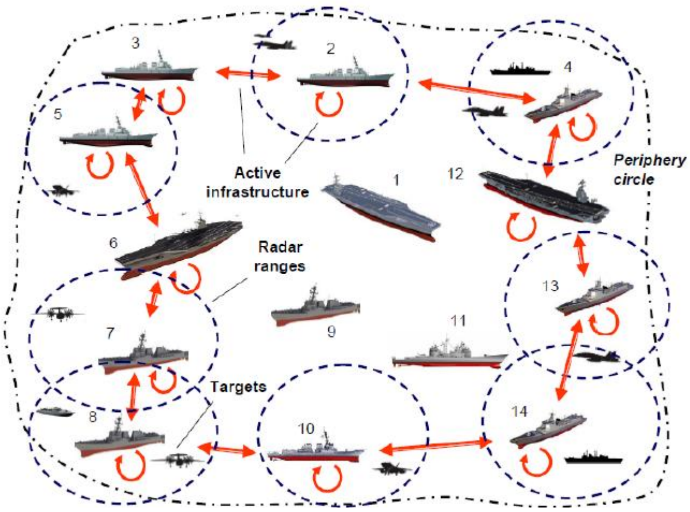


Fig. 15. Ring infrastructure example

```
frontal ( Periphery = (4, 12, 13, 14, 10, 8, 7, 6, 5, 3, 2 ), Transit );
nodal (Seen);
hop ( direct, 2 );
repeat (
  free ( loop (
      Seen = detect_merge ( targets ) ;
      select_impact ( Seen ),
      Transit = Seen; hop ( infra ); merge ( Seen, Transit ) ) ),
  linkup ( infra, withdraw ( 1, Periphery ) ) )
```

This self-evolving spatial program, starting from any periphery unit (number 2 in our case), creates ring infrastructure covering all peripheral units and operating without any central control. The growing ring infrastructure, even without waiting for full completion, begins regularly collecting & distributing targets locally seen, leaving the final choice for attacks to individual units, see Fig. 16.

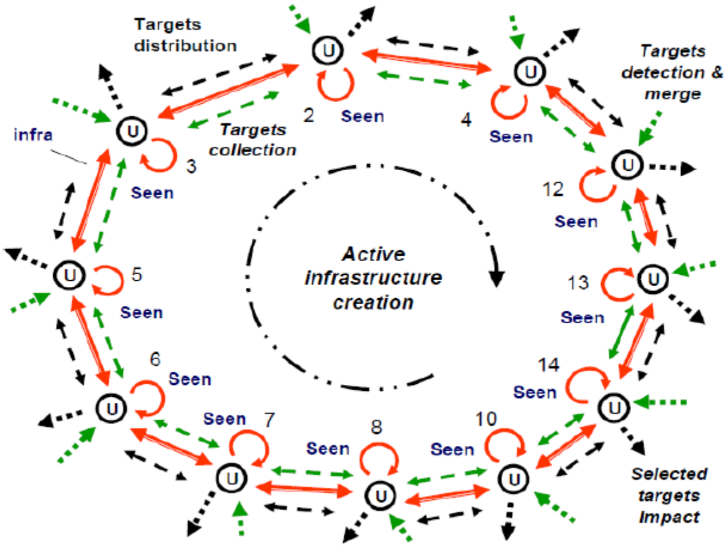


Fig. 16. Details of the ring infrastructure creation & operation

4. Robotic Swarm Attack under SGT

SGL can describe and provide global-goal-driven behaviour of large robotic swarms which can operate in a holistic manner, without any central resources. An example of initial stage of the swarm attack on distributed naval fleet is depicted in Fig. 17, which starts collective movement to the expected area.

