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Innovative control education using a low cost intelligent robot platform

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SUMMARY
With the fast development of the control theory and engineering, robotics and artificial intelligence have become the focus in the field of intelligent systems. But research in this field is based on a series of experiments and requires various robot platforms which are often unaffordable by the universities in developing countries. The intention of this paper is to present the idea of applying innovative control education and building a laboratory using low cost equipments. In this paper the architecture and control system of a new kind of low cost intelligent robot, "Ability Storm", is introduced. It not only shows the technical aspect, but also illustrates the related applications in control education. The versatility and effectiveness of this affordable intelligent robot platform are demonstrated through a number of experiments, including both basic laboratory experiments and other innovative project-oriented design, such as robot fire fighting, which clearly show the practicality and robustness of this cost-effective robot platform.

KEYWORDS: Low cost platform; Innovative control education; Constructivist teaching; Robotics; Artificial intelligence.

1. INTRODUCTION

There are many challenging issues in control education in the 21st century. To succeed in the highly competitive environment, we have to innovate control system education. Only in this way can we provide the engineering students with a challenging and well-motivated learning environment to prepare them for their future engineering career.

The progress of control shows that control education must be "both conceptual and experiential."[1] Abstract concepts are elegant and powerful, but learning is always enhanced by direct experience, concrete examples and real-world relevance. During the NSF/CSS Workshop on New Directions in Control Education held in 1998, many experts in this field have given a "philosophical perspective on the future directions of control education."[2] They mentioned that one of the trends in control education is "a return to the roots of the field; that is, a return to the more practical side of controls with a de-emphasis on the more mathematical methods that have dominated the education process in recent years." They suggested that the students and faculty should spend more class time on practical issues and project/team work, and also "broaden the basis of controls to relate it to various other specialties such as electronics, computers, and communications."

In face of these changes and competitions, more and more sensible educators have got to realize that it is high time that we reform today's control education system. These scholars and experts in control education identified the future directions in control education and made specific recommendations on how to pursue the goals.[3] The goal is to produce engineers who are well versed in both the theory and the practical hands-on aspects of control.

We are delighted to notice that some steps in this direction have already been taken at some universities in Europe and US (such as University of Cambridge, Lund Institute of Technology, Cornell University and MIT). For example, a "practice-oriented" Master of Engineering (M.Eng.) degree had been instituted as a first professional degree at MIT. Of course, research-oriented M.S. and Ph.D. programs would continue to serve the needs of those who wish to pursue academic careers or find employment in the industrial research departments.[4]

1.1. Control education in developing countries

Educators and scholars in developing countries also noted that control education should be broadened to include experimental and applied research topics. There is a consensus that existing programs in control do not pay sufficient attention to experimental work. Our students should be better prepared for the needs of industry and for keeping up with a rapidly changing technology.

With the arrival of the 21st century, robotics and artificial intelligence are rapidly developing, in which new theory and concept emerge much faster than ever before. What is more important, practice and experiment plays a prominent role in their work. Universities in developing countries are making great efforts to provide modern laboratory equipment and experimental research for students. But due to financial limitation and practical education status in developing countries, it is often unaffordable for these universities to institute advanced laboratories equipped with various expensive equipment. One intention of this paper is to bring forward a plan of establishing a laboratory using low cost laboratory equipment.

In our robotics laboratory in Dalian University of Technology (Dalian, P.R.C.), we use a new kind of low cost intelligent robot, "Ability Storm", to carry out projects and

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laboratory work based on constructivist teaching. Our aim is to build our laboratory as a national teaching base of innovative control education with low cost laboratory equipment.

1.2. Related work

Since innovation plays an increasingly important role in modern research and engineering, many scholars and educators have introduced innovative ways in university education. R. Siegwart[5] (Swiss Federal Institute of Technology of Lausanne) brings forward an innovative course in mechatronics teaching, which is called "Smart Product Design." This "Hands-On" education enables students to "integrate knowledge from the many disciplines involved in designing and building the mechatronics products today". It provides students with an opportunity to work on real systems and learn "hands-on". During the course, the students are given a basic robot platform "SmartROB" and other necessary hardware to accomplish a cheap and flexible mechatronics design. They have to solve unforeseen problems. Primitive "intelligence" is introduced into the system and reliability and robustness are to be addressed.

Other scholars such as A. Krasniewski and J. Woznicki[6] also propose the idea of flexibility and adaptability in engineering education. They suggest that we should introduce an entirely new attractive system of study "which should be based on the requirements of students and markets". Such systems allow students to have more freedom to design their individual programs of study and adjust their course loads according to their different characters. About innovative education, C. J. Steiner,[7] from Monash University in Melbourne (Australia), has her own thoughts. She believes innovation is a process by which technological ideas are generated, developed and transformed into new business products, while technical management is the process of influencing a technical group's activities toward certain goals.

