Development of An Unmanned Autonomous Concrete Floor Robotic Troweling System

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Abstract

It is natural to introduce an automatic floor troweling system to a spacious concrete floor from the point of construction cost and time. Among several methods it would be the efficient to modify an existing available ride-on trowel into an unmanned and remote controlled troweling robot. The handling mechanism of a power trowel is converted to electric actuation of DC servo motors. Overall control system is designed to have a network-based real-time distributed architecture under CAN in order to distract the computational load concentrated on central main controller. The remote controller not only contains many functions to direct the troweling robot in the same way as riding operator does, but also works as input and monitoring devices in an autonomous mode.

The positioning system of the laser range scanning sensor and several reflective beacons, and the job planner based on a blueprint of the floor provides the troweling robot with intelligence to work and navigate autonomously within a given floor area.

1 Introduction

In many building construction situations, it is necessary to provide a smoth and flat appearance to floor which has a finish material such as concrete applied at wet state. However, since the material so applied, such as concrete, is invariably rough and uneven, it is also necessary to provide troweling jobs to make the floor even over large surfaces. Thus, it was common practice to employ teams of manual laborers to draw trowels, sometimes of considerable size, over such manually applied surfaces of concrete. However this practice is quite obviously time consuming, labor-intensive and thus expensive. Moreover the quality, the degree of flatness, is quite dependent on laborer's skill. In order to handle this problem, power trowel systems [2][3] has been introduced recently to concrete troweling tasks to increase the productivity as well as the quality at finishing stage of concrete pavement. Especially, in case of troweling concrete surfaces or requiring super flat floor where many skilled labors at high cost are demanded, powel trowel systems are good solution to reduce the toal construction periods and expenses.

There are several types of power trowel system. First one is a drawing-type power trowel which a human operator draws or pushes with handles. Even though this type of trowel machine is portable and simple easy to operate, however the result of troweling depends on the operator's ability and each machine requires a human operator. The second one is so called ride-on power trowel [3] which an operator rides on and controls manually with levers. Though this type of trowel system has an advantage of doing work based on widely experienced judgement, the result of troweling also depends on an operator's ability. Therefore the uniform working results would be expected with a troweling robot because the intervention of human factor can be reduced. Furthermore, in constitution of the automatic concrete flooring system, it is essential to have an autonomous troweling system after forming, spreading and screeding processes.

Finally, there is a semi-autonomous troweling system such as Surf-robo[2]. This system is operated by remote operator's panel via wired or wireless communication. And also, the system has an autonomous troweling capability for a prespecified pattern of movement. But the system does not have an absolute position sensor for the body, it is often resulted unexpected movement due to the uneven friction between trowel-

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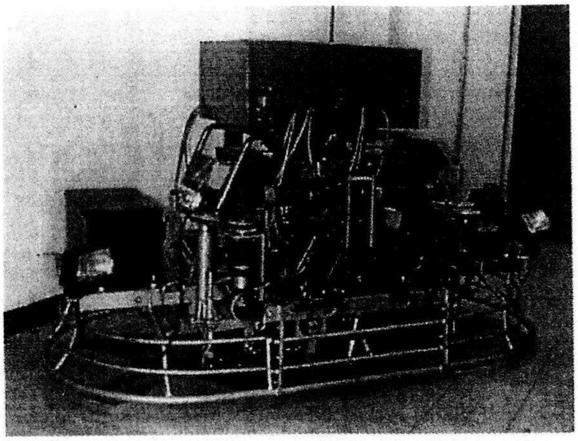

Figure 1: The unmanned autonomous troweling robot

ing blade and floor.

In this paper, design experiences are described for developement of an unmanned autonomous concrete floor troweling robotic system, where the system is designed to have several key feature as follows :

i) autonomous navigation with laser positioning sensor
ii) remote operation via wire/wireless communication
iii) user specified troweling pattern tracking
iv) automatic troweling pattern generation with collision avoidance
v) advanced man-machine interface with monitoring capability

For the system hardware, we employed RAZORBACK RIDER PRO900 [4], which was designed originally for ride-on powel trowel. The mechanical structure of the machine was reconstructed in consideration of operational functions as above. Its mechanism will be outlined shortly afterwards. The electric control system is designed to be a network-based distributed architecture which consists of Industrial PC-based main controller and network-based motor controller.