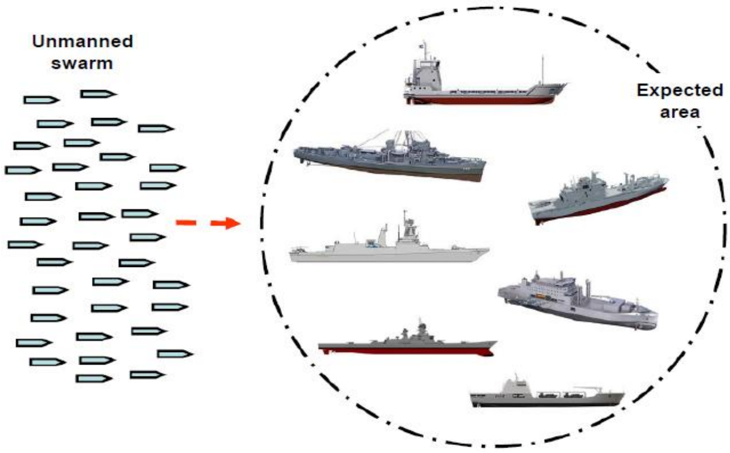


Fig. 17. Initial stage of robotic attack

The complete swarm scenario including full movement, area correction & encircling, targets collection & attacks in SGL may be as follows, see also Fig. 18.

```
hop (direct, all);
Nodal (  Area      = expected_area_coordinates,
         Limits    = next_step_guidelines,
         Range1 = allowed_distance_between,
         Range2 = vision_range,
         Range3 = shooting_range,
         Range4 = communication_range, Offer, Seen1, Seen2 );
frontal ( Transit );
loop ( Offer = randomized_next ( Area, Limits );
       if ( empty ( hop ( Offer, Range1, all ) ), shift ( Offer ) );
       ( nonempty ( Seen1  = detect ( objects, Range2 ) );
         update ( Area, Limits, Seen1 ) ); Transit = Area;
```

```
  hop ( Range4, all ); update ( Area, Transit ) ),
( nonempty ( Seen2 = detect ( targets, Range3 ) );
 impact ( Seen2 ) ) )
```

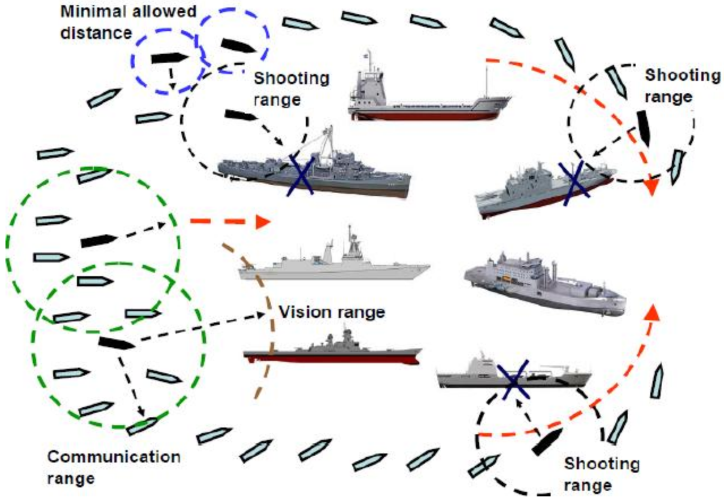


Fig. 18. Subsequent stages: swarm coordinated movement & dissipation, targets attacks

5. Withstanding Cruise Missile Attacks under SGT

SGT can effectively organize discovery, tracing, analysing, and annihilation of multiple low flying objects with unpredictable routes (like cruise missiles, see Fig. 19) by cheap distributed sensor networks operating under mobile spatial intelligence provided by the technology.

a *b* *c*

Fig. 19. Cruise Missile Examples: a) V-1 rocket was the first cruise missiles ever made; b) Tomahawk as a typical subsonic land-attack cruise missile; c) also existing a variety of super- and hypersonic missiles

Cruise missiles have several advantages over ballistic missiles; they can be updated during flight, often pursuing complex routes to avoid detection (see Fig. 20, also [12]). Their low flight altitude makes them very stealthy against air defence radars, and fuel efficient turbofan engines allow cruise missiles to be lighter and cheaper than their ballistic counterparts.

