БЪЛГАРСКА АКАДЕМИЯ НА НАУКИТЕ • BULGARIAN ACADEMY OF SCIENCES

ПРОБЛЕМИ НА ТЕХНИЧЕСКАТА КИБЕРНЕТИКА И РОБОТИКАТА, **65**
PROBLEMS OF ENGINEERING CYBERNETICS AND ROBOTICS, **65**

София • 2012 • Sofia

Tracked Locomotion and Manipulation Robots

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Abstract: *The article presents an overview of high-mobility ground platforms and robots with an accent on high-mobility tracked robots. An overall classification of robots is made according to their work environment and the scale of their locomotion mechanisms and tasks. More than 35 different highly mobile tracked platforms and robots are analyzed and compared by their physical dimensions, weight, payload, locomotion system, speed, battery type, operations time, sensors, manipulators and Degree Of Freedom (DOF).*

Keywords: *Mobile robot, unmanned ground vehicle, tracked platforms, environment investigation.*

1. Introduction

Mobile Robots (MR) are technical systems with a wide range of capabilities and a variety of applications. The main importance in their classification (Fig. 1) is given to the kind of *work environment*, the *scale* of their locomotion mechanisms, as well as to the *tasks* of the robot [1].

The functionalities (*tasks*) of MR define them as:

- *Mobile Platforms* (MP) for transporting and observing objects and measurement of environment parameters;
- manipulator mobile robots used for an active impact on objects (technological operations, taking samples and specimens) [2];
- *hybrids* between the above functional groups.

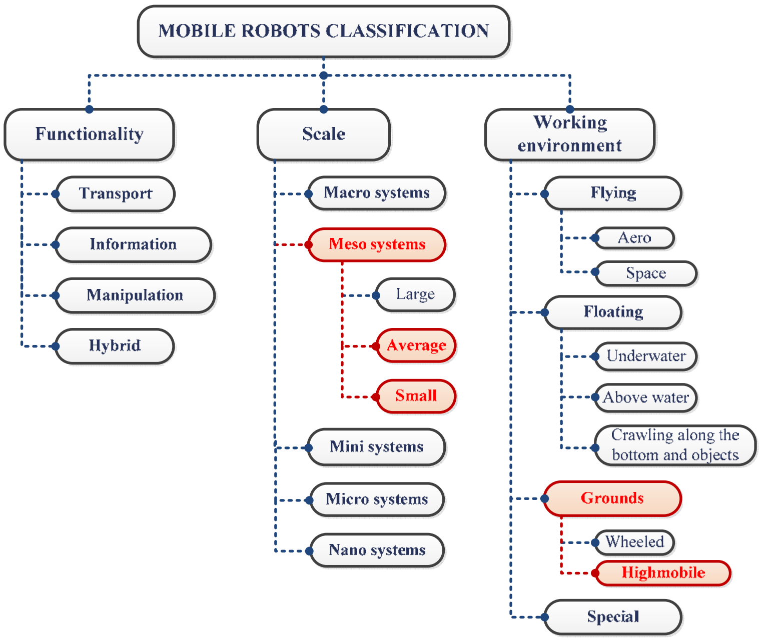


Fig. 1. Mobile robots classification

The MR sizes, as well as the amount of movement of the locomotion mechanisms, naturally define the systems as *macro*, *meso* and *mini*. The development of MEMC technologies has created the foundations for building *micro robots*, as well as prospects of *nano* systems. The variety of meso systems (such of anthropomorphic dimensions, motions and objects) requires an additional classification of them as *small*, *average* and *large* MR.

The specifics of work environment are structurally important for the differentiation of the following basic classes:

- *flying systems* with 6 DOF in the atmosphere and in space;
- *underwater* – with 6 stages of DOF and specific capabilities of moving on the bottom, underwater objects and also on the surface;
- *special* – for moving inside pipes and along power lines, moving with gripping, suction to walls and ceilings, digging into loose structures, moving inside organisms, etc.;
- *ground* – for moving on a surface (up to 3 stages of DOF) in conditions of gravitation and friction.

