The development trend of the robot

1. Preface:

Climbing robot is an important branch in the field of mobile robot, flexible mobile on vertical wall, replace artificial under the condition of the limit to complete various tasks, is one of the hotspot in research of the robot. It is mainly used in the nuclear industry, petrochemical industry, shipbuilding, fire departments and investigation activities, such as the building external wall cleaning, material storage tank in petrochemical enterprise testing and maintenance, the outer wall of large steel plate spray paint, and in building accident rescue and relief, etc., and achieved good social benefits and economic benefits, has wide development prospects.

After 30 years of development, the field of robot which has emerged a large number of fruitful results, especially since the 1990 s, especially rapid development in the field of climbing robot at home and abroad. In recent years, due to the development of a variety of new technology, the robot which solved many technical challenges, greatly promote the development of the climbing robot. The robot design activities of universities in our country also has a wide development, this kind of atmosphere for our robot research and development of special and professional talents' cultivation is of positive significance.

2. Climbing robot research status abroad

1966 Japanese professor west light wall mobile robot prototype is developed for the first time, and performance success in Osaka prefecture university. This is a kind of rely on negative pressure adsorption climbing robot. Then appeared various types of climbing robot, has already begun to the late 80 s application in the production. Japan's most rapid development in the development of climbing robot, mainly used in the construction industry and nuclear industry. Such as: Japan shimizu construction company has developed with the outer wall of the building industry coating with ceramic tile of the robot, they developed by negative pressure adsorption cleaning climbing robot, on the surface of the glass for the Canadian embassy to clean. Tokyo university of technology development of the wireless remote control magnetic adsorption climbing robot. In Japan's miti "limit homework robot" national research

projects, supported by day CDH, developed a large pot of negative pressure adsorption surface inspection robots used in nuclear power plants, etc.

Other countries are also added to the climbing robot research upsurge, such as: Seattle Henry R Seemann under the funding of the Boeing company developed a vacuum adsorption crawler "AutoCrawler" robot. On the two tracks each containing a number of small adsorption chamber, with the moving of the crawler, adsorption chamber form continuous vacuum cavity and makes the crawler walking against the wall. American CaseWestern Reserve University developed by using four climbing robot prototype "legs". Similar to the first two robots, the robot depends on four "legs" on biomimetic viscous materials to adsorption, the prototype is the four legs wheel on the sole of the foot even special distribution is more advantageous to the robot stable crawling on the wall. The quality of the robot is only 87 g. Polytechnic school in the early 1990 s, British Portsmouth has developed a climbing robot multilegged walking type. Adopting modular design, the robot is composed of two similar modules, each module includes two mechanical legs and leg controller. According to the task need to install a different number of legs, reconfigurable ability. Mechanical legs using bionics mechanism, simulation of the large animals arm muscle function, is two type, including upper and lower two and three double-acting cylinder, with three degrees of freedom. Good stability and bearing capacity is big, the robot's lightweight, and can span bigger obstacles. In addition to the leg on one end of vacuum cups, robot equipped with suction cups, abdomen mass ratio of powder and make the robot has a larger load of 2:1.

3. Climbing robot research status in China

China is also in a similar study since the 1990 s. In 1988 at the national "863" high technology program, under the support of the robotics institute of Harbin institute of technology has successfully developed the use of magnetic adsorption and vacuum adsorption two series of five types of wall climbing robot. Successful development of the our country the first wall climbing robot remote detection, using negative pressure adsorption, omni-directional mobile wheel, used for nuclear waste storage jars of wall weld defect detection. Developed in 1994 for tall buildings wall climbing robot cleaning