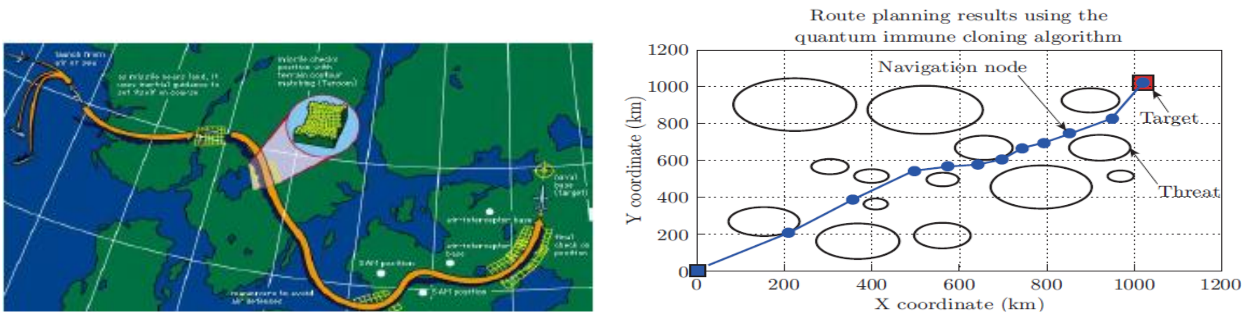
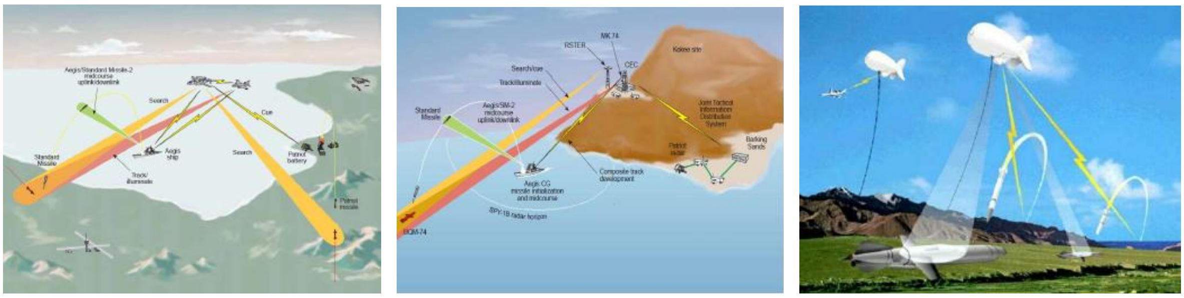


Fig. 20. Cruise missiles complex rotes

5.1. Existing Cruise Missile Defence Solutions

There are few, but not universal ones, due to the extreme difficulty of dealing with these types threats, as follows.

Aerial sensors (See Fig. 21 *a*) are the best defence against low-flying cruise missiles, because they offer far better detection and tracking range than ground-based systems. The bad news is that keeping planes in the air all the time is very expensive, and so are the aircraft themselves. Another solution is called Mountain Top [13], where high elevation points on the ground can be used to trace and target low flying missiles, as in Fig. 21 *b*.



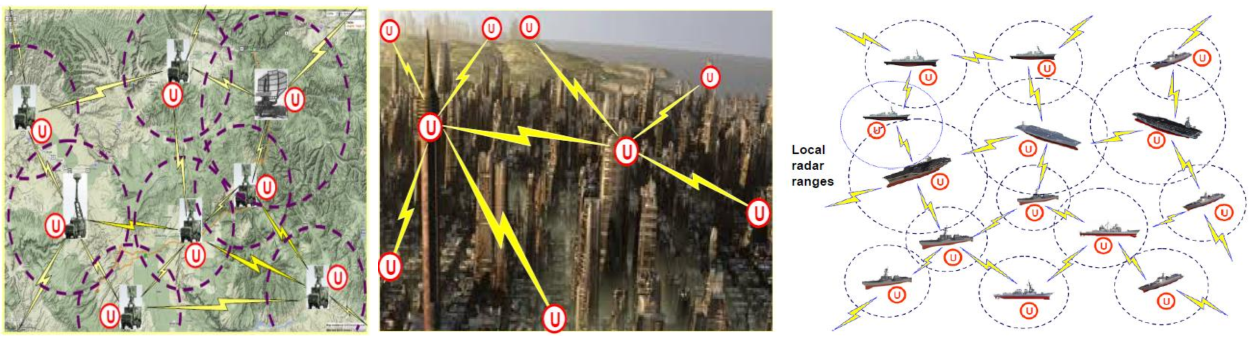
a *b* *c*

Fig. 21. Existing cruise missile defences: a) using aerial sensors; b) Mountain Top; c) JLENS

The primary challenge becomes the development of a reliable, affordable, long-flying, look-down platform. One that can detect, track and identify incoming missiles, then support over-the-horizon engagements in a timely manner. The Joint Land Attack Cruise Missile Defence Elevated Netted Sensor (JLENS) [14] looked like that system, see Fig. 21 *c*. The unmanned, tethered platforms can complement each other through the operation of both broad-area and precision radar systems, providing an over-the-horizon early warning capability. (The project already cancelled, however, due to financial constraints.)

