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TECHNOLOGIES FOR BUILDING SYSTEMS OF REMOTE LINING OF COMMUNICATION LINES: A PRACTICAL EXAMPLE OF IMPLEMENTATION

*The subject matter of study in this article is ways to build systems for remote laying of communication lines and solve the problem of their implementation. The goal is to simplify the process of developing robotic systems to solve applied problems. The tasks to be solved are to consider technologies of laying and to define the role of the robotic decisions used in them; consider and analyze existing compact solutions; consider existing tools and kits for rapid creation and testing of electromechanical systems; describe the features of conceptual and practical implementations of the system. According to the tasks, the following **results** were obtained. The existing methods and equipment for laying communication lines are analyzed. The types of lines placement according to the method and working conditions is considered. Standard equipment and experimental or less common equipment samples are analyzed. The results of a comparative analysis of the currently most well-known robotic solutions used to automate the placement of communications are presented. The existing robotic compact solutions the functionality of which is similar to the object of research are considered in detail. Three devices from various manufacturers designed to perform specialized tasks and has similar specificity of work including the need to move in confined spaces in the vertical and horizontal directions and deliver a payload to the destination are considered. The key differences in the considered devices including modular architecture, simplification of the electrical component of the system due to the frame, adaptability, and adaptability of the device to various environmental conditions are given. The quantitative characteristics of the devices such as the speed of movement, the size of the device itself, and its weight are analyzed. A technological stack that allows the rapid prototyping of a system with similar functions is considered and analyzed. The results of the classification of three sets for the rapid construction of a digital system with an indication of their advantages and disadvantages are given. The qualitative characteristics of development tools such as the prevalence of components, the complexity of use, and their cost are analyzed. An approach for the fast construction of a digital system based on modular reprogrammable components is proposed. **Conclusions**. The areas of application of existing solutions, the way of their implementation, and unique features that can be useful in solving the problem of placement of communications are considered. The scientific novelty of the results obtained is as follows: a unique architecture of a robot for placement of communication lines with movable segments for movement in space is proposed; a set of programmable modules as part of the developed system is presented. The process of choosing electronic components for building a system is discussed. A digital interface for interacting components and the robot as a whole is described. The possibility of reprogramming the developed robot to restore its working capacity is devised.*

***Keywords:** communication lines; mobile device; reconfiguration.*

Introduction

In modern life, the presence of electrical appliances, smart systems and devices greatly simplifies human activities at an ever-growing pace of life. Moreover, one of the disadvantages of such systems is volatility. And although mobile and economical technical solutions have been around for a long time, they still need to be recharged from a common power source. An effective way to provide power supply is the lines laid from distribution nodes to consumer devices [1].

That is why there is a need for a universal method of laying power lines and communications. It is necessary to consider already existing methods, structures and devices for performing a set of considered operations.

The purpose of this article is to simplify the process of developing robotic systems for solving applied problems. The research objectives of the article are: analysis of existing robotic solutions, systems and their development, as well as analysis of tools for the rapid construction of robotic systems.

Section 1 of this article describes the laying technologies and the role of the robotic solutions used in them. Section 2 describes the existing compact solutions and provides a comparative analysis Section 3 describes an analysis of existing tools and kits for quickly building and testing electromechanical systems. B Section 4 describes the concept of ensuring the reliability of modular systems. Section 5 describes an example of a practical implementation of a robotic system for laying communication lines.

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1. Analysis of robotic systems for laying communication lines

The process of laying communication lines, depending on the place of its implementation, differs both in technical equipment and in the organization of labor. For example, when laying a line underground, it is necessary to have pre-dug trenches or built tunnels, which in turn requires the use of heavy construction equipment. The process itself will take place due to a system of levers, a winch and a pushing cable [2]. In special cases, it is possible to use a radio-controlled traction robot following the example of the TP250 robot [3].

For laying the cable through the air, in addition to the cable itself, it is recommended to use a steel cable-base. The communication line itself is laid by firing the end of the cable from a gas gun [4].

In rare cases, a rope-walker robot can be used following the example of the ULC Robotics robot [5].

In the case of cable laying indoors and in tunnels, it is common practice to lay the cable blowing method using hydraulic or pneumatic systems based on compressors [6]. There were no cases of using robotic systems in this case.

Based on the above, we can conclude that the use of robotic solutions significantly reduces labor costs and the human factor during laying work. However, the use of existing solutions requires large material costs for equipment and advanced training of employees to work with it, which makes them economically unprofitable.