The above robots use natural grounds, roads, streets, playgrounds, including underground tunnels, as well as ducts in buildings and engineering systems.

This article summarizes the class of the high-mobility ground MR of small and medium type, which have universal capabilities and can be used for a wide range of tasks. This paper analyzes the construction properties of the track MP, as well as the technical trends for development of the basic samples equipped with a manipulator. Particular attention has been taken on the integration of the manipulation and locomotion movements and systems.

2. High-mobility ground robots

Current ground robots are a particular class of universal systems that can be applied to a range of different activities:

- workshop and warehouse transport, information and transport tasks and cleaning during the processes of manufacturing and servicing;
- analysis and working in dangerous environment, during natural disasters and cataclysms, military and security tasks;
- laboratory research and training.

While the first group includes specialized and relatively cheap robots, the second one consists of multifunctional *high-mobility systems with remote control*. In this case, the complexity, variety and dynamics of the environment and tasks require commands to be issued by a specialized operator or by a specialized team used for observation, analysis, making decisions and leading MP.

The scene of work apparatus includes:

- building premises and technical facilities (industrial and transport);
- urbanized regions (buildings, yards, canals, tunnels, roads, grounds and railways);
- variable landscape and surface.

The abundance of artificial, flat, smooth and solid foundations (floors, streets and grounds) enables fast and energy efficient movement by wheeled mobile platforms with conventional constructions: three-wheeled-differential; classical four-wheeled, one- and two-wheeled balancing. These systems are simple but they only enable circumvention (going round) obstacles in a plain.

Extending the tasks, profile and the kind of base, as well as the variety of obstacles in space, requires high-mobility robots of the following classes to be used (Fig. 2):

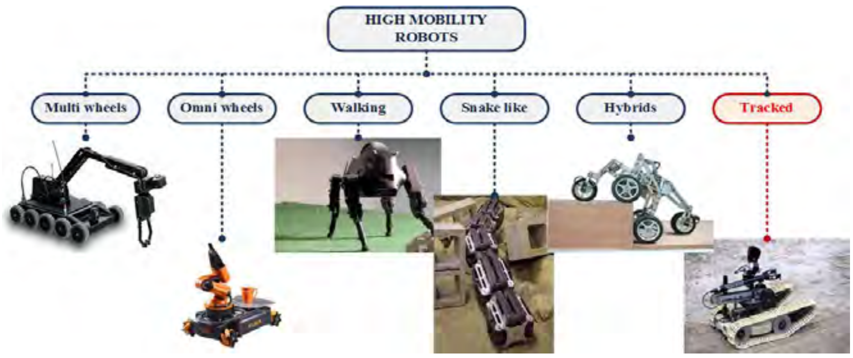


Fig. 2. High-mobility robots classification

- *multi wheel* with four, six, ten [22] active wheels and omni-wheels [3];
- *walking*, with high adaptability to the ground [4]
- *snake like* (hyper redundant) locomotors [5];
- *tracked* , which are basic in this analysis;
- *hybrid*: wheel-walking [6], walking-wheeled, walking-tracked, wheel-tracked, etc.

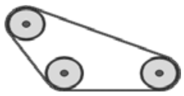
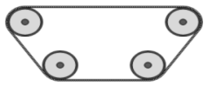
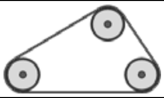
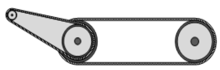
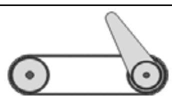
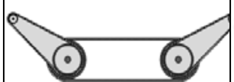
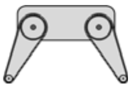
Tracked MP and MR are the most common systems used in research tasks and risk operations.