Moveover, there are two indispensable requisites to build an autonomous troweling system. First, a job planner forms the scheme how to move the troweling robot around the working floor from a given blueprint avoiding obstacles such as pillars and iron rods. Second, the positioning system identifies the current posture of the robot in working area by contact with external references.

2 System Description

The ride-on powel trowel which is manually handled by an operator has been converted into the unmanned troweling robot as shown in Fig. 1. Each DC servo motor controller within small box is attached close to corresponding motor. Remote controller and job planner in main controller with above systems constitutes an autonomous concrete floor troweling system. The manual twin lever of directing the movement are replaced with the electric-powered actuation to be an unmanned system.

Table 1: Specification on the unmanned troweling robot by electric actuation

Ride-On Trowel			
manufacturer	Allen engineering corp., USA		
product	Razorback Rider PRO900		
engine	Honda GX620 – 650cc, 13.6KW		
trowel	4 blades, 2 rotors		
Attached Components			
DC motors	steering	pitch	accelerator
power[W]	100	60	10
gear ratio	100:1	50:1	33.2:1
torque[Nm]	0.265	0.157	0.029
generator	75A, 12V		
battery	40AH		

2.1 Unmanned Troweling Robot

The mechanical system of the original ride-on trowel divides mainly into trowel part and handling part. The trowel part with four blade wings levels off the floor by turning force powered from a gasoline engine. The handling part is in a form of two steering levers, two pitch levers and two pedals so that an human operator on riding controls with his both arms and both feet. The twin steering lever in the middle directs the movement and the pitch lever on either side adjusts the pitch angle of blade wings. The right pedal steps on an accelerator and the left pedal stops the trowel at an emergency.

While leaving the trowel part as it is, we substitute only the handling part for an electrically powered mechanism. The timing belt and pulley mechanism is applied in order to connect both axes between the servo motor and the joint of lever, which helps avoiding severe modification of original mechanism. Totally six DC servo motors are used as three for steering, two for pitch, and one for accelerator. And other electric devices are installed for automatic starting of the engine and power system The specifications on the troweling robot are listed in Table 1. The planetary gear of high ratio is used for steering due to large payload on mo-

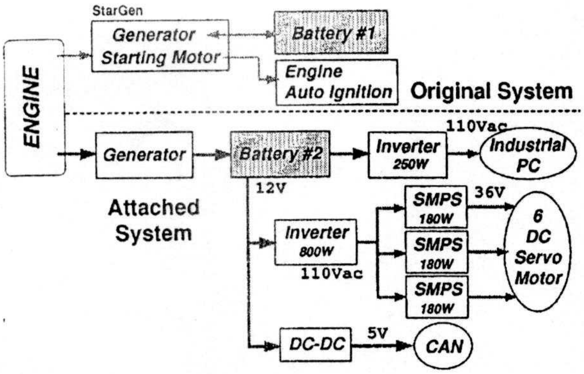

Figure 2: Reconstruction of power system in trowel robot

tors.

2.2 Reconstruction of Power System

Because self-power contained robot has the advantage of moving around the floor without an umbilical power code, all the power used in the troweling robot generates from an engine. The umbilical code can supply power continuously but may restrict the workspace and dexterity of movement. A motorcycle gasoline engine is loaded on the inside center and supplies the rotating force to the trowel part through gear box. The battery and the starting motor also is already loaded to supply the power to engine ignition and lightening system through an electric generator.

Additional electric power is required to attach new equipments for the automatic trowel robot, and then another generator and battery should be installed because of a lack of an existing capacity. Roughly a tenth of power capacity of the engine is drawn for new system. Two inverters are inserted in need of various form of electric power and separate lines of suppliment to controller and actuators for safety. The power flow chart from the engine to each equipment is shown in Fig. 2.

