Bulgarian Academy of Sciences

Institute of Information and Communication Technologies

Department Embedded Intelligent Technologies

A B S T R A C T

of

PhD Thesis

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Group Control of Robotized means for Transport of Loads

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Introduction

The term "mechatronics" is of Japanese origin, with two aspects commonly understood in Japan:

- mechanical design, propulsion, application of sensors in sophisticated intelligent systems, taking into account the level of technology and market conditions;

- continuous training in the mechatronics of engineers.

The term "robot" is of Slavic origin. It is formed by the Czech word "robota", which means heavy and laborious labor. The Czech writer K. Chapek, in 1920, mentions mechanical robots as human engineers in the play "R.U.R" (Rosumski Universal Robots). Robots are depicted as an engineering product comparable to man in mechanical and intellectual terms.

Depending on whether they operate with objects or move toward the base, the robots are manipulative (including technological) and locomotive (mobile). Their control systems can run either on their own or via periodic commands from a supervising operator (remote control). Taking into account changes in the work environment and manipulated objects, we have adaptive robots. Depending on the application areas, we can talk about industrial and research robots. A special class is the training robots. Recently, a mixed class has evolved - serving and household robots.

In this dissertation some problems of the group control of robotic means of transporting loads are addressed. It is structured as follows:

Chapter 1. Overview, analysis and systematization of mobile robots by size, construction, purpose and control system. Examples of some of these features and their characteristics are shown.

Chapter 2. Overview, analysis and systematization of types of mobile robot group control. Examples are given with leader-follower and distributed formation.

Chapter 3. An Innovative Approach for Group Control of Mobile Robots. Examples are given with a centralized control structure, communication aspects, the Webot simulation environment is described.

Chapter 4. Experimental Results. A robotized cart for carrying luggage is presented as well as simulation results for types of group control.

Conclusions from the experiments were made and the used literature was applied.

Described are the scientifically applied contributions of the PhD student.

A list of publications is provided.

Chapter 1. Overview, analysis and systematization of mobile robots

Mobile robotics is an interesting area for exploration of types of movements and their possibilities for use in machines that have to move autonomously, often without roads, specially prepared terrain, in the presence of obstacles, narrow places, etc. One of the possible approaches to classifying mobile robot types is by way of movement. In this sense, they are wheeled, chained and walking. Motion can be continuous or interrupted. For robots with interrupted movement, we also have a climbing type. In practice, specific mobile robots are also encountered, e.g. flying, as well as mixed type. An exemplary classification of terrestrial mobile robots is given in Fig. 1.1.

Mobile robotics has been booming at the end of the last century.

In addition to remote-controlled anti-terrorism tools, early mobile robots have been created most often for research.

According to its purpose, mobile robots are grouped as industrial, research, service (household,), entertainment and transport.

According to its functional capabilities, modern mobile robots (MR) can also be defined as:

