Combine 3D Software and Remote Control to Progress Operating Simulation of Automatic Guided Vehicles

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The purpose of this research is to build a simulating operation system of automatic guided vehicles (AGV) at a construction site, which including (1) construction path planning system (2) real-time vision information, and (3) simulation system of automatic guided vehicles at the construction site. This paper proposes an efficient method that provides VR-based AGV path guidance with Caligari Truspace 3D software and Python Script. We designed an interactive vision information interface by using LEGO Mindstorms Vision Command combined with Visual Basic ActiveX; and also built an automatic guided vehicle with the functions of obstacle avoidance by LEGO Robotics Invention System. The majority of this research is to develop an effective construction site management model, and develop a construction path planning and a real-time system.

Keywords: *automatic guided vehicles, LEGO mindstorms, path planning, virtual reality, vision information.*

Introduction

In a construction site, there exists various types of work in production to be engaged for each task; facing these different construction scopes, construction machinery and equipment, and construction materials, the site supervisor must properly plan beforehand the task and working domain, to enable each type of work in a production to be completed. For the conveyance and arrangement of construction material, it must consider the distance between the working location and the stacking area to reduce conflicts and enhance the working efficiency (P.H. Wang and N.C. Shih, 2002).

The main task for the site supervisor in the construction site is to actually supervise workers executing their works and avoid mistakes in construction or dangerous construction practices. However, some construction sites have wide construction scopes and workers undertake different works in various sections or floors. To prevent inefficient construction practices or incorrect construction methods, site supervisors have to continuously supervise every construction scope and inspe ct construction practices, or have to increase the supervising personnel to obtain more effective construction control and reduce the problem of repeating works caused by mistakes in construction. In most supervising processes, decisions and judgments made by site supervisors are based on their accumulated experiences in the past (S.Y. Kuo, M.D. Wang and D.S. Wu, 2001). In construction sites, site supervisors may not be able to supervise the progress of the construction all the time. Therefore, negligence of construction personnel, misunderstanding of tasks, or mis-coordination with other workers, will cause mistakes in construction, and affect the construction progress and efficiency. Hence, providing beforehand, simulated and coordinated practices in a construction site which has a high level of difficulty and complexity, will make most workers familiar with coordinated tasks or progress correcting mistakes; this is very helpful to improve the construction efficiency.

Currently, automation of Taiwan construction projects is still not popular; and people mainly operate construction machinery and equipment. With the same situation as above, in the process of construction machinery and equipment operation, operations performed by operators are based on their accumulated experiences in the past and current site conditions. Therefore, it becomes unable to control the construction quality and the progress, accumulate the case experiences, and gain the effect of learning curve (C.J. Huang, 1999). Consequently, undertaking beforehand, a construction path plan, simulating the best combination of best path and construction machinery and equipment, and establishing an effective feedback review scheme, will facilitate verification of the effect of the plan, avoid the mistakes of artificial operation, and effectively record execution experiences; this then, can improve construction efficiency, reduces the cost, and improve construction quality.

Automatic Guided Vehicles (AGV) already plays an extremely important role in the manufacturing automatic system. In proliferating automation, using an AGV to complete transporting and storage of the raw material or the product, can largely enhance the efficiency and the flexibility of the manufacturing system, reduce artificial operation fault, simultaneously enhance productivity, and reduce operation cost to strengthen product competition. There are two types of AGV guidance, one type is using magnetic induction to track a wire buried in the floor or using optics method to trail a sign pasted on the floor; the other type is using a laser scanner fixed on an AGV to receive the laser signal reflected by a laser reflector preset on the path, and calculate the AGV locations by geometry principle calculation. These methods must have the preset-path, and therefore limit the AGV path design and the degrees of freedom of movement (S.P. Chen, 2002). This research proposed a path guidance method based on virtual reality, to act as AGV's movement guidance. At the construction site, there are many variations that cannot be forecast and controlled. Therefore, an AGV executed task at the construction site is not like the one in general factories where it moves in a well planned area. In order to let the AGV move correctly at the construction environment, it not only needs the best pre-planned path, but also the ability of active obstacle detection for the AGV and preloaded movement program. These can enable the AGV to have active feedback reaction while meeting different obstacles and handle changeable conditions at a construction site.