3. Tracked mobile platforms

Tracked mobile platforms have proven advantages to wheel based ones when moving on low contact pressure grounds (loose soil, deep mud, fresh snow) and various rough surfaces. They are represented by a construction variety shown in Table 1. The most common one is the group of two-track MP with a differential drive. The compact mini MP (1) with mass of up to 5 kg, is distinguished by its small dimensions and weight as well as a high reliability and resistance.

The increase of the mobility of MP can be done by lengthening the chains or by changing their shape. This is achieved through adding one or more passive tensioning wheels, a modifying the form of the suspension or trough lifting of the drive wheels axis.

Table 1. Tracked platforms classification

No	Group MP	Track scheme	Platforms, name
1	Mini tracked		 EyeDrive [24]
2	Long tracked		 MMP-40T [25]
3 / 3.1	Tracks with improved mobility		 Element [26]
3 / 3.2			 Robotnik Rescuer [27]
3 / 3.3			 Johnny 5 [7]
4	Active flippers		 510 PackBot [8]
5	Passive flippers		 FirstLook [23]
6	Six-tracked		 Silver [9]
7	Walking crawlers		 AZIMUT [10]

Military robots 510 PackBot use active flippers (4) – auxiliary chain elements elongating the main chain. Such a configuration greatly increases the height of obstacles which can be overcome. MP – 110 FirstLook includes passive flippers (5), which enables flipping of the robot during movement. MP – Ratler [11] has the ability to change the angle of crossing of the chains and in this way it improves the mobility on highly rough terrains. Additional elements require 1-2 additional motors to be added apart from the principal ones.

Improving movement on complex terrains can also be achieved through four basic chains, which are mobile towards the body of the platform [12-14]. MP – Silver is a sample of the six-track (6) MP, which have a two-chain locomotion system, additionally widened on both sides by four active flippers. Increased mobility of MP – Chaos [12] is due to its module undercarriage, which, according to the situation can be: chain, wheel, walking or hybrid.

MP – AZIMUT has a clear chain-walking (7) structure through articulating integration of the four end chain elements. Four engines are used for the chains and another four for their articulation.

Another group of chain MP [15, 16] is characterized by the ability to actively change the shape of its chain mechanism in order to improve the cohesion when moving on various terrains. These are also defined as chain systems with variable geometry.

In recent years there is also development of mono-chain MP. Created in Carnegie Mellon University, AURORA robot [14] contains only one flexible and elastic strap. The idea is being developed with flexible chains and multi-chain systems [17] of such modules. The trouble with such assemblies is the difficulty of situating the payload.

4. Tracked robots

The mobile platforms can serve as transport and for data acquisition. By adding to them one or more multifunctional manipulators with specialized tools and grippers [8], a universal MP is achieved. In Table 2 the technical features of 10 such mechanisms are summarized. Their application is essentially in research tasks and in operations in hazardous environment. Mainly two-chain [29-34] and four-chain [8, 35] systems are included. Module assemblies offer a constructive variety, but the integrated assemblies are more functional and efficient.

In the table the technical characteristics are compared of two groups of a group of robots: small and medium MP of own weight respectively in the range of 6,35-85 and 100-375 kg. Their dimensions are in the range of: length – 422-1473 mm, width – 30-780 mm and height with a taken in manipulator – 152-1240 mm. Maximum movement speed can divide them into two groups: slow (up to 1 m/s) and fast (1.0 – 2.2 m/s). Their power systems include accumulators: lead, nickel and lithium with a capacity of 7.2 – 13 Ah, providing autonomous operating time within 2-10 hours range. Remote control is achieved through a cable (incl. optical), through RF (Radio Frequencies) which is mainly used for data and for Wi-Fi connection for video signals. To observe the environment and the objects in it, as well as for navigation, RTZ (Pan, Tilt and Zoom) IR (Infra Red) and CCD (Charge-Coupled Device) colour and black-and-white cameras with laser guidance and autofocus are used. When in the regime of wired tethering, robots are directed through a system with one or more joysticks. Manipulators have 3-8 DOF.