CLR - Ⅰ, adopts the omni-directional mobile mechanism, the robot in situ can arbitrarily change the direction of movement. After the development of the CLR - Ⅱ, driven by two independent ways -- coaxial two-wheeled differential mechanism, through the coordination of two rounds of speed control to realize the omni-directional mobile robot, the robot ontology and using power line carrier communication methods between the ground control station. Above-mentioned three climbing machine adopts single suction cup structure, spring air sealed, ensure the crawl robot with high speed and reliable adhesion ability. In 1995 successfully developed the metal corrosion by magnetic adsorption climbing robot, structure of permanent magnetic adsorption, accomplished by two tracks positive &negative mobile turn. The robot can do for petrochemical enterprises to the outer wall of the metal material storage tank to spray paint, sandblasting, as well as with automatic detection system to test the tank wall thickness. Developed in 1997's detection of water wall climbing robot, a circular permanent magnet adsorption block in conformity with the tank wall arc, improve the adsorption capacity, and improve the efficiency of the operation. Shanghai university also conducted early tall wall cleaning robot research, successively developed a vertical wall climbing robot and spherical wall climbing robot. The spherical wall climbing robot adopts many suckers, negative pressure adsorption, 6 foot independent driving leg feet walking style, can be used for different radius of curvature of the spherical outer wall since 1996, the Beijing university of aeronautics and astronautics has successfully developed WASH2 MAN, CLEANBOT 1, SKYCLEAN, "hanging basket type window robot" and "LanTianJie treasure" curtain wall cleaning robot prototype. For all the window is brushed pneumatic robot; Hanging basket type cleaning robot, the robot depends on the roof of the safety line traction, attached with the negative pressure made by fan robot on the wall in the application background of national grand theatre ellipsoid ceiling cleaning developed suitable for complex curved surface from climbing robot prototype, the climbing mechanism, mobile mechanism, cleaning robot has many similarities, but due to its special working environment and mission requirements, in terms of theory and technology has some particularity.

4. The key technology of robot:

4.1 adsorption mechanism, adsorption mechanism of action is to produce an upward force to balance the gravity of the robot, keep it on the wall. Currently, magnetic adsorption methods mainly include vacuum negative pressure adsorption, adsorption, propeller thrust and binder etc. Several ways. Due to the adsorption methods each have limitations, climbing robot developed by often targeted strong, applies only to a specific task, difficult to generalize. Robot design need to work on task, environment, choose the right means of adsorption. In recent years, people through the study of the adsorption mechanism of gecko reptiles such as the soles of your feet, making the polymer synthesis of viscous material, the use of van der Waals force between the molecules and molecular materials, can be obtained on the contact area of small huge adsorption capacity, and has the advantages of adsorption has nothing to do with the surface material properties. Short life but at the moment, the use of these materials, the use of a certain number of times after lose viscosity, practical, need further study.

4.2 mobile mechanism and motion control system: mobile mechanism and the movement control system of robot which major wheeled mobile mechanism, more foot type, such as caterpillar, among them, the wheel and foot type which has been widely used, caterpillar much for magnetic adsorption method. Obstacle ability is wall robot which used to an important indicator of performance. When work surface is convex, groove, the robot to go through these obstacles, we must have enough obstacle ability. All kinds of mobile mechanism, more foot type robot obstacle-navigation ability is stronger, its each leg small suction cup is placed, when faced with obstacles, can control the "leg", make the small suction cup across the obstacles one by one. Wall mobile mechanism of the robot can make the robot on the premise of reliable adsorption can move on the wall. Due to the particularity of climbing robot working in wall, mobile mechanism and adsorption mechanism exists coupling, which brought some difficulties to the robot's motion control. Than climbing robot sucker foot type and legs with a suction cup at the end, every move a leg needs to be done "to eliminate suction - leg - Wallace leg, left leg - generate adsorption force" a series of actions. In this process, the robot mobile mechanism of the action should coordinate with each other, and the adsorption mechanism to to guarantee the flexible mobile robot on the wall. In addition,

there is also a mobile mechanism and adsorption separation, such as single suction cups, robot sucker adsorption, sustainable continuous movement of driving wheel mobile robot, motion control is relatively simple.

Energy supply and drive mode: 4.3 the driving mode of energy supply and energy supply way with people via the wire line for the machine to provide energy such as electricity, gas, also has a built-in battery, cylinders and so on. Drive ways mainly have the pneumatic motor and other several ways. Climbing robot is designed to adopt high efficiency quality than drive and source of power, especially the wireless control cases. Using motor drive, energy supply mainly include polymer lithium battery, nickel metal hydride batteries, electrochemical batteries and fuel cells. In addition, due to the energy of internal combustion engine - - gasoline, hydrogen fuel can have higher weight ratio, such as advanced micro internal combustion engine can also be applied to the climbing robot.