- Transport
- Information
- Manipulation
- Hybrid

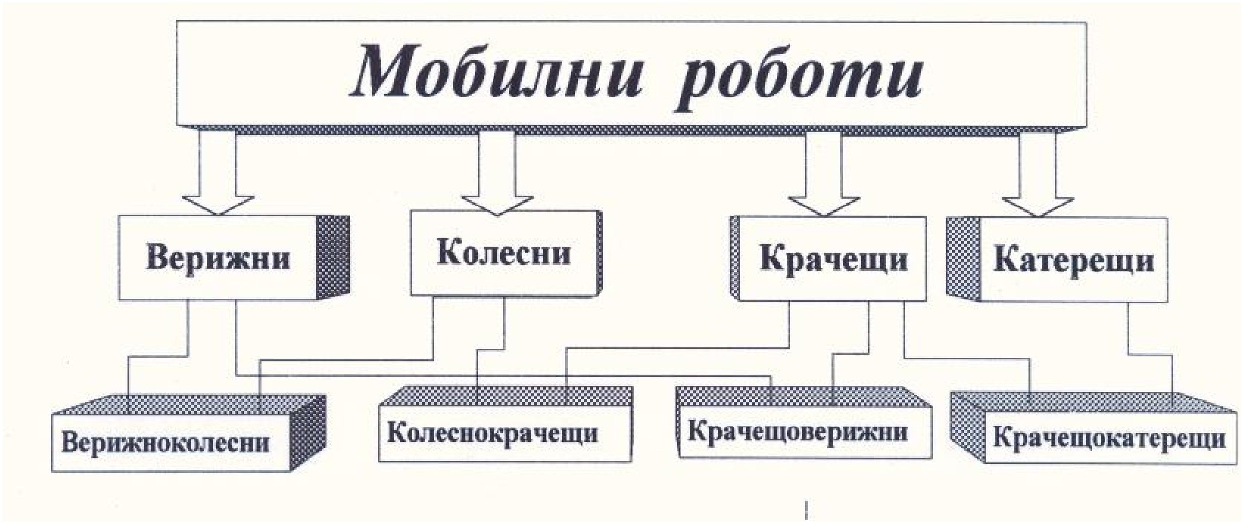

Fig. 1.1. Classification of mobile robots

Objective and tasks of dissertation:

The aim of the dissertation is to investigate the types of mobile robot group control and to offer innovative approaches for group control of mobile robots with applications for transport of loads.

To achieve this goal, the following tasks should be addressed:

1. Overview, analysis and systemization of types of mobile robots and methods and tools for group control.

2. Explore some approaches for group control of mobile robots in leader-follower and distributed formations.

3. To propose a structure, organization and composition of a group control system for mobile robots.

5. Provide innovative approaches for building robotized transport vehicles.

6. Perform experiments for group control of robotized transport vehicles in different modes. Results to be analyzed.

Chapter 2. Overview, analysis and systematization of types of mobile robot group control

Group robot control is a very increasingly applied research area. The main problems described and solved in most articles are related to the solving of the mathematical equations for control and to the creation of control algorithms.

There are different strategies and approaches that can roughly be categorized as a behavioral approach, a leader-follower approach, virtual structure, artificial potential, and column theory for control the formation of multiple mobile robots.

In a behavior-based approach, each robot is assigned several desirable behaviors (such as avoiding obstacles, avoiding collisions, attracting targets), and final control is obtained by weighing the relative importance of each behavior.

In the leader-follower approach, a robot acts as a leader that generates a reference path for the robot group, and the remaining robots in the group act as followers to maintain the desired separation and relative spacing with respect to the leader.

With the virtual structure approach, the entire formation is treated as a whole. Robot control laws are displayed in three steps. First, the dynamics of the virtual structure is determined. Then the movement of the virtual structure becomes the desired movement for each robot. Finally, the individual robot tracking controllers are extracted.

. A method for controlling linear feedback for a formation of mobile robots is presented, using a leader tracking formation and two control algorithms are presented: as shown in Fig. 2.1 and Fig. 2.2.