Table 2**.** Technical specification of analyzed tracked mobile robots

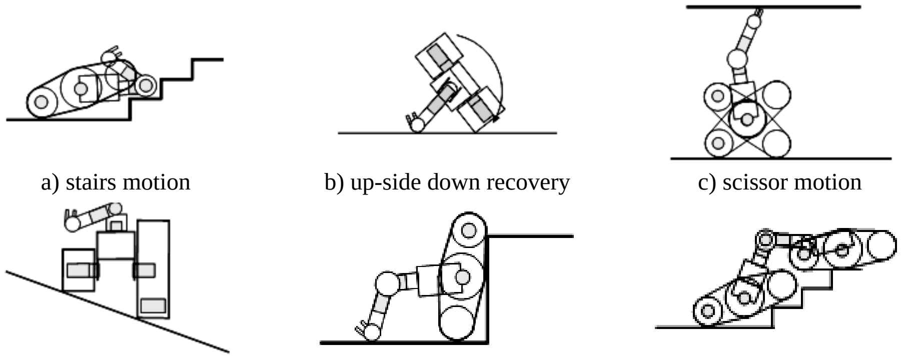
			Locomotion system					Energy system		Control		
No	Robot	Institu-tion	Dimen-sions	Weight	Payload	Traction	Speed	Power supply	Operati-on time	Sensors	Remote Control	Manipu-lator
			L/W/H, mm	kg	daN		m/s		h			DOF
1	Dragon Runner [31]	Qinetiq	422/310/ 152	6.35	4.5	n/a	2.3	n/a	n/a	PTZ camera	Wi-Fi	4
2	510 PackBot [8]	iRobot	686/406/ 178 with flippers 889/521/ 178	10.9**	45.4	n/a	2.6	Li-Ion, 11.1 V, 7.2 A.h	≈4	Video cameras	2.4/4.9 GHz, 15.1" LCD, joystick	8
3	Matilda I/II [36]	Mesa Robotics	762/533/ 305	27.7	n/a	n/a	0.89	NiMH 4×12 V	6-10	PTZ, colors and b/w camera	900 MHz data,1.8/2.4 GHz video, 4 joysticks, 12.1" LCD, fiber-optics	5
4	Digital Vangurad [37]	Allen Vanguard	1040/450/ 560	56	80	2 motors	0.63	2×12 V, 13 A.h	3-5	PTZ, colors CCD LED	2.4 GHz WLAN, 2 joysticks, touch LCD, video and audio	6
5	Caliber T5 [32]	Icor	870/440/ 560	64	91*	2 speed gearbox	slow 0,89 fast 2.22	Lead-Acid 24 V, 8 A.h	2-4	2 colors IR cams, PTZ color CCD laser orientation	900 MHz, 2.4 GHz video, cable (153 m), variable speed joystick, 8.4" LCD, audio	3
6	Talon [30]	Qinetiq	864/572/ 427	71	45 113*	n/a	2.3	Lead-Acid 2×36 V, 8 A.h, Li-Ion 36 V	2,8	IR cams, 1 with automatic focus (300×)	Fiber-optics (300 m), Wi-Fi (800 m), digital data, analog video and audio	3
7	MR-7 [33]	ESI	980/450/ 820	122		n/a	0.89	n/a	2÷3	Color wide angle, PTZ CCD	cable/ Wi-Fi, data, audio and video, 15" LCD	5
8	710 Warrior [35]	iRobot	889/768/ 457	157.4	68	2+2	3.58	Li-Ion	n/a	Video cameras	Wi-Fi (800 m), joystick	n/a
9	Andros Wolverine [29]	Northrop Grumman	1473/737/ 1016	367.74	n/a	6×6	0.89	Lead-Acid 4×12 V	n/a	PTZ, b/w, colorful (72×)	cable/RF, joystick, 15" LCD, videorecord	3
10	tEODor [34]	Telerob	1300/685/ 1240	375	350	n/a	0.83	n/a	n/a	2 cams for motion detection, PTZ	433 MHz RF RT×/ 2.3/1.3 GHz video	7