3 Real-Time Distributed Controller

Overall control system for the troweling robot is designed to have a network-based architecture, as shown in Fig. 3., breaking from a general centralized control architecture commonly used before. The communication between each controller is performed under CAN(Controller Area Network). The basic reason is to reduce computational loads of a central controller by distributing the loads to each decentralized

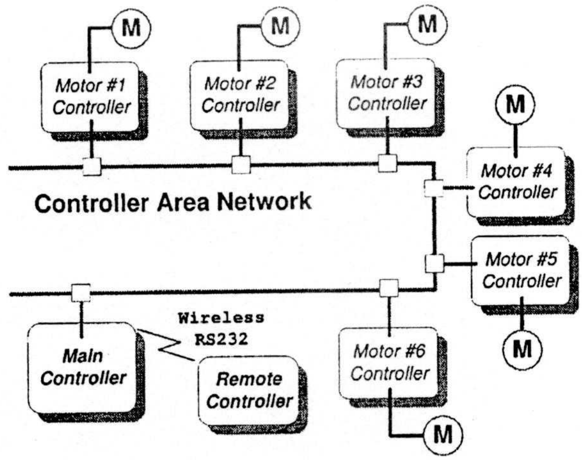

Figure 3: Network-based distributed control architecture of the overall control system

controller and to cut down efforts for wiring because motor controllers need so many control lines and input/output signals. This control architecture is not only convenient to maintain and repair the system but also enhances the efficiency of production by reducing the amount of line connections. Further, the cost for the main central controller decreases since its heavy computational loads for motor control is transferred to each controller. The main controller communicates with the remote controller by the wireless RS-232C modem and the motor controller is linked up the main controller by CAN which is a high speed real-time network up to 1Mbps. CAN is very adequate for real-time control because its communication arbitration is accomplished by hardware handshake using its network identification number and the communication data overhead for networking is very small compared with other network protocols.

Developed compact motor controllers can be installed right nearby corresponding DC servo motor in order to reduce the noise in industrial field and increase credibility on motion control. The structure of overall control system is shown in Fig. 3.

3.1 Main Controller

The main controller instructs the troweling robot according to the remote controller or self-decision like a human brains. Because the main controller receives the data about current posture of the robot from positioning system and contains a job planner, it can supervise the troweling procedure. We use industrial PC PCA-6145 manufactured by Adventech which contains Intel 486DX4-100MHz, three ISA slot, and PC/104-

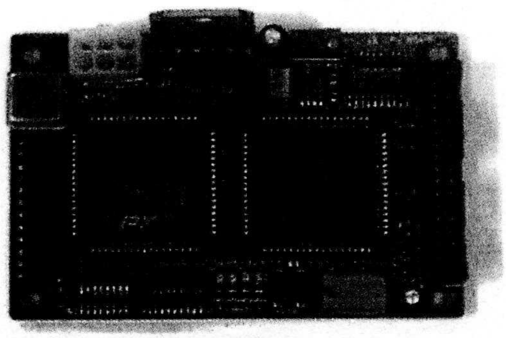

Figure 4: The DC servo motor controller with the built-in motor driver and CAN module. - $90mm \times 60mm$ (W×H)

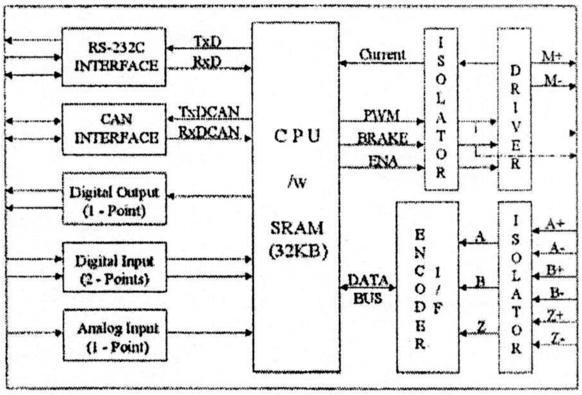

Figure 5: The internal structure of the motor controller

BUS CAN interface module to communicate with motor controllers. An interface card for AccuRange-4000 laser rangefinder, shown in Fig. 7 at the following section, is included in ISA slot in order to detect the posture of the troweling robot by triangulation. The software program is stored at flash memory inside CPU module. To send and receive message such as command and status the application layer over CAN protocol is established in the main controller as well as in the motor controller.