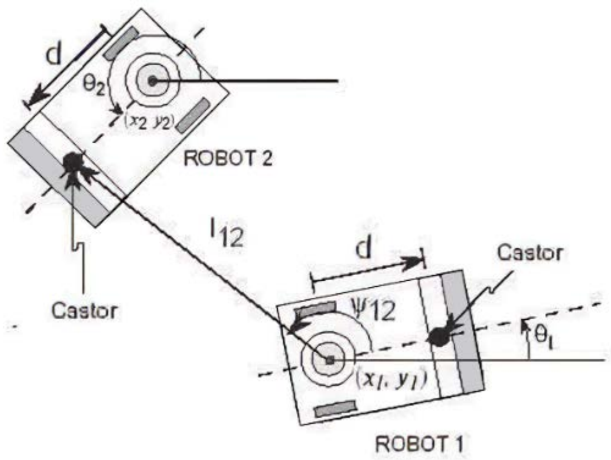

Fig 2.1. Group control with 1 lesder

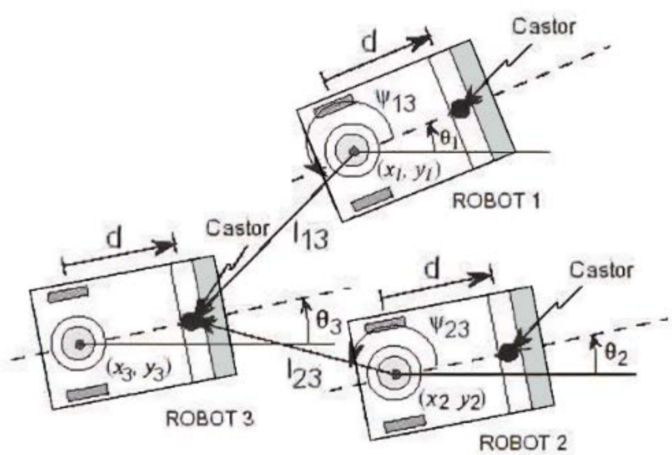

Fig 2.2. Control with 2 leaders

A system with multiple mobile robots with six F1-F6-tagged robots and one virtual leader denoted by L. is discussed. The communication graph of the multi-mobile robot system is shown in Fig. 2.3.

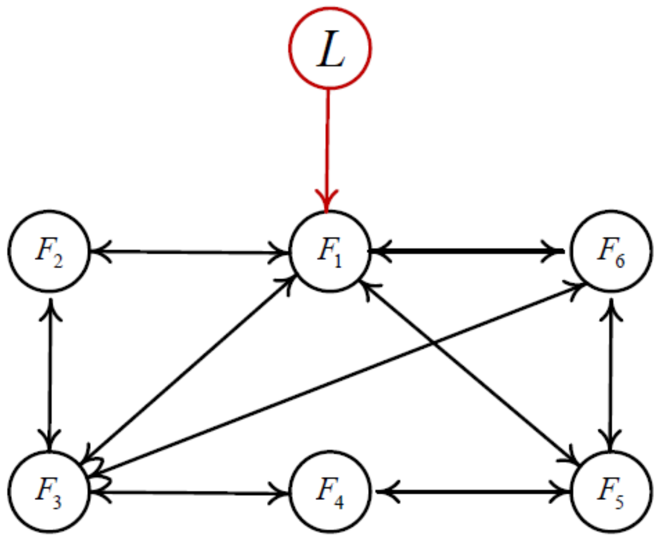

Fig. 2.3. The communication graph with six tagged robots and one virtual leader denoted.

Chapter 3. An Innovative Approach for Group Control of Mobile Robots.

Group robot control has received much attention in recent years. Several approaches to managing a robot group have been proposed in the literature.

In a behavioral group formation, group behavior (or mission) includes some low-level actions (or subtasks) and is designed to achieve the global goal where the individual robot must perform low-level actions to meet the group goal. In a leader-follower formation, a robot is designated as a leader whose movement determines the movement of the group, and the other robots are controlled to follow their leaders with the divisions and camps. In the formation of the virtual structure, robots behave like particles embedded in a rigid virtual structure. Other methods are proposed, based on artificial potentials and graph theory. A new formation approach has recently been developed, where the task of forming is formulated as a linear-quadratic differential game of Nash through the use of graphical theories. Other scientists have transferred the problem to the synchronization control problem, and a synchronous controller has been developed to convert both position errors and synchronization to zero when switching tasks. The method of retractable horizon RH, also known as Method of Advanced Predictive Control (MPC), aims to resolve optimization problems on the forecast horizon for input and limit control.

An approach is proposed combining a method of autonomous navigation and localization together with a follower management method through the developed controllers in Chapter 2.

This type of system must be able to meet the criteria for implementing a centralized structure for managing a group of mobile robots. The developed system is based on the principle of wireless communication over a Wi-Fi network. Figure 3.1 shows a block diagram of the centralized structure control system.