Note: * dragging payload; ** without batteries; n/a not available

5. Hybrid locomotion and manipulation systems

Integrating functions of the manipulator and locomotion is a new trend in the development of high-mobility robots [19-21]. Manipulation abilities are naturally complemented by the movements of the mobile base-MP, as well as mobility is extended by supporting through links of the manipulator. In the constraints of a limited total number of drives a high integral mobility and manipulation is achieved.

MP-Helios VIII [20] consists of a two-chain astir locomotive mechanism and manipulator (Fig. 3), which actively helps the robot in overcoming complicated obstacles and stable movement on on extremely various surfaces. This enables: stairs motion (a, e, f), up-side down recovery (b), support in unstable configurations (c) and stability on slopes (d).

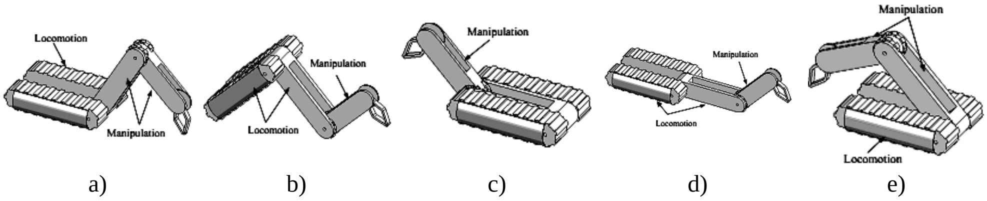


a) stairs motion b) up-side down recovery c) scissor motion
d) stability on slopes e) step climbing f) articulated configuration

Fig. 3. HELIOS concept motion capabilities [20]

MP developed by Ben-Tzvi [21] (Fig. 4) extends the integration between the two motion systems. Through hybridization of locomotors and manipulation a high level of mutual supplement is achieved. Symmetry and interchangeability of mechanisms are set. The advantages of chain and snakelike systems are integrated with a high static resistance. In the schemes a-e optional manipulation capabilities of different configurations are shown.

Structural and functional integration of locomotor and manipulator, as well as of the locomotion and manipulation helps expand the overall capabilities of robots in a small number of drives and thus an eased power, communication, remote guidance.



a) b) c) d) e)

Fig. 4. Different modes of configuration of the Ben-Tzvi platform for manipulation purpose [21]

The manipulator successfully supports the locomotion functions through:

- additional passive support to the base to extend the static stability;
- creeping while overcoming high obstacles;
- static and dynamic balancing of the platform;
- pulling and pushing on steep slopes by mutual coordination of motions.

6. Conclusions

Investigation robots integrate a high-mobility platform with a manipulator interact or gather samples in a hazardous environment. The locomotion systems most used for this purpose are the chain ones. The trends of extending mobility through various chain constructions have been analyzed. The functional complementarity of locomotion and manipulation motions is a current trend in the integration of the relevant systems.

Acknowledgments: The research results presented in this work are supported by the National Science Fund - MEYS with Project No DVU56/02-2010 - "Mobile wireless controlled investigation platform".

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Манипуляционные роботы с гусеничной платформой

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(Р е з ю м е)

В статье представлен обзор платформ и роботов высокой мобильности с акцентом на высокую мобильность гусеничных роботов. Произведена общая классификация роботов в зависимости от их рабочей среды, от масштаба механизмов их передвижения и от заданий. Проанализировано более чем 35 различных высоко мобильных гусеничных платформ и роботов, а также и их физические размеры, вес, грузоподъемность, скорость, тип аккумулятора, время автономной операции, датчики и степень свободы (DOF) манипуляторов.