2. Comparative analysis of compact robotic systems

Among the existing automatic solutions, one can single out such projects as a robot worm called "VermiBot", developed by a group of young engineers and pupils of the Solaris robotics lovers center. Its main purpose is to carry out emergency rescue operations underground: in ditches, sewer tunnels and caves. Also, the developers consider it advisable to use the work for laying work. The main advantage of the solution is considered: ease of production and the ability to move in any plane.

The basis of such a solution is a module – an independent unit of the device, of which it is composed. The modularity of the device allows you to expand and modify the device if necessary. A distinction is made between the following modules in the device: motion module and control module. The motion module consists of plastic cross-shaped structures, driven by an electric motor. During operation, the structure changes its geometric parameters, which sets the device in motion. The control module contains the power supply and the control board. The board controls the supply of current to the motors and determines the order of operation of the motion modules.

The authors set the ultimate goal of development to improve the device for use in the space industry during the colonization of planets [7].

Another noteworthy solution can be considered a series of fast robotic worms "Inchworm", developed by the Medical Laboratory of the Israel Institute of Technology. Presented as compact piston-stroke devices. Their main purpose is to service small pipe and vessel systems in medical equipment.

The device consists of: a modified electric motor and stepping rings. The motor is equipped with a shaft with a special thread, which sets the trajectory of the vertical movement of the ring during movement. The stepping rings are equipped with weakly sliding feet on the outer side and a rod inserted into the thread on the inner side. In the future, it is planned to modify them to work in the human cardiovascular systems [8].

Finally, from the non-worm-like, you can single out the spider-robot from the Festo company. There is no direct purpose at the moment and was developed by the company with the aim of demonstrating the company's capabilities. The robot is a 15x magnified robotic replica of an existing spider from the species Capparaceae aureola.

It has a body in its construction, and 4 pairs of extremities. Able to move in two ways: by rearranging the limbs and rolling, after folding the limbs in the form of a wheel [9].

Comparison of the main characteristics of the considered examples is presented in table 1.

Table 1

Distinctive features of devices

	Speed, m/s	Length, m	Weight, g
Vermi Bot	0.1	1.3	1400
Inchworm	0.05	0.06	40
BionicWheelBot	0.5	0.55	580

The analysis shows that the area of application of the system requires the device to be tenacious, small in size and maneuverable. Of the analogs considered above, one can single out:

– modularity of the system, which allows expanding the system depending on the tasks;

– the presence of servo limbs to adapt to the environment in which the device will operate and the ability to collectivize the task by using more than one instance of the system.

3. Analysis of the technological base for rapid prototyping using modular solutions

There are platforms, platforms, sets of modules and constructors that allow you to quickly create technical solutions with minimal effort and resources. It is advisable to use them to create technical solutions for highly specialized tasks.

Among the many, the following solutions can be distinguished:

1. IQBX is an electromechanical construction set made of hollow blocks and modules that can be connected to them.

The basic blocks of the set include: hollow structural (single-section and multi-section), accumulator blocks, blocks with electronics and drive blocks with a built-in motor-reducer. In addition to the basic blocks, the set contains fasteners, Lego-compatible adapters and cable loops for connecting electrical and electro-mechanical parts to each other [10];

2. Lego Technic – line of compatible Lego plastic rods, electrical modules and mechanical parts.

Such kits often contain the following types of parts: beams and plates for the frame, gears and axle pins, pneumatic elements, modules with pin connections, and servos, power supplies [11].

3. Arduino – a set of open source hardware and software for building simple automation and robotics systems.

The set is a wide range of electronic components, microcontrollers of various capacities and shapes, ready-made devices with unified interfaces and mounting methods [12].

For the kits described above, you can compare the characteristics presented in the table 2.

Based on the above, we can conclude that available technological solutions can provide a sufficient element base to cover most technological problems. Depending on the requirements [13] for the systems being developed, the sets can be combined with each other in order to compensate for each other's shortcomings.

4. Providing the possibility of reconfiguring modular systems at the design stage

In most technical solutions, the reliability indicator plays a significant role. Often, its basic indicators are achieved by selecting high-quality components and introducing safety blocks. However, in systems of particular importance, a system of reserves for vital nodes is introduced.

In normal mode, the reserve can be fully used (hot reserve), due to which the total load on the system is partially reduced, or partially (warm reserve), in which part of the intended functions of the module remains unused.

The boards and components discussed in the previous sections, due to their prevalence, are factory solutions. This means that the process for their production and pre-assembly is standardized. In turn, standardization provides high basic reliability due to quality components.