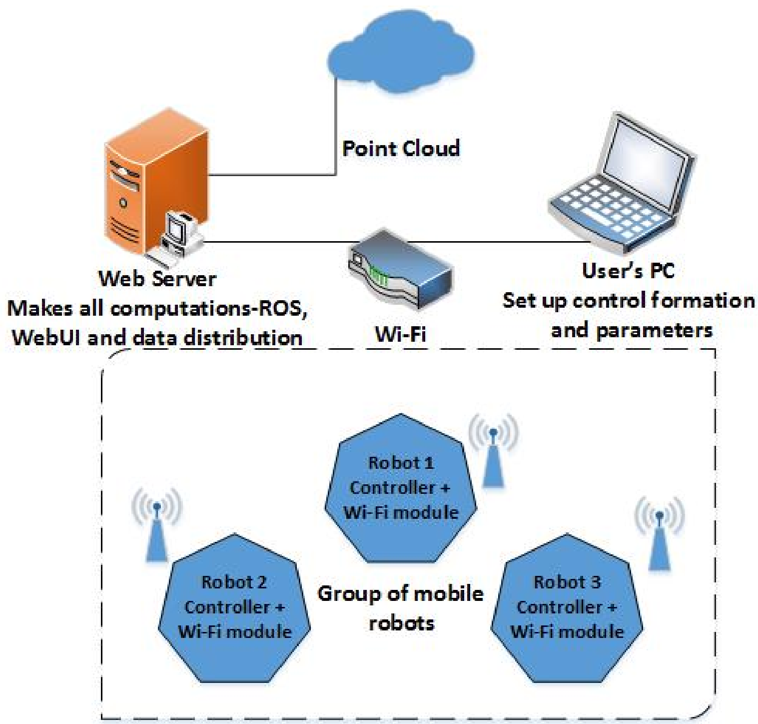

Fig 3.1. Control system for centralized structure of mobile robots

The proposed system has the following principle of operation. The leader's computer is exported in the form of an external server that has enough computing power for a large volume of calculations. And the leader himself can be any of the robot group. Leader becomes a symbolic leader to be followed. All robots connect to the wireless router and communicate with the main computer server. A local server is started on this computer to take care of data distribution and to provide a user interface for remote control. This allows for remote control and monitoring of the behavior of the robots by an external computer.

A Webot simulation environment is presented. Its parameters and capabilities are described. Viewed is the ROS operating system, how it is used and, in the ROS version for Webot.

Chapter 4. Experimental Results

4.1. Robotized transporter of loads

For the purpose of the experiment a robotized cart - cargo carrier (luggage, etc.) has been developed. The aim is, in an autonomous way, that the carrier should serve a single operator-traveler following and carrying his luggage. The robot stand, called "The Stalker", is a hands-free load carrying system that maintains a safe distance while following its operator, thus allowing its complete freedom of movement, Fig. 4.1. The aim is to automate the displacement of large and / or heavy luggage, an action encountered on every trip.

The main design of The Stalker includes a wireless connection to the owner via a handheld brass with sensors, and Stalker's respective sensors. This mechanism is programmed to follow a person and to keep a safe distance (1-2 meters). The device will have a built-in rechargeable battery that will be plugged into a charging socket, fig. 4.2.

Fig. 4.1. The Stalker

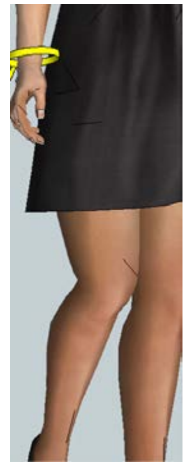

Fig. 4.2. The brass

The main components of the system are represented - engines, controllers, sensors, batteries, lights and more.

The main logic for robot control is provided by a pair of infrared transducer sensors. These devices are transceivers made to be used in pairs, which give an easy way for two robots to know where they are from each other. Sensors work by transmitting and receiving infrared light, just like a TV remote. Each sensor has four IR transmitters and four IR receivers. The sensors alternate between transmission and reception, and so they do not "confuse" their own transmission of light.

4.2. Wireless control of a group of mobile load carriers

Until recently, wireless communications had a limited application mainly related to mobile phones, but in the past 10-15 years, their convenience has pushed them to the top of the communications applications. Wireless networks, connection to specialized sensors, transmission of data related to operating parameters and many other areas where wireless communications have recently been applied.

The IEEE 802.11 standard works in accordance with the two lower levels of the Open System Interconection (OSI) physical and channel level. Any network application, protocol, or operating system can work at that location on a wireless network as well as it does on an ordinary Ethernet network. The basic architecture, features, protocols, and services are defined in the 802.11 standard, while the 802.11b specification affects the physical level, changing the rate of exchange and access to higher.

The Blootooth Consortium (IEEE 802.15.1), founded in 1998 by IBM, Intel, Toshiba and Ericsson and Nokia, has developed a standard that establishes a wireless network providing a 1 Mbit / s transfer rate. The consortium now includes more than 1,500 companies, including Microsoft, Dell, Lucent Technologies, Motorola and 3Com. Bluetooth communications take place in the 2400-2483.5 MHz frequency range.