Some people and companies have engaged in designing and producing low cost equipment for students and children; for example, F. G. Martin[8] of the MIT Media Laboratory and LEGO Group. In a series of work, Martin implemented design-rich environments for teaching engineering science to university undergraduates (1994) and studied notions of feedback and control in fifth-graders (1998). In his studies, Martin developed a workshop-format course in which students received a kit of materials and a specification for a competitive contest challenge. During his innovative teaching, the students are not merely users of the technology, but become designers as they work through problems and express their own ideas with it.

1.3. About this paper

Regarding the related work mentioned above, this paper introduces the idea of applying innovative control education using the low cost intelligent robot "Ability Storm" provided by Grandar Electronic & Information Co. Ltd., Shanghai. Our laboratory has redesigned and updated this platform so as to make it more suitable for R&D work/project in universities. The technical kernel of this platform is listed below:

- More robust and efficient Embedded System.
- Higher reliability and modularization for easy-to-extended mechatronics system.
- Foolproof interactive programming language: *JC 1.0*.
- Integrated visual programming environment.
- Low cost, reliable and versatility for R&D in universities.
- Advanced robotics and automation platform based on constructivist teaching method.

In this paper, the basic hardware, sensors, wireless communication and software environment of the low cost intelligent robot platform "Ability Storm" are described firstly. Then the constructivism and constructivist teaching in robotic & automation are discussed. The last part of this paper contains experiments, projects and laboratory work based on constructivist teaching, and the conclusions.

2. "ABILITY STORM": LOW COST INTELLIGENT ROBOT

"Ability Storm" is a small, powerful and versatile intelligent robot platform capable of functioning under very competitive conditions. It's a hemispherical mobile robot, which looks like a soap bubble. The robot kinematics is of the differential drive type, i.e. with two independently controlled propulsion wheels. "Ability Storm" is 13 cm high and its diameter is 24 cm (Figure 1).

"Ability Storm" is increasingly popular in Chinese universities and colleges. Its price is not higher than 500 USD for one "Ability Storm" with the standard configuration.

2.1. The architecture of "Ability Storm"

This low cost intelligent robot platform uses a Motorola based controller. The default processor board has a M68HC11 microcontroller with 32K bytes of RAM, serial port, wireless communication module and other periphery device driver circuits. The M68HC11 CPU is optimized for low power consumption and high-performance operation at bus frequencies up to 4 MHz, which include six powerful addressing modes, 8 analogue ports, 16-bit address bus, 8-bit data bus, serial communication interfaces and 4 general I/O ports. The M68HC11 family is supported by dozens of independent hardware and software development tools, which allow one to efficiently develop, monitor, test and debug his code to have your applications realized fast. The architecture of "Ability Storm" is shown in Figure 2.



Fig. 1. The low cost intelligent robot "Ability Storm" (the right one is equipped with a gripper).

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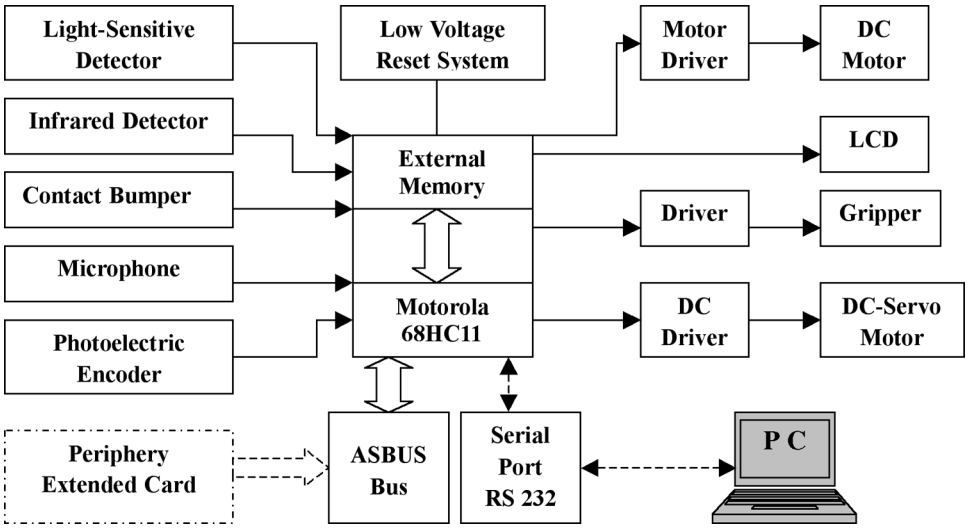


Fig. 2. The architecture of the low cost intelligent robot "Ability Storm".