Table 2

The main advantages of tool kits

Technology	**Advantages**	**Disadvantages**
IQBX	− presence of strong elements for a design; − a large variety of executive modules; − availability of standardization of modules; − compatibility with other platforms.	− high cost of components; − no gradation in the size of the components; − limited circulation and difficult access to the market; − complex for assembling.
Lego Technic	− high availability of components worldwide; − great variety of executive modules; − easy for assembling.	− high cost of components; − fragility of components; − low compatibility with other platforms.
Arduino	− low cost of components; − high availability of components worldwide; − simplified programming language; − intuitive extensible development environment; − availability of ready-made solutions for sensors and actuators; − a large number of solutions in open access (popular in the community).	− lack of optimization in standard libraries; − the inability to use all the resources of the microcontroller when using libraries.

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Also, for versatility and high compatibility, redundancy of ports, circuit elements and power lines is introduced into many components. This redundancy allows you to increase the resource of the device at the design stage.

In addition to the known methods of ensuring reliability, it is proposed to use the possibility of reconfiguring technical systems as a means of partial restoration of functionality in the event of their failure. For this case, it is assumed that the segments of the system are distinguished and their gradation according to the degree of importance and the grouping according to the similarity of the element base.

In this case, it becomes possible to use elements of less important segments of the system as a reserve for segments with higher priority.

Also, manual modification of such blocks is not excluded in order to expand their potential as a component of the system. An example is the expansion board for the UART-USB converter module, which implements additional transmitter controls [14].

5. Case study of robotic system implementation for remote lining

The considered solutions and system development tools based on standard modules are used to build a robotic system for laying communication lines. In the practical implementation of the system, it is assumed to use the modular principle of constructing the entire system.

Each module is equipped with a set of standard functional elements, namely:

– electric motors (EM) used to drive hinged and screw structures;

– harness systems (HS) for contact with the surface in the working area;

– strapping structures (SS) for holding the device in the required position and converting the rotary type of movement into a translational;

– motor control drivers.

In addition to the elements that allow the frame to be set in motion, each module contains a part of the distributed control and navigation system of the device.

During the assembling of device, the modules are connected in series and together form an electromechanical frame, shown in Figure 1.

The list of elements located on the device (Figure 2) includes:

– video camera unit (Cam) responsible for capturing the image in front of the device [15];

– accelerometer and gyroscope unit(A/G);

– peripheral board unit (PB) responsible for receiving and transmitting data between the device and the operator;

– central board unit (CB) for frame control and parts coordination.

This allows the operator to adjust the device to work in different conditions [16], arranging the modules in a convenient order for work.

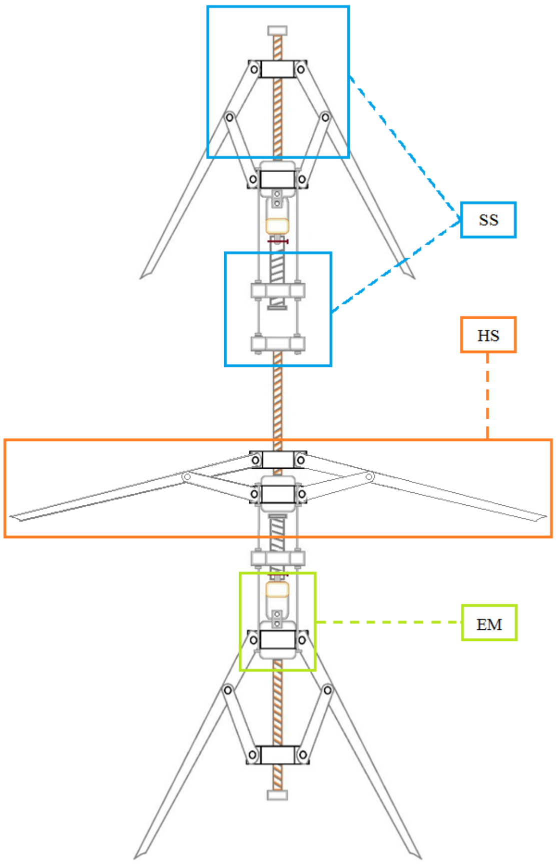

Figure 1. Electromechanical frame

To effectively control and organize the operation of the device, a wireless module with a UART interface is used. The bandwidth of such a channel is sufficient for remote control and configuration of the device.

This will greatly simplify the task of management and coordination, and also open up the opportunity for organizing joint interaction of a group of devices at a low level.

The device assumes the presence of feedback with the operator in the form of a real-time camera, backlight and a web interface for comfortable work from any device.

Conclusions

The mobile technologies are widely used in modern life, and the implementation of onboard devices with rapid prototyping based on predeveloped universal blocks is a big step for fast development of robotic systems including automated remote laying of communication lines. The introduction of such a system is advisable, since the use of such systems makes it possible to automate the process of pulling and positioning the cable with minimal human involvement.