5.2. Embedding Networked SGL Interpreters into Distributed Sensors

Embedding SGL interpreters into networked radar stations can convert the latter into universal distributed self-organized supercomputers capable of solving any problems within the space covered. These may include discovery, tracing, analysing, and destroying multiple aerial objects and low flying cruise missiles. Communicating radars can be effectively integrated with SGL interpreters in large environments of different natures and their combinations, see Fig. 22.



a *b* *c*

Fig. 22. Embedding SGL interpreters into networked sensors: a) in open land terrain; b) in urban environments; c) in maritime systems

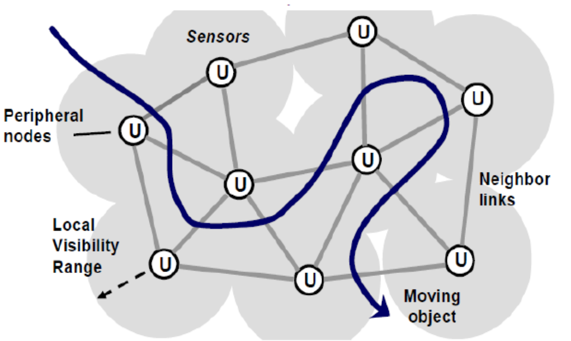


Fig. 23. Complex and unpredictable missile route

Individual sensors have limited ity range, but well organized distributed sensor networks empowered with SGT can provide continuous global vision of complexly moving objects through the space covered (see Fig. 23), with their detailed study and destruction, if required.

5.3. Distributed tracking scenario in SGL

The SGL program (with comments on its structure) is shown in Fig. 24, starting in all sensors, catches the object it sees and then follows wherever it goes, if not seen from the current point any more (i.e. its visibility becomes lower than the given threshold).

Starting in all peripheral nodes

In a peripheral node, repeatedly

Individual tracking mobile intelligence

```
frontal ( Object, Threshold = min_visibility_allowed );
hop ( nodes, periphery, all );
  whirl (
    nonempty ( Object = search ( aerial, Threshold, new ) );
    release (
      repeat (
        loop ( visibility (Object ) >= Threshold );
        max_destination (
          hop ( neighbor, all ); visibility ( Object ) );
        visibility ( Object ) >= Threshold )
    ) )
```

Fig. 24. SGL mobile tracking scenario

Some stages of the distributed object tracking dynamics are shown in Fig. 25, where the spatial intelligence following the physically moving object via virtual networked space investigates the whole surrounding region if it disappears from the current radar station – then moves to the SGL-empowered neighboring radar where it is seen best.