Safety problems: 4.4 the robot by interference, environmental change circumstances, how to ensure the safety of the robot is attached to the wall without falling, falling or after how to minimize the damage of the robot. The past buildings cleaning climbing robot, developed by most used by in carrying the car at the top of the tower, hoisting and wire rope of insurance system on the robot. Robot for some other purposes, such as detection with small climbing robot, the goal is not sure, cannot use the rope way of insurance, so need to study new way to prevent falling. Could consider using a parachute, small power into a pulp, fast supporting resistance drop plate, etc., these may be a future development direction of climbing robot safety measures.

5. Development trend of the robot

Hard drive, sensor and control the development of software technology has greatly promoted the development of climbing robot technology, the demand of the practical application is also put forward the challenge, the development of robot climbing robot development trend in the aggregate, basically has the following several aspects. (1) the development of new adsorption technology. Adsorption technology has been a bottleneck of the development of the robot, it determines the application range of the robot. (2) the task of robot from simplification to muti_function change direction. The

past most climbing robot which is used for washing, spraying, detection and so on homework, homework tasks are often confined to a single task. Now people want climbing robot can equipped with a variety of tools, are working on different occasions. (3) the miniaturization, micromation is currently the trend of the development of the robot. On the premise of meet the functional requirements, small volume, light quality of robot can be less energy consumption, high flexibility, and in some special occasions are also need robot with small volume. (4) by the mooring operation development to the direction of untethered. Because the robot working space is generally larger, mooring operation greatly limits the robot working space, so, in order to improve the flexibility of robot and expand the working space, no cable is changed and is now and the future development trend of the robot. (5) by simple remote monitoring to intelligent direction. Combined with artificial intelligence, the robot can in a closed environment has a certain capacity for independent decision and complete the task, and have ego to protect ability, is the important direction of mobile robot, is also a important development direction of mobile robot climbing wall. (6) the adaptability of the reconfigurable robot is an important indicator. In order to make the robots could be used in different occasions, according to the mission requirements, under the condition of the system does not need to design, make full use of existing robot system, should make with reconfigurable robot, which has a modular structure. According to the mission requirements, the need of module is directly connected to form a new robot.

译文：

1.引言：

爬壁机器人是移动机器人领域的一个重要分支,可在垂直壁面上灵活移动,代替人工在极限条件下完成多种作业任务,是当前机器人领域研究的热点之一。它主要应用于核工业、石化工业、造船业、消防部门及侦查活动等,如对高楼外壁面进行清洗,对石化企业中的储料罐外壁进行检测和维护,对大面积钢板进行喷漆,以及在高楼事故中进行抢险救灾等，并且取得了良好的社会效益和经济效益，具有广阔的发展前景。

经过 30 多年的发展,爬壁机器人领域已经涌现出一大批丰硕的成果,特别是20 世纪 90 年代以来,国内外在爬壁机器人领域中的发展尤为迅速。近年来,由于多种新技术的发展,爬壁机器人的许多技术难题得到解决,极大地推动了爬壁机器人的发展。在我国各高校机器人设计活动也已经很广的开展起来，这种氛围对我国机器人的研制开发特别以及专业方面人才的培养是具有积极意义的。

2.国外爬壁机器人研究现状

1966 年日本的西亮教授首次研制成功壁面移动机器人样机,并在大阪府立大学表演成功。这是一种依靠负压吸附的爬壁机器人。随后出现了各种类型的爬壁机器人,到 80 年代末期已经开始在生产中应用。日本在开发爬壁机器人方面发展最为迅速,主要应用在建筑行业与核工业。如：日本清水建设公司开发了建筑行业用的外壁涂装与贴瓷砖的机器人,他们研制的负压吸附清洗玻璃面的爬壁机器人,曾为加拿大使馆清洗。东京工业大学开发了无线遥控磁吸附爬壁机器人。在日本通产省"极限作业机器人"国家研究计划支持下,日晖株式会社开发了用于核电站大罐的负压吸附壁面检查机器人等。

其他各国也加入到爬壁机器人研究的热潮中如：美国西雅图的 Henry R Seemann 在波音公司的资助下研制出一种真空吸附履带式爬壁机器人“AutoCrawler”。其两条履带上各装有数个小吸附室,随着履带的移动,吸附室连续地形成真空腔而使得履带贴紧壁面行走。美国 CaseWestern Reserve University 研制的采用 4 个“腿轮”的爬壁机器人样机。与前两种机器人相似,该机器人依靠 4 个“腿轮”上的仿生粘性材料来吸附,样机不同的是这 4 个腿轮