3.2 Motor Controller

As shown in Fig. 4 we have developed a new-type motor controller that a motor driver and a CAN communication module are built in. It is designed using Intel 87C196CA for control and National LMD18200 for motor driving. It contains 1 digital output, 2 digital input, 1 analog input, 1 PWM output and encoder

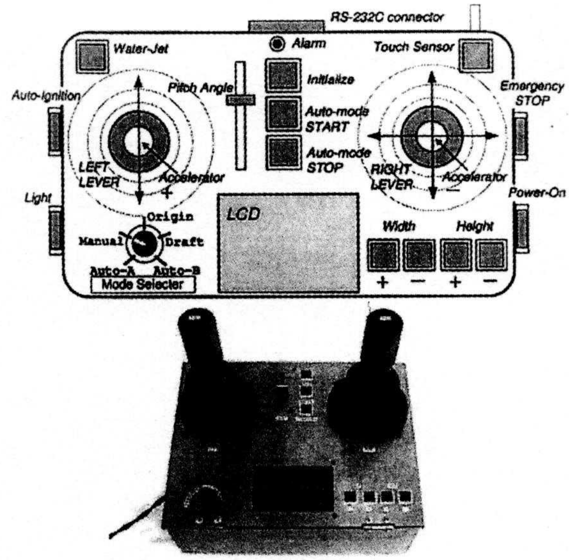

Figure 6: The remote controller and its function specifications

unit as shown in Fig. 5. An RS-232C interface also is provided for the software development. It is possible to control the DC servo motor in position, velocity and even torque mode.

3.3 Remote Controller

The handling of the remote controller is almost same as that of the original ride-on trowel. The right joystick moves transversely and longitudinally while the left joystick moves only longitudinally as twin steering lever of the trowel does. The pitch of both trowels declines simultaneously in the same degree by one slider. The accelerator is controlled by push-buttons on the top of both joysticks. The other functions required in troweling such as ignition, watering, lightening and touch sensor are implemented on the panel. The status and commands are communicated between the remote controller and the main controller in the robot by a wireless modem.

Here, it should be noted that the developed remote controller is able to read a data stream of working trajectory palnned and downloaded by a notebook computer via serial communication while the data stream is sent to the main controller of the robot via wireless serial communication. Also, the remote controller has a LCD unit in order to display current operating status and current position of our troweling robot. After downloading of a motion trajectory, the robot is moving autonomously with following the given trajectory

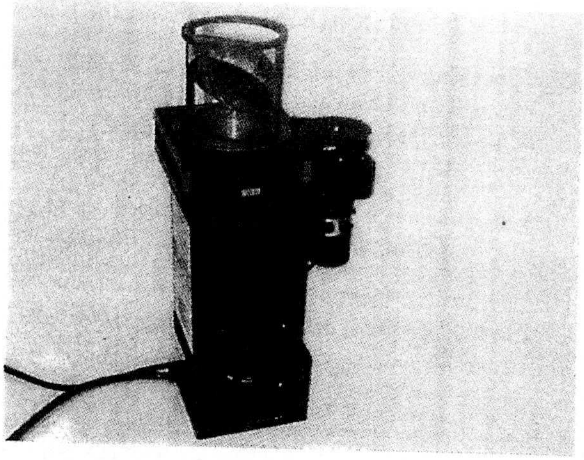

Figure 7: Laser line scanner – 360° full rotation of mirror and rangefinder ACCURANGE 4000

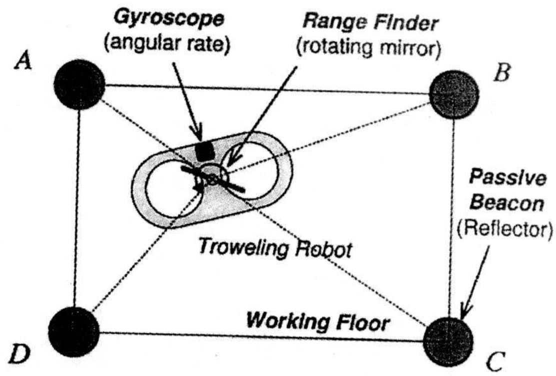

Figure 8: Robot positioning method by triangulation with line scanner and reflective beacons, and angular rate of gyroscope

by sensing its location. The semi-autonomous system with the remote controller improves the working condition for an operator, otherwise one riding the trowel would suffer from severe vibration.