This research attempted to combine the „Caligari Truespace 6.0“ 3D graphical design software, which has a very friendly user interface, and its built-in programming language, „Truespace Python“, to establish a virtual reality based path guidance method as the simulation of the AGV operation procedure. In addition, the Vision Command, vision detection system, and ActiveX components of LEGO Mindstorms system from LEGO CO. were applied together with the Microsoft Visual Basic programming language to design a vision control interface with an interactive scheme. Use LEGO Robotics Invention System 2.0 to construct a programmable AGV with an active detection function; control the different operators via remote control and real-time vision control, using the collaborative operation technique to process the simulation and evaluation of transport operation at construction sites.

Hardware Configurations

Personal computers and peripherals

In recent years, the development of personal computer (PC) software and hardware has made great strides, and has caused the PC became an inexpensive general data processing tool. The main operating system, Windows, integrates multiplex processing functions with Plug-and-Play for hardware installations; PCs not only have enormous compatibility in integrated software performance, but also greatly simplified installation and integration of all hardware interface devices. Due to a huge enhancement of the central processing unit (CPU) clock, virtual reality simulations and the matched performance of related interfaces have greatly improved (M.H. Huang, 2002). In this research, based on a PC and its multimedia peripherals, we plan to match the Windows operating system with inexpensive consumer-level graphical design software and use the Microsoft Visual Basic 6.0 programming language to develop easy-to-use control and monitoring interfaces. In addition we used LEGO Mindstorms series product from LEGO CO. to construct an inexpensive, easy-to-use and flexible automatic control simulation system.

LEGO Mindstorms Robotics Invention System

LEGO Mindstorms Robotics Invention System is a new product, researched and developed by Media Laboratory of LEGO CO. and Massachusetts Institute of Technology (MIT) in 1984. This product mainly consists of a programmable controller (RCX), as shown in figure 1, which links to DC servomotors, collision sensors, light sensors, rotation sensors, temperature sensors and approximately 700 other pieces of Lego components. Through the various arrangements of these components, users may construct an assortment of automatic controllable simulation mechanical systems according to their demand. The central controller (RCX) of this set of components, is like an ultra large piece of Lego in appearance, and includes a monochrome liquid crystal display, four control buttons, three DC servomotor connectors and three sensor connectors. RCX has a built-in Hitachi H8 CPU, 32KB memory (RAM) and an infrared transmission port (Paul Wallich, 2001). With the infrared transmission module of this package set combined with the USB interface of a PC, the RCX can have bidirectional data communication with the PC. Users, via a PC can control the RCX to drive DC motors immediately, and collect the sensor values; users also may complete the RCX program code in the PC, load this to the RCX using the infrared transmission module, and then start target tasks in the executing programs of RCX.

The biggest characteristic of the Lego system is reusability; by utilizing its modularity and disassembly characteristics, a number of possible combinations can be created. Because of its easy composition and modularity characteristics, complex mechanical components can be composed and completed in a short time - there is no need for special tools and adhesives. Also, as a result of the material properties of Lego, the composed mechanical model does not need lubrication to operate smoothly; and