2.2. Basic hardware and affordable sensors for "Ability Storm"

This low cost robot platform is made from high quality aluminium and plastic material. It uses high precision gears; furthermore, it has been designed for prolonged continuous operation as necessary for unprofessional students.

The "Ability Storm" is a modular, openly structured and powerful intelligent robot platform. It can run 2–4 DC-servo motors and the maximum speed can reach 0.6m/s. Its mechanical design employs the easy-to-pack modular structure, which makes it easier in rebuilding. The robot platform uses an extended ASBUS bus and it has a 32-channel digital I/O.

The "Ability Storm" controller is well coupled to the sensors. This is important for mobile robots to have immediate access to the most recent sensor data. Basic sensors, effectors and accessories for the low cost robot platform are listed below:

- Infrared detection module.
- Light-sensitive detection module.
- Incremental encoder.
- Grippers and arms.
- Microphone and speaker.
- Rechargeable battery power.
- Contact bumper omnidirectional around the robot.

"Ability Storm" can also connect to other sensors or periphery devices such as ultrasonic range sensor, infrared range sensor and 6-channel servo motor driver.

2.3. Wireless communication

Communication is the necessary function for mobile robot. Via wireless communication, a robot can conveniently transfer information between the robot and computer or among different robots. FC-201/E is a kind of low power consumption wireless communication module. Its duplex communication function can be applied in peer-to-peer or one-to-many model. The robots can thus be controlled from a remote computer, which makes the research in multi-agent systems easy. Being reliable, inexpensive and easy-to-use, the duplex communication function is the best choice for our low cost intelligent robot platform. The architecture of wireless communication between robot and computer is shown in Figure 3. The wireless communication between two or more robots follows the same principle and protocol. In order to identify the command, each robot is given an exclusive ID. When the robot that acts as the leader in this group sends a message to the following robots, each of the following robots will decode the message and then compare the special control word in the message with its own ID. If it matches, this robot will execute the command; or it will be abandoned and robot just accomplishes its current task.

FC-201/E has two types of communication protocol: P version protocol and E version protocol. Our robot wireless communication uses E version protocol because its transmission is fully transparent; it is also independent of the protocol and data structure in the upper-layer device. The transmission distance is confined within 100 meters in order to guarantee stable communication. The baud rate is set to be 9600bps when it is connected to the computer; otherwise the baud rate is set to 2400bps when it is connected to a robot.

2.4. Software environment

The software environment of "Ability Storm" is composed of the interactive programming language *JC 1.0* and the visual human-machine interface. *JC 1.0* is the successor of *ANSI C* in the *C* family. From *ANSI C*, *JC 1.0* inherits the well-known characteristics such as:

- Abundant data structure and structured control sentence.
- Allow direct and convenient access to most of the internals of the machine from the language level without having to resort to an assembler code.
- Easy to replant between different OS.

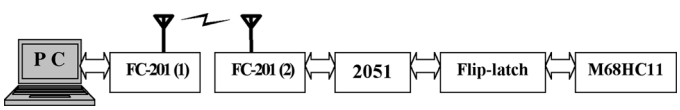


Fig. 3. The wireless communication between the robot and PC.

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- Resulting code executes faster than most other high level languages.

At the same time, some new concepts are added to *JC 1.0*, which make it easier to be used in the mobile robot "Ability Storm". The merits in *JC 1.0* include:

- Using the modern object oriented concepts and very simple programming.
- Highly compiling efficiency.
- Remove the problems of classical systems (memory leakage, dangling pointers, illegal references) that cause crashes.
- Support for multi-task management (having different task state and different task priority; task executes according to task time slicing).

JC 1.0 cannot directly compile and build the code for the target processor. The source code is firstly compiled to the virtual machine based pseudocode, and then the pseudocode is decoded and executed by the operating system of the "Ability Storm". One merit of the complier used by *JC 1.0* is that it can compile directly from an editing window and generate native or portable code without any other necessarily separate linking.

JC 1.0 can be installed on Windows 95/98/2000 or Windows NT 4.0. "Ability Storm" is connected to the PC using serial ports (RS 232 & RS422). It supports multi-task with its maximum task course up to 32, and the corresponding switch-time is less than 0.1ms. Its average compiling rate is 30000P/s.