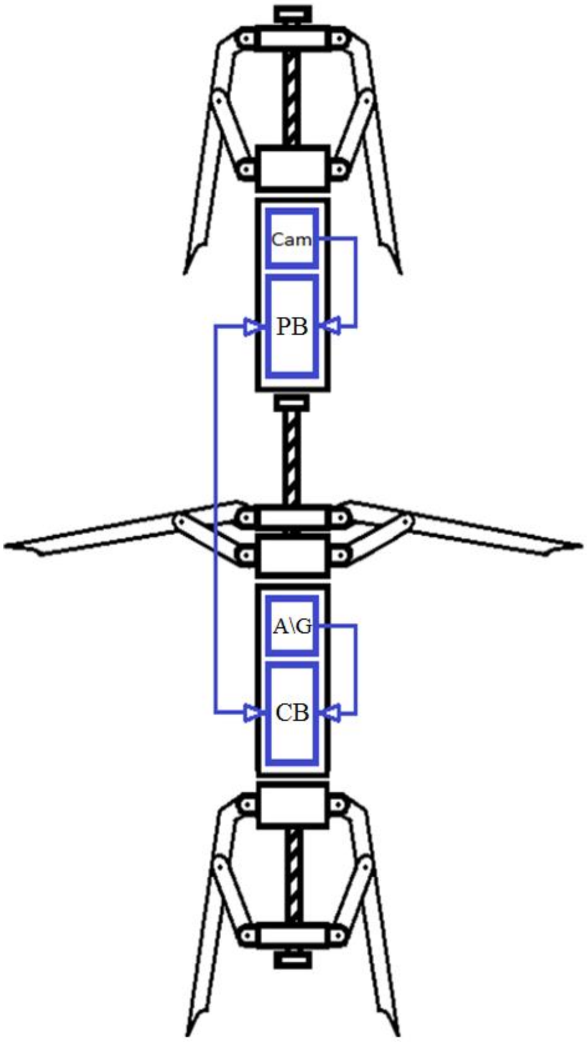

Figure 2. Location of control modules

It was shown that the real hardware system can be prototyped and assembled using standard modules. Among the advantages of such approach it is possible to mention stability of the tested modules, ability to use such building blocks for distributed and remote development across the entire world, wide support of community in the Internet and the IDE with hundreds of libraries for peripheral sensors and actuators.

The popular development kits were compared with providing analysis results and advantages for each of them. Defiantly the Arduino environment and the set of boars is the most popular at the moment and include AVR, STM and another chips.

The lowest price for such blocks is also important reason for usage of suck blocks for rapid prototyping the system with it.

The subsystems for controlling the device for remote laying of communication lines were developed and tested. The possibility of introducing extra features for the reliability of the entire system in the management programs of these subsystems is outlined.

The topics closely related and necessary for the development of this project were also considered, the existing solutions were investigated and the basic requirements for the device were made. In particular, it concerns critical communications [17].

In future versions of the device, it is planned to develop specialized replaceable modules for specific surfaces, environments and working conditions.

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ТЕХНОЛОГІЇ ПОБУДОВИ СИСТЕМ ДИСТАНЦІЙНОГО ПРОКЛАДАННЯ КОМУНІКАЦІЙНИХ ЛІНІЙ: ПРАКТИЧНИЙ ПРИКЛАД ВПРОВАДЖЕННЯ