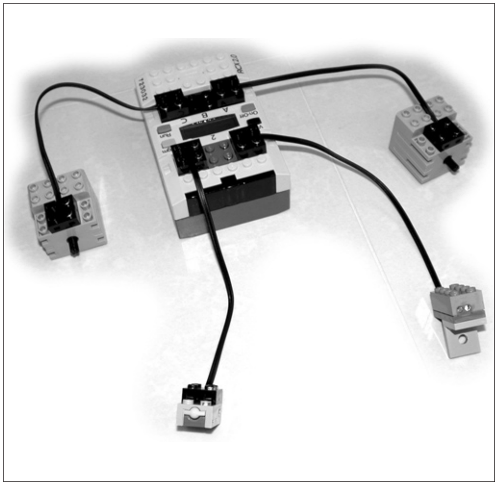


Figure 1
RCX

therefore requires no maintenance. Due to the price and reusability of Lego components, the cost of the automatic control mechanical model composed by Lego is significantly reduced, and the flexibility and the modifiability of the system are greatly enhanced (Mario Ferrari, Giulio Ferrari, and Ralph Hempel, 2002).
RCX Code using the RCX programming language provided by LEGO CO., has already been encapsulated as an ActiveX component;; therefore users can load this component in program development environments, such as Visual Basic etc. Currently, the latest version for ActiveX components of RCX is „LEGO Spirit OCX2-Phantom" (freeware). This programming language provides related commands for controller status setting, servomotor driving, servomotor viewing and sensor status accepting, and also basic logical decision commands. Users can use it to build a loop structure program.

LEGO Mindstorms Vision Command
LEGO Mindstorms Vision Command, one of the LEGO Mindstorms series products, is designed to match the visual monitor system promoted by the Robotics Invention System. This package set contains a PC Video Camera, corresponding special Lego modules and a set of visual control programs. This system can perform basic real-time image display, photo taking and video recording etc., undertake dynamic tracing and color identifying, execute real-time control commands by way of PC to RCX, and advanced image setting on user demand.

Movable Automatic Guided Vehicles
To confirm that using 3D graphical design software to perform practical AGV control applications is feasible, this research constructed a movable tracked vehicle with vision detection system, as shown in figure 2, and in the front end had two LED light sensors used to measure the distance from obstacles. Applying the pre-completed control program to direct the movable tracked vehicle to stop, indicate, turn and fend etc. at the proper moment, and feed back the current status via the infrared transmission module to PC as a reference for the next command. Also, users can refer to the real-time images transmitted by Vision Command System to instruct commands.

Software Configurations

Application Circumstance
This research uses Caligari Co.'s Truespace as the main 3D graphical design software to build a virtual construction site, and combines the Python programming language with Truespace to develop control interface and object behavior in this virtual environment. As illustrated in figure 3, the key data of the simulation process is sent to the LEGO Robotic in Invention system, and control is given to the LEGO AGV to undertake the practical operation simulation. During the development process of using Truespace 3D graphical design software to build a virtual construction site AGV simulation, a high level of computer graphics skill is not necessarily needed to build a virtual construction site as Truespace has an easy-to-operate user interface and a complete set of 3D Model building functions. Also, as Truespace's file type is highly compatible, 3D Models made by other popular graphical design software are can be read in Truespace. Using

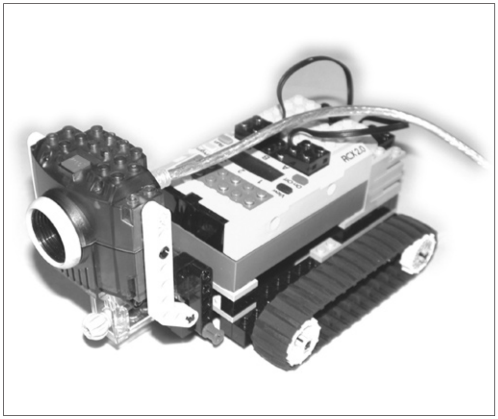


Figure 2
LEGO AGV

Truespace's built-in Python programming language, program management can be applied on any objects and design procedures created by Truespace. In addition, since Truespace has the physical phenomenon simulation functions (gravity, buoyancy, wind power, collision, speed, and acceleration etc.), cooperating with the Python programming control, it can simulate object behaviors extremely similar to that in the real world. This research first used the Truespace model building functions to build a virtual environment of the construction site. The operator applied the input path turning point method in this scene to plan the drive path of the AGV. After the path turning point plan had been completed, the AGV program constructed by the Python programming language is executed. The program loads the model files of the AGV, and then executes the path movement program to perform the AGV movement simulation. If no obstacle collision occurs while moving, then it outputs a set of path data to the PC for the LEGO AGV simulation to use.