4 Troweling Robot Positioning by Triangulation

The positioning method by triangulation is illustrated in Fig 8. Among several combinations we select a configuration of rotating transmitter and stationary reflectors because passive beacon is preferable to active one in concrete flooring where the location of beacons would always change as the working floor does. The line scanner is composed of a rotating mirror and the rangefinder ACCURANGE 4000 manufactured by Acuity Research Inc. A DC motor with position encoder drives the mirror through a timing belt and pulley not to block the laser beam in rotating. The histogram of the distance over a full circle can be acquired and analyzed to extract the point corresponding to each beacon. From known location of each beacon the position and the orientation of the troweling robot can be determined in reverse. Because at least three beacons must be visible for triangulation, beacons are deliberately distributed in working floor or sometimes more beacon are needed. The capacity of the rangefinder up to 50,000 samples per second and 50 feets gives 10 times update of current posture every second.

It is susceptible for the robot to rotate due to slight imbalance of steering or irregular floor condition. To get a good troweling result the robot needs to advance straight line along with rotation of its body. Therefore the gyroscope of angular rate type GYROSTAR-ENV05H manufactured by Murata Electronics is added to compensate the relatively slow update of the orientation from line scanner system. On controlling its rotational movement the angular rate is very useful as feedback information.

5 Job Planner

The autonomous operation of troweling system divides following three modes.

- Manual : An operate outside working area handles the troweling robot by the twin joystick and the other buttons in the remote controller in similar way that a riding operator does.
- Auto-A/B : The size of rectangular area to be trowelled enters with width/height button while the mode selector in the remote controller is set to size mode. There are two different troweling patterns as shown in Fig. 9. One pattern drifts to right side and the other to left side. Within this rectangular area the troweling robot repeats straight and turning movement.
- Draft : The blueprint of working floor is entered as CAD data format. An operator runs the job planner programmed at notebook computer. Fig. 10 shows the work of job planner which finds the optimal path with avoiding obstacles within a given floor. This result is downloaded to the remote controller of the troweling system by serial communication.

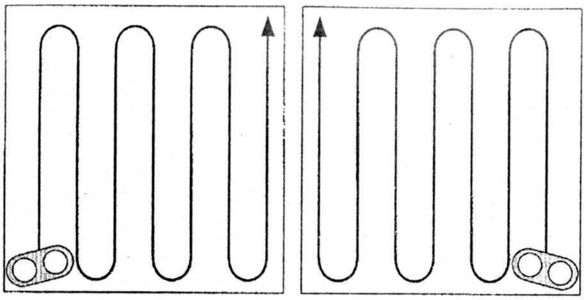

Figure 9: Path patterns in Auto-A and Auto-B mode

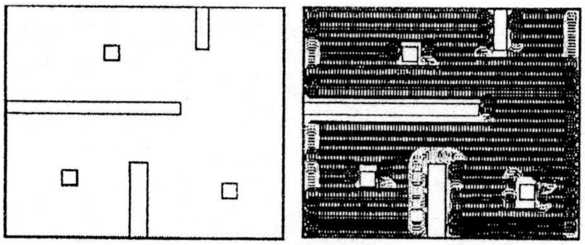

Figure 10: The optimal path generated by job planner from given working area in draft mode

In draft mode the hierachical local searching algorithm is proposed for obstacle avoidance. This algorithm uses not global informations but local information such as euclidian distance between cells and the number of cells containing obstacles, which reduces the memory capacity.

6 Conclusion

We have developed the autonomous concrete floor troweling system taking an existing ride-on power trowel as a basic platform. An power trowel is converted into the electric-powered automatic troweling robot. To construct overall control system of network-based distributed architecture, the motor controller and the remote controller are newly designed and the real-time CAN is applied to it. The laser positioning system and job planner are implemented so that the troweling robot works autonomously around a flat floor.

Now experiments are undergoing to check its function and increase performance of this system.

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