3. CONSTRUCTIVISM AND CONSTRUCTIVIST TEACHING IN CONTROL EDUCATION

Constructivism is a view of learning based on the belief that knowledge isn't a thing that can be simply given by the teacher. Rather, knowledge is constructed by learners through an active mental process of development; learners are the builders and creators of meaning and knowledge.[9] Constructivism is also an approach to teaching and learning based on the premise that cognition (learning) is the result of "mental construction." In other words, students learn by fitting new information together with what they already know. Constructivists believe that learning is affected by the context in which an idea is taught as well as by students' beliefs and attitudes.

Constructivist teaching is based on the belief that learning occurs as learners are actively involved in a process of meaning and knowledge construction rather than passively receiving information. Learners are the makers of meaning and knowledge. Constructivist teaching fosters critical thinking and creates motivated and independent learners.

Educational curricula and teaching methods are changing. One component of the current redevelopment of all subject area curricula is the change of the focus of instruction from the transmission curriculum to a transactional curriculum. In a traditional curriculum, a teacher transmits information to students who passively listen and acquire facts. In a transactional curriculum, students are actively involved in their learning to reach new understandings.[3] Constructivist teaching lays emphasis upon the students' innovation and the ability to verify what they had learned in the course of learning. Hence, the laboratory should provide the students with a robust and versatile platform for their experiments.

The aim of education in electrical engineering is to train the professional technologist in this field. Teaching through experiments and practice lessons is the best way to implement constructivist teaching. Thus, the research platform and instrument are the most important and necessary tools and media for control education. From the practical teaching experience, innovative control education using constructivist teaching should comply with the following principles:

- Students should play the leading role in the practice teaching.
- Pay more attention to the effect of "scene and setting" in the course of learning.
- Build the idea of "cooperative effort" in the teams.
- Lay emphasis on the design of "learning environment" (not the "teaching environment").
- Use all kind of information to facilitate learning (not teaching).
- Make sure that the final goal of learning is to fulfill the "knowledge construction" (not accomplish the teaching plan).

4. THE CORRELATED CURRICULUM AND LABORATORY WORK BASED ON "ABILITY STORM"

4.1. Course and Experiment based Constructivist Teaching

In order to successfully apply the constructivist teaching method, we design various experiments and hands-on practice based on "Ability Storm" for the curriculum in Chinese university, which include electronics, computer science, control theory and the related applications. For example, we have designed a pulse width modulation experiment. The experimental result can be observed by the mobile robot's tracking which is easier to observe and more interesting than the traditional one. This experiment system can be further improved by adding an encoder to implement closed loop control. Other control theory, such as PID control and fuzzy control algorithms, can also be applied using the same platform. We list the correlated curriculum in the following points:

- Intelligent robots.
- Principle of Sensing Device.
- Principle of Single Chip Computer.
- Procedure Control.
- Programming with *C* Language.
- Analogical Electronics.
- Digital Electronics.
- Computer Interface Technology.
- Electrical Engineering Practice.
- Experiment of Microcomputer.

4.2. Thesis projects

Both the undergraduate and graduate students must complete a thesis project to obtain their degree in electronic

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engineering. Students can select their area of specialization freely. About 20–25 undergraduate and 8–12 graduate students per year do their thesis project in the field of automatic control. The projects can be classified into 3 groups: industrial projects, research projects on advanced control theories and the related applications, and intelligent robotics and biorobotics. Using "Ability Storm", some students in our laboratory complete theses for their Bachelor degree and Master degrees based on innovative project-oriented design, such as robot fire fighting, robot soccer and other specially planned robot competitions. The robot fire fighting competition and robot soccer competition among dozens of Chinese key Universities are also held each year. Our robot team based "Ability Storm" platform shows always excellent performance. During the robot fire fighting project and competition set for the undergraduate, students in the senior class use different searching strategy to navigate in an unknown environment. The robot has not any prior information about the environment and is not allowed to use any artificial landmarks or any other form of engineering of the environment. While a robot finds a candle-flame, it will approach the candle step by step to avoid colliding with it. When the appropriate distance is achieved, a mini electric fan equipped on the top of the robot will blow out the candle and return to the starting point as soon as possible. In order to avoid getting lost and a lesson overlapping search in the unknown zone, the students should design their own path-planning algorithm and experiment continuously to make the algorithm more practical and robust. Take the environment showed in Figure 4 for example, one path-planning algorithm is called "Left Hand Rule" or "Coastal Planning". But this algorithm cannot detect the "island region" that appears in the center of the maze. So additional algorithms (such as "Double Hand Rule" or "Random Scout") should be added to make the whole strategy more successful. In the demonstration of the path planning algorithm in Figure 4, the "Left Hand Rule" (the point line in Figure 4) is firstly used to search regions A, B and C; then the "Right Hand Rule" (the dash line in Figure 4) is used to search the "island region" D. According to the competition rule, the robot should get back to the starting point (black-color-filled circle in Figure 4) at the end.