LEGO control platform is mainly constructed using the Visual Basic program development environment. It is designed with a user interface using real-time image feedback. The main task is the development of a control module used to manage and coordinate the flow paths among components. LEGO Spirit OCX is an ActiveX component developed by LEGO Invention System. This research used the new version of LEGO Invention system 2.0, LEGO Spirit OCX2, also called Phantom. During the system execution period, the control module inputs commands to the central controller RCX of LEGO Invention System and collects the RCX execution status data, through Phantom via the infrared transmission module with USB interface. Vision Command is an extended real-time image monitor system package from the LEGO MindStorms series; the LEGO CCD in this system can display real-time images using LEGO Code, guide operators to know the surrounding environment status of LEGO AGV, and instruct real-time commands to modify the LEGO AVG executing motion to RCX through its dynamic detection function. Visual Basic 6.0 is the main program development platform used to develop the LEGO AGV program, and integrated with LEGO Spirit OCX2---Phantom and Vision Command ActiveX etc., is used to write the system control program. The Windows control panel constructed using Microsoft Visual Basic 6.0 is shown in figure 4.

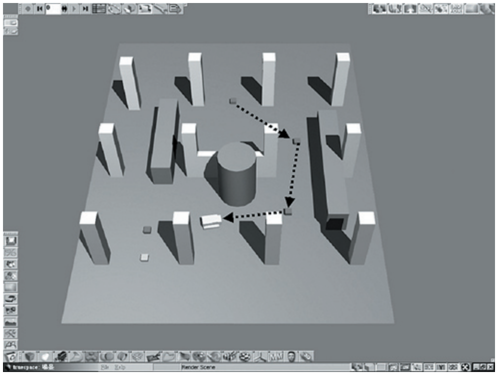
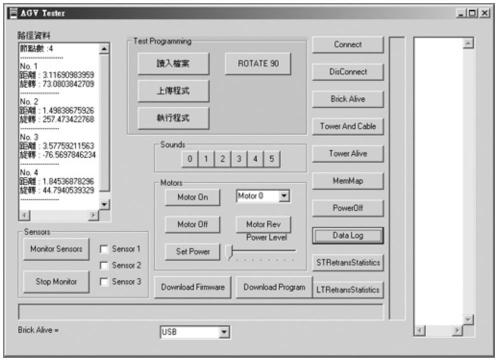


Figure 3
The virtual construction site

Program Construction

The LEGO AGV control program of this research can be divided into two parts. One part is used to construct windows control interfaces and integrate each control interface, and is executed on Windows platform on a PC. The other part is the RCX control program, which has to be loaded into RCX and executed by RCX central controller before LEGO AGV begins its tasks. Therefore, in fact, this simulation system program establishes two sets of programs for PC-end and RCX-end, and these programs have parallel executions. The control module executed under Windows platform is mainly used to coordinate and receive signal flow among all components. The function structure of this program is first to input path data after Truespace 3D graphical design software has executed task flows for simulation; and then move to code structure of LEGO AGV control program and load it into the RCX. After the operator executes the start task command, it starts to receive

Figure 4
The Windows control panel constructed using Microsoft Visual Basic 6.0



the triggered events from all components and executes the related program control according to the preset situation. In addition, the output path data of Truespace is in text file format; the file includes the number of total points, the distance between each point and the vehicle rotation angle etc. The communication between each component of the central control module and the transmission of event messages are supported by ActiveX compiler functions. Visual Basic program code includes, not only the Windows control interface built by its powerful form and windows editing functions but also programming syntax provided by Lego Spirit OCX2-Phantom and Vision Command. The programming syntax provided by Lego Spirit OCX2 is mainly applied on RCX control commands, and used to read and set RCX variables, set sensitivity parameters of sensors, set torsion output value of servomotor and drive the RCX to execute program tasks. Vision Command ActiveX control components provide the functions to display real-time images and execute photo taking and video recording.