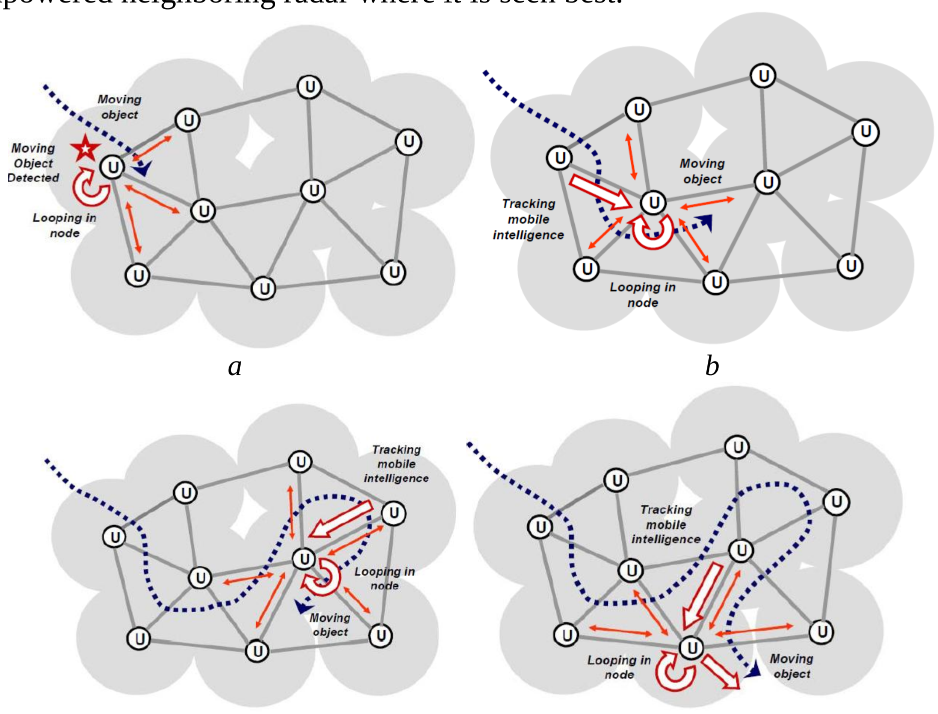


Fig. 25. Mobile intelligence following and tracing mobile physical object

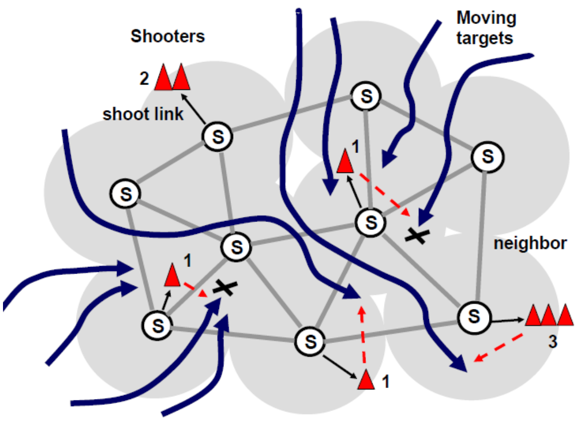


Fig. 26. Multiple targets simultaneous tracing & destruction in SGT

Multiple, coordinated attacks by low flying cruise missiles with conventional or nuclear payloads are considered at present as the most dangerous threats and challenges, to naval systems too. These can be effectively handled by mobile spatial intelligence of SGT, with global optimization and management of impact resources, as in Fig. 26.

Each new target is assigned individual tracking intelligence which will propagate in distributed virtual space following the target's movement in physical space. Different mobile intelligent branches evolving in space can cooperate with each other (also with global optimization processes, also in SGL) in finding optimal solutions to use limited impact resources. If there are available shooters in the vicinity and shooting is allowed and technically feasible, a kill vehicle can be launched against the target.

6. Other Investigated Application Areas in SGT

Intelligence, Surveillance and Reconnaissance (ISR) [15]. SGT can integrate distributed ISR facilities into flexible goal-driven systems operating under unified command and control, which can be automatic. These integrated systems can analyze and properly impact critical infrastructures, both native and adversary's, as well as create new infrastructures for a variety of purposes.

Military robotics [16]. SGT paves the way for unified transition to automated up to fully unmanned systems with massive use of advanced robotics. One of practical benefits may be effective management of advanced robotic collectives, regardless of their size and spatial distribution, by only a single human operator, due to high level of their internal self-organization and integral external responsiveness.

Human terrain [17]. SGT allows this new topic, originally coined in military, to be considered and used in a much broader sense and scale than initially planned, allowing us to solve complex national and international conflicts and problems by intelligent and peaceful, predominantly nonmilitary means, while fully obeying existing ethical standards.

Missile defense [18]. Providing flexible and self-recovering distributed C2 infrastructures it can, for example, effectively use distributed networks of cheap ground or low-altitude sensors to discover, trace and destroy multiple cruise missiles with complex routes, versus existing expensive high-altitude planes, drones, and aerostats (with an example already shown above). Other examples, also related to ballistic missiles, show the applicability of SGT for the defence against.

Command and Control [19]. Description in SGL of semantic-level military missions is much clearer and more compact (up to 10 times) than if written in NATO-related Battle Management Languages (BML). This simplicity may allow us redefine the whole scenario or its parts at run-time when goals and environment change rapidly, especially for asymmetric situations and operations, also naturally engage robotic units.

Distributed interactive simulation [20]. The technology can be used for both live control of large dynamic systems and distributed interactive simulation of them (the latter serving as a look-ahead to the former), also any combination thereof, with watershed between the two changing at run-time.

7. Conclusions

The Spatial Grasp Technology can effectively establish global control over large distributed systems, maritime ones including. It can task and re-task complex missions at runtime, on the fly, quickly responding to changing situations, goals, and environments. Due to formalized representation of missions in a special high-level language, it becomes possible to effectively automate command and control and massively use cooperative unmanned components. Concerning advanced underwater sensor networks and anti-submarine warfare, SGT, based on high-level, intelligent, semantic-type management, can reduce up to a hundred times underwater communications, which may be vital due to their natural low bandwidth.

SGT's previous variants had a number of trial implementations in different countries. The technology can be ported, on an agreement, on any software or hardware platform within short time and by small group of system programmers. A broad market is envisaged for SGT, especially in spatial intelligence, infrastructure protection, cyber and hybrid warfare, and massive cooperative robotics, both military and civil.

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