上脚掌的特殊分布更有利于机器人在壁面上稳定爬行。该机器人质量仅有 87 g。20 世纪 90 年代初,英国朴次茅斯工艺学校研制了一种多足行走式的爬壁机器人。采用模块化设计,机器人由两个相似的模块组成,每个模块包括两个机械腿和腿部控制器。可根据任务需要来安装不同数量的腿,可重构能力强。机械腿采用仿生学机构,模拟大型动物臂部肌肉的功能,为两节式,包括上、下两个杆和 3 个双作用气缸,具有 3 个自由度。稳定性好,承载能力大,利于机器人的轻量化,并能跨越较大的障碍物。除腿端部各有一真空吸盘外,机器人腹部设有吸盘, 使机器人具有较大的负载质量比,可达 2∶1。

3.国内爬壁机器人研究现状

中国也于 20 世纪 90 年代以来进行类似的研究。1988 年在国家“863”高技术计划的支持下,哈尔滨工业大学机器人研究所先后研制成功了采用磁吸附和真空吸附两个系列的 5 种型号壁面爬行机器人。研制成功的我国第一台壁面爬行遥控检测机器人,采用负压吸附,全方位移动轮,用于核废液储存罐罐壁焊缝缺陷检测。1994 年开发的用于高楼壁面清洗作业的爬壁机器人 CLR-Ⅰ,采用全方位移动机构,机器人在原地就可以任意改变运动方向。之后开发的 CLR-Ⅱ,采用两轮独立驱动方式———同轴双轮差速机构, 通过对两轮速度的协调控制实现机器人的全方位移动,机器人本体和地面控制站之间采用电力线载波通讯方式。上述 3 款爬壁机器人均采用单吸盘结构,弹簧气囊密封,保证了机器人具有较高爬行速度和可靠的附着能力。1995 年研制成功的金属管防腐用磁吸附爬壁机器人,采用永磁吸附结构,靠两条履带的正反转移动来实现转弯。该机器人可以为石化企业金属储料罐的外壁进行喷漆、喷砂,以及携带自动检测系统对罐壁涂层厚度进行检测。1997 年研制的水冷壁清检测爬壁机器人,呈圆弧形永磁吸附块与罐壁圆弧相吻合,提高了吸附力,也提高了作业的效率。上海大学也较早开展高楼壁面清洗作业机器人的研究,先后研制出垂直壁面爬壁机器人和球形壁面爬壁机器人。该球形壁面爬壁机器人采用多吸盘、负压吸附、6 足独立驱动腿足行走方式,可用于不同曲率半径的球形外壁 1996 年以来,北京航空航天大学先后研制成功 WASH2 MAN,CLEANBOT 1,SKYCLEAN,“吊篮式擦窗机器人”和“蓝天洁宝”等幕墙清洗机器人样机。为全气动擦窗机器人;吊篮式清洗机器人,机器人依靠楼顶上的安全吊索牵引移动,利用风机产生的负压使机器人贴附在壁面上以国家大剧院椭球形顶

棚清洗为应用背景研制的适用于复杂曲面的自攀爬式机器人样机,由攀爬机构、移动机构、清机器人有许多相似之处,但由于其特殊的工作环境和任务要求,在理论和技术等方面又有一些特殊性。

4. 爬壁机器人的关键技术：

4.1 吸附机构：吸附机构的作用是产生一个向上的力来平衡机器人的重力,使其保持在壁面上。目前,吸附方式主要有真空负压吸附、磁吸附、螺旋桨推力及粘结剂等几种方式。由于这些吸附方式各自都有局限性,所研制的爬壁机器人往往针对性较强,只适用于某种特定任务,较难通用化。机器人的设计需要针对工作任务、环境,选取合适的吸附方式。近年来,人们通过研究壁虎等爬行动物脚掌的吸附机理,制作出高分子合成的粘性材料,这些材料利用分子与分子之间的范德华力,在很小的接触面积上就可获得巨大的吸附力,而且具有吸附力与表面材料特性无关的优点。但目前这些材料的使用寿命较短, 使用一定次数之后就失去粘性,难以实用化,需要进一步进行研究。