In this research, the behavior control of LEGO AGV is entirely controlled by the RCX, therefore, the LEGO AGV execution tasks have to be written into the RCX program code and then loaded into the RCX for execution. LEGO AGV, via RCX program code, controls and drives its servomotor to produce behaviors, such as going forward, going backward and turning; it also controls the torsion output value of motor to result the speed differences. After the RCX program reads and judges the input values of collision sensors and LED light sensors, LEGO AGV generates the feedback reaction, which it should have. All behavior modes of LEGO AGV are written into several program code units, called task and subroutine. A task can use the push stack method to call several subroutines to be combined for execution. Utilizing this type of program composition can cause LEGO AGV to have multiple behavior modes. The PC-end master control module via LEGO Spirit OCX2 ActiveX components, through the infrared transmission module with USB interface, drives the central processor in the RCX to execute the relevant task; and by way of loop structure code and the timer function provided by the central processor, return a feedback for the servomotor status and sensor's input values. The value of this feedback not only provides a motion reference that the microprocessor in the RCX-end can refer to when executing tasks but also can be transmitted to the PC-end through the infrared transmission module providing real-time information about LEGO AGV status via master control module in Windows platform.

The main task of the master control module is to input the output path data from virtual construction site, and translate this into the main task program code for LEGO AGV and load it into the RCX. It also monitors system messages during task execution, and decides the follow-up execution program code to be used and the motion of the related components according to the situation. The RCX of LEGO AGV executes the related program code according to the target task given by the master control module. When requesting motions of a highly real-time nature, for example the collision sensor feeds back the collision message, the program for executing feedback motion and monitoring will be executed directly by the central processor of LEGO AGV. Therefore, the phenomenon of real-time command detention caused by the signal delay of infrared transmission module can be avoided.

Conclusions

This research attempted to develop an AGV simulation system integrated with 3D graphical design software and remote visual monitor. Integrating different software and hardware provides the preliminary path plan simulation for construction machinery and the function of remote control and monitoring. Because of the great enhancement in PC performance, improvement of interfaces in 3D graphical design software, and reinforcement of software functions in recent years, the construction and control of computer virtual reality has became very efficient and a reality. Using LEGO Invention System to design and construct the AGV lets users have a robot construction method different from general industries. Users can employ an economical, easy and simple-operative method to build a simplified model of completed automatic control system. In this research, for convenience, the situation of a real construction site and the complexity of machines movements were greatly simplified. After several experiments, we believe that using PCs combined with 3D graphical design software, visual images and program control to operate the construction machinery has the viability and the characteristics summarized as follows:

1. The AGV simulation environment constructed by Truespace 3D graphical design software lets users experience and record the drive path of an AGV via an intuitive and simple method.
2. The Windows graphical user interface lets operators control and monitor the behaviors of an AGV in an intuitive method.
3. Using CCD real-time image transmission lets operators know the surrounding environment of an AGV ; the independent decision making by the sensors of an AGV enables more effective operation.
4. AGV can feed back the practical servomotor status and input data of sensors to the central control module; therefore we can establish a feedback review scheme after accomplishing the tasks that can be an evaluation and record of the operator's operational performance.

References

S.P. Chen: 2002, VR-Based Teleautonomous System for AGV Path Guidance, Master thesis, Southern Taiwan University of Technology, School of Electronic Engineering, Taiwan.

C.J. Huang: 1999, A Study on Real-time Motion Planning and Controlling for Construction Equipment Using Global Positioning System (GPS), Master thesis, National Taiwan University, School of Civil Engineering, Taipei.

M.H. Huang: 2002, Manipulation of a Mobile Robot System with Voice and Remote Vision Information, Master thesis, Chang Gung University, School of Mechanism Engineering, Tao-Yuan.

S.Y. Kuo, M.D. Wang & D.S. Wu: 2001, A Current Study of Taiwan Construction Factory Apply Information Technology on Management, The 15th Conference of Construction Engineering and Management Union Research Results, pp.269-279.

Mario Ferrari, Giulio Ferrari, and Ralph Hempel (ed.): 2002, Building Robots with LEGO Mindstorms, Syngress, USA.

Paul Wallich: 2001, Mindstorms Not Just a Kid's Toy, IEEE Spectrum, pp.52

P.H. Wang & N.C. Shih: 2002, Apply Mobile Device on Monitoring of Architectural Construction, Architectural Institute of the Republic of China - The 14th Conference of Architectural Research Results.