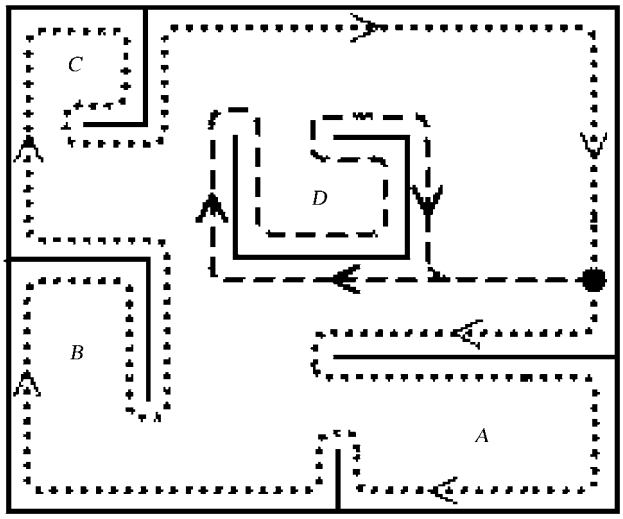


Fig. 4. Artificial environment and demonstration of a path planning algorithm for robot fire fighting.

4.3. Laboratory R&D work

Evolutionism has become one of the foci in the field of robotics and artificial intelligence. Using the subsumption architecture, we produce experiments of a single robot and multi-robot system based on behaviorism, which uses the bottom-up systems in contrast to the traditional top-down system.

The core part of this R&D work is about behavior-based robotics that is guided by principles from nature and aims to develop methods for synthesizing artificial systems, ranging from physical robots to autonomous software agents, and to use robotics to model and analyze natural systems, ranging from insects to humans.[10] Generally, the research in this field is based on a series of experiments and requires various robot platforms, which is often unaffordable for a university in developing countries. Our laboratory uses "Ability Storm" to implement the idea of behavior-based robotics. The basic work deals with subsumption architecture and the elemental behavior algorithm in designing the robots behaviors. In order to model group behavior, we use groups of "Ability Storm" to demonstrate aggregation, dispersion, following, flocking, foraging, task division and other biological group behaviors. The subsumption architecture of "Ability Storm" includes five layers: basic moving, avoiding obstacles, roaming, searching and path planning, from the bottom layer to the upper layer. The inferior the layer is, the higher priority it has. The robot chooses different actions according different sensor data input. For example, we scatter four robots randomly in the experiment zone. First, they roam and avoid various obstacles around them. At the same time, they search each other according to a predefined searching algorithm. When they find each other, they can send and receive messages via wireless communication and compare the ID number to determine which one is the header in this group. Then other robots will follow the commands of the header to complete the task set by user from host computer, such as to reach the destination one by one or to parade in various order. Further research involves design of complex behavior, coordinating multiple behaviors, data of multi-sensor fusion, learning and adaptation in unknown environment. Learning has been called the hallmark of intelligence; thus achieving adaptive and learning capabilities in artificial systems is one of the greatest challenges of artificial intelligence.[10] Based on the early work in psychology, the reinforcement learning method is used to improve the behavior-based robot's learning. The robot will be punished or rewarded by the environment directly. Some neural networks methods can be applied in this research.

Biologically inspired imitation is also one of our interests. In autumn 2000 our research center cooperated with Grandar Electronic & Information Co. Ltd. to build a biorobotics laboratory. The R&D work in this laboratory is designing various robots to resemble the equivalent behav-

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ior found in species, ranging from ants, crabs, and chickens to chimps and humans.[10]

5. CONCLUSIONS

Engineering students trained by constructivist teaching and possessing more practical experience will have the best chances to "compete as innovators in the global marketplace and to assume management responsibilities in industry and government".[7] Also, graduate students intending to pursue academic careers need to be proficient in the laboratory to become fully competent control systems educators.

In this paper we introduced the work in our laboratory on innovative control education using a low cost intelligent robot platform. We also present the idea of developing laboratories using affordable equipment, especially in the robotics and artificial intelligence field.

So far, dozens of key universities in China have selected this innovative and low cost intelligent robot as a R&D platform. These universities include Zhejiang University, Shanghai Jiaotong University, National University of Defense Technology, Northeastern University, Tongji University, and etc. Thus we can forecast that more and more low cost laboratory platform and equipment will be established in universities of developing countries. All these will greatly promote these universities' innovative control education and contribute to the overall quality of education.

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