4.2 移动机构及运动控制系统：移动机构及运动控制系统爬壁机器人的移动机构主要有轮式、多足式、履带式等,其中,轮式和足式使用较为广泛,履带式多用于磁吸附方式。越障能力是爬壁机器人壁面适应性能的一个重要指标。当工作面上有凸起、沟槽时,机器人要通过这些障碍物,就必须有足够的越障能力。各种移动机构中,多足式机器人的越障能力较强,其每个腿部都置有小吸盘,当遇到障碍物时,可控制各个“腿”,使小吸盘逐个跨过障碍物。壁面机器人的移动机构可以使机器人在可靠吸附的前提下能够在壁面上灵活移动。由于爬壁机器人工作于壁面的特殊性,移动机构常和吸附机构存在耦合,这给机器人的运动控制带来了一些困难。如多吸盘足式爬壁机器人,腿末端各有一个吸盘,每移动一个腿需要完成“消除吸力—抬腿—迈腿—落腿—产生吸附力”一系列动作。在此过程中,机器人移动机构的动作要和吸附机构相互协调,才能保证机器人在壁面上的灵活移动。此外,也有移动机构与吸附机构分离的,如单吸盘爬壁机器人,吸盘可持续吸附,驱动轮连续运动实现机器人的移动,运动控制较为简单。

4.3 能源供应及驱动方式：能源供应及驱动方式能源供应方式有通过电线管路为机 器人提供电、气等能源的方式,也有自带电池、气瓶等方式。驱动方式主要有电机气动等几种方式。爬壁机器人的设计尽量采用具有高功效质量比的驱动

器和动力源,特别是采用无线控制情况下。采用电机驱动时,能源供应主要有聚合物锂电池、镍氢电池、电化学电池和燃料电池。此外,由于内燃机的能源———汽油、氢等燃料具有较高的能重比,先进的微型内燃机也可应用于爬壁机器人。

4.4 安全问题：机器人在受到外界干扰、环境变化情况下,如何保证机器人安全附着于壁面而不至于坠落,或坠落后如何尽量减小机器人的损伤。过去所研制的高楼清洗爬壁机器人, 大都采用由置于高楼顶上的运载小车、卷扬机构和系在机器人上的钢丝绳组成保险系统。而对于一些其他用途的机器人,比如侦查用的小型爬壁机器人,其目标并不确定,不能采用保险绳的方式,因而需要研究新的防坠落方式。可以考虑采用降落伞、小功率螺旋降落浆、快速撑起阻降板等,这些可能会成为未来爬壁机器人安全措施的发展方向。

5.爬壁机器人的发展趋势

驱动、传感、控制等硬软件技术的发展极大地推动了爬壁机器人技术的发展,实际应用的需求也对爬壁机器人的发展提出了挑战,爬壁机器人的发展趋势归结起来主要有以下几方面。(1)新型吸附技术的发展。吸附技术一直是爬壁机器人发展的一个瓶颈,它决定了机器人的应用范围。(2)爬壁机器人的任务由单一化向多功能化方向发展。过去所研制的爬壁机器人大多用于清洗、喷涂、检测等作业,作业任务往往只局限于单一的任务。而目前人们则希望爬壁机器人能够装备多种工具,在不同的场合进行工作。(3)小型化、微型化是当前爬壁机器人发展的趋势。在满足功能要求的前提下,体积小、质量轻的机器人可较小能耗,具有较高灵活性,并且在某些特殊场合也需要机器人具有小的体积。(4)由带缆作业向无缆化方向发展。由于爬壁机器人的作业空间一般都较大,带缆作业极大地限制了机器人的作业空间,所以,为了提高机器人的灵活性和扩大工作空间,无缆化成为现在和未来爬壁机器人的发展趋势。(5)由简单远距离遥控向智能化方向发展。与人工智能相结合,使机器人在封闭环境中能够具有一定的自主决策能力, 完成任务,并具有自我保护能力,是移动机器人发展的重要方向,也是爬壁移动机器人的重要发展方向。(6)可重构是机器人适应能力的一项重要指标。为了使机器人能够应用于不同场合,根据任务需求,在不需要重新设计系统条件下,充分利用已有的机器人系统,应使机器人具有可重构性,即具有模块化结构。根据任务需求,把需要的模块直接连接起来组成新的机器人。