ZigBee technology has been developed primarily for the needs of a low-cost, wireless-based solution that supports small data streams, low power consumption and reliability. This is the only standardized technology addressing the unique needs of network applications related to remote sensing and control of various sensors.

A comparative feature of standards and some wireless protocols is presented.

Other standards are also given. The ISA 100 standards refer to the construction of wireless systems in an environment used for control and automation, with their main focus being the field hierarchical level.

4.3. Simulation experiments and results

Since the construction of several mobile robotized carts to carry loads with a larger gauge and a higher weight as described in 4.1. is too expensive, we use Webot simulations for group control purposes.

The experiments conducted are in the Webots environment, which is described in Chapter 3. The experiments themselves are divided into three variants. The first type of experiment is with three robots in the leader-follower formation. The second type of experiments is with seven robots again in the leader-follower formation, and the third type of experiments is with seven robots and formation of three leaders. The forced changes during the execution of the formations are done with the mouse cursor moving a robot to different positions with different orientation.

All experiments are on the leader-follower formation, as experiment 3 is a follow-on form of a virtual leader. The control structure in all experiments is centralized - each robot is managed based on the position and orientation of a leader.

Experiment 1

The formation consists of three robots, one leader and two followers. The type of management is centralized. Figure 4.124 shows the desired formation with the assignments of each follower. Here the leader has already gone some way from his job to move around, and the followers follow him successfully.

Figure 1. 4.124

Experiment 2

The purpose of this experiment is to check the stability and behavior of the controllers for a larger group of robots with one leader. The experiment also checks the response of controllers to spontaneously alter the position and / or the orientation of the leader or change the position / orientation of one of the followers. When one of the followers is displaced, the overall shape is retained, and he immediately recovers his position until he reaches his job (Figure 4.128).

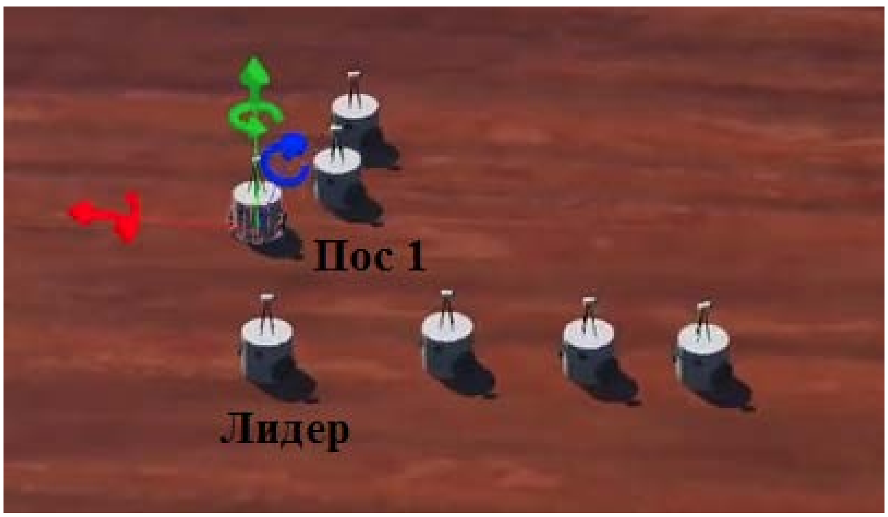

Figure 2.4.128

Experiment 3

In the third test, we modify Leader 1's position and observe the behavior of the entire robot group (Figure 4.1212, a). As a result of Leader 1's shifted position, Leader 2, who is a follower of Leader 1, is instantly moving to his new position towards him, whereby the whole movement begins to move in the direction of Leader 2. The acceleration of the followers' dynamics is watches as they strive to stand in the right positions with their leaders (fig. 4.1212, б).