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Предметом вивчення в даній статті є способи побудови систем для дистанційної прокладки ліній комунікації та вирішення завдання їх впровадження. **Метою** є спрощення процесу розробки робототехнічних систем для вирішення прикладних завдань. **Завдання**: розглянути технології укладання і визначити роль використовуваних в них роботизованих рішень; розглянути і проаналізувати існуючі компактні рішення; розглянути існуючі інструменти та комплекти для швидкого створення і тестування електромеханічний систем; описати особливості концептуальної та практичної реалізацій системи. Відповідно до поставлених завдань, були отримані наступні **результати**. Проаналізовані існуючі методи та обладнання для прокладання ліній комунікації. Розглянуто види прокладання згідно зі способом та умовами праці. Проаналізовано як стандартне обладнання, так й експериментальні, або малопоширені його зразки. Наведено результати порівняльного аналізу найбільш відомих на даний момент роботизованих рішень, що використовуються для автоматизації прокладки комунікацій. Детально розглянуті існуючі роботизовані компактні рішення, функціональність яких схожа з об'єктом дослідження. Розглянуто три пристрої різних виробників, розроблених для виконання спеціалізованих завдань, які володіють схожою специфікою роботи, включаючи необхідність пересування в замкнутому просторі в вертикальному і горизонтальному напрямках і доставкою до місця призначення корисного вантажу. Наведено ключові відмінності розглянутих пристроїв, включаючи модульну архітектуру, спрощення електричної складової системи за рахунок каркасу, адаптивність та пристосованість пристрою до різних умов навколишнього середовища. Проаналізовано кількісні характеристики пристроїв, такі як швидкість пересування, розмір самого пристрою та його вага. Розглянуто і проаналізовано технологічний стек, що дозволяє здійснити швидке прототипування системи зі схожими функціями. Наведено результати класифікації трьох наборів для швидкої побудови цифрової системи із зазначенням їх переваг і недоліків. Проаналізовано якісні характеристики інструментів розробки, такі як поширеність компонентів, складність використання та їх вартість. Запропоновано підхід швидкої побудови цифрової системи на основі модульних компонентів які допускають перепрограмування. **Висновки**. Розглянуто області застосування існуючих рішень, спосіб їх реалізації та унікальні особливості, які можуть бути корисні при виконанні завдання прокладки комунікацій. Наукова новизна отриманих результатів полягає в наступному: запропоновано унікальна архітектуру робота для прокладки з рухомими сегментами для переміщення в просторі; наведено набір програмованих модулів в складі розробленої системи. Обговорюється процес вибору електронних компонентів для побудови системи. Описується цифровий інтерфейс для взаємодії компонентів і робота в цілому. Формулюється можливість перепрограмування розробленого робота для відновлення працездатності.

Ключові слова: лінії комунікацій; мобільний пристрій; реконфігурація.

ТЕХНОЛОГИИ ПОСТРОЕНИЯ СИСТЕМ ДИСТАНЦИОННОЙ ПРОКЛАДКИ ЛИНИЙ КОММУНИКАЦИИ: ПРАКТИЧЕСКИЙ ПРИМЕР ВНЕДРЕНИЯ

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Предметом изучения в данной статье являются способы построения систем для дистанционной прокладки линий коммуникации и решение задачи их внедрения. **Целью** является упрощение процесса разработки робототехнических систем для решения прикладных задач. **Задачи:** рассмотреть технологии укладки и определить роль используемых в них роботизированных решений; рассмотреть и проанализировать существующие компактные решения; рассмотреть существующие инструменты и комплекты для быстрого создания и тестирования электромеханических систем; описать особенности концептуальной и практической реализаций системы. Согласно поставленных задач, были получены следующие **результаты**. Проанализированы существующие методы и оборудование для прокладки линий коммуникации. Рассмотрены виды прокладки согласно способу и условиям труда. Проанализировано как стандартное оборудование, так и экспериментальные, или малораспространенные его образцы. Приведены результаты сравнительного анализа наиболее известных на данный момент роботизированных решений, используемых для автоматизации прокладки коммуникаций. Детально рассмотрены существующие роботизированные компактные решения, функциональность которых схожа с объектом исследования. Рассмотрены три устройства различных производителей, разработанных для выполнения специализированных задач и обладающих схожей спецификой работы, включая необходимость передвижения в замкнутых пространствах в вертикальном и горизонтальном направлениях и доставкой в место назначения полезного груза. Приведены ключевые отличия рассмотренных устройств, включая модульную архитектуру, упрощение электрической составляющей системы за счет каркаса, адаптивность и приспособленность устройства к различным условиям окружающей среды. Проанализированы количественные характеристики устройств, такие как скорость передвижения, размер самого устройства и его вес. Рассмотрен и проанализирован технологический стек, позволяющий осуществить быстрое прототипирование системы со схожими функциями. Приведены результаты классификации трех наборов для быстрого построения цифровой системы с указанием их преимуществ и недостатков. Проанализированы качественные характеристики инструментов разработки, такие как распространенность компонентов, сложность использования и их стоимость. Предложен подход быстрого построения цифровой системы на основе модульных перепрограммируемых компонентов. **Выводы**. Рассмотрены области применения существующих решений, способ их реализации и уникальные особенности, которые могут быть полезны при решении задачи прокладки коммуникаций. Научная новизна полученных результатов состоит в следующем: предложена уникальная архитектура робота для прокладки с подвижными сегментами для перемещения в пространстве; приведен набор программируемых модулей в составе разработанной системы. Обсуждается процесс выбора электронных компонентов для построения системы. Описывается цифровой интерфейс для взаимодействия компонентов и робота в целом. Формулируется возможность перепрограммирования разработанного робота для восстановления работоспособности.

Ключевые слова: линии коммуникации; мобильное устройство; реконфигурация.

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