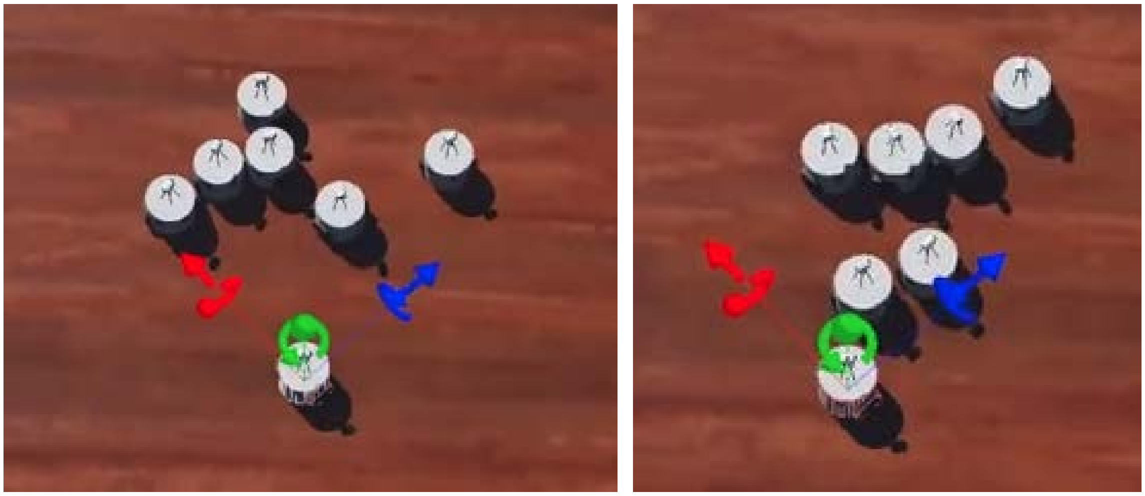

Fig . 4.1212 a) б)

Conclusion

Group robots control finds more and more applications. The proposed control systems, based on the type of mobile robot structure, enable the robot groups to expand their functions and capabilities. This leads to an increase in the scope of application of this type of robot as well as to a more practical application and use of a group of mobile robots.

Future studies are designed to make comparisons using the two systems under review (centralized and distributed) and to offer methods for their improvement.

Expected areas of application of robotized load carriers may be:

• Airports - Possible hire by traveling people

• Hotels and Resorts - For use by guests instead of porters.

• Hospitals - For the transport of equipment and medicine

• Homes for people with disabilities

• Industrial enterprises

• Warehouses and shops

• Repair workshops

• Homes for the elderly and for personal use

For broader entry of group-controlled mobile robots into industry, services and at home (beyond simulations and games between mobile robot groups), the following tasks (or improvements to existing solutions) should be addressed:

1. Most rapidly develops the miniaturization and increase of the computing power of the hardware - digital and power electronics, drives.
2. The creation of new software applications is also under way - databases, dialog systems, communication protocols, intelligent and autonomous sensors.

Other possible solutions:

3. Improvement of spatial orientation in 3D environment, not only for better orientation, but also for better manipulation of objects. More cameras, Kinect sensors, different benchmarks in the work environment are used for this purpose.
4. Improve communication between robot and operator in order to better understand and execute commands and data. To this end, methods for facial and voice recognition are being developed, incl. in different languages and dialects.
5. Improvement of methods and tools with application in mobile robotics for submitting assignments and destinations through map coordinates, addresses, etc., incl. and in 3D version (multi-level buildings, warehouses, etc.).
6. Improvement of methods and tools with application in mobile robotics for self-learning of mobile robots in static or slightly changing environment. To this end, fuzzy logic, neural networks and artificial intelligence methods are used.

CONTRIBUTIONS

In accordance with the aim of the dissertation - to investigate the types of group robots control and to offer innovative approaches for group control of mobile robots with application for loads transport, scientific and applied research was made, as a result of which the following tasks have been solved:

1. Surveys, analyzes and systematizations of types of mobile robots and types of methods and tools for group control of mobile robots were made.
2. Some approaches to group control of mobile robots type "leader-follower" and "distributed" have been explored.

The following contributions have been achieved, which are mainly scientifically-applied :

3. The structure, organization and composition of a centralized / distributed group control system for mobile robots is proposed.
4. An innovative approach to building a control system for group control using the ROS operating system and Webots simulation environment is proposed.
5. An innovative approach has been proposed for the construction of a robotized means for transporting large dimensions and weight loads.
6. Experiments and simulations have been carried out with the innovative approach and structure for the group control of robotized means of transport of loads with one leader in different modes. The results are analyzed.
7. Experiments and simulations have been carried out with the innovative approach and structure for the group control of robotized means of transport of loads with several subordinate leaders in different modes. The results are analyzed.

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