PROTOTYPING AND AUTOMATING A CONCRETE SURFACE GRINDING MACHINE FOR IMPROVING INFRASTRUCTURE CONDITIONS

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Abstract:

A remote-controlled and automated concrete surface grinding machine is introduced in this paper. The machine is designed to grind the unsmoothed concrete surface of bridge decks, airport runways, and road pavement. The remote control was required because of the hazardous working condition created by the concrete dust. A graphical man-machine interface (MMI), a path planning system, and sensors including GPS and sonar made the precise and safe operation of the machine possible. The automated quality control system being developed currently would ensure the work quality of the machine by detecting uneven concrete surface and performing the required grinding work properly.

Keywords: Concrete Surface Grinding, Graphic Control Interface, Wireless Remote Control, Global Positioning System

1. Introduction

Concrete surface of infrastructure including bridge decks, airport runways, and concrete pavement requires a precision finish of surface conditions. Unsmoothed surface degrades the quality and comfortability of highways. In case of newly constructed concrete bridge decks, unsmoothed concrete surface needs to be eliminated because unsmoothed deck surface eventually creates uneven thickness of the pavement layer. In addition, the bond between the deck and the pavement layers needs to be provided by eliminating a thin layer of concrete surface. The degraded concrete surface layer of any existing concrete structure should also be eliminated before maintenance and/or rehabilitation work is applied. One of the common approach to improving the surface condition is manual grinding using a conventional concrete surface grinding machine. The grinding work, however, is usually executed in an unsafe and environmentally hazardous conditions. The objective of this paper is to introduce an automated concrete surface grinding machine. The machine is designed by improving a conventional concrete surface grinding machine. The grinding machine is retrofitted by adding electronic motors, GPS, sensors, and a graphical man-machine interface, a path planning system, and a quality control system for the purpose of remote control. These functions will be used to give automatic controllability including path planning, position detecting, collision avoidance, and quality control of the processed concrete surface. With the developed remote-controlled concrete grinding machine, the exposure of the workers to the hazardous concrete dust could also be avoided.

2. Characteristics of concrete surface grinding work

The manual operation of concrete surface grinding work involves several challenges. First of all, the work environment is very hazardous. As seen in Figure 1, the laborers that deal with small scale concrete surface grinders are exposed to concrete dust during operation. The operators of large scale concrete surface grinders with a vacuum dust collector are not free of dust hazard either. Secondly, the quality of the grinding work completely depends on the skills of the laborer and/or the operator. Due to the hazardous work conditions, it is very difficult to keep the skilled workers resulting in the bad quality or even re-work of the operation. The manual grinding work may also easily create accidents such as collision between grinders, laborer, and structures. The concrete grinding operation also creates air and water pollution problems. The small scale grinding machines shown in Figure 1 do not have dust collectors, therefore creating air pollution problems. Some grinding machine use water in order to cool off the heat of the diamond grinding head, therefore creating polluted water mixed with concrete dust.

Figure 1. Manual Operation of Concrete Surface Grinding

Table 1 summarizes the characteristics of concrete surface grinding work.

Table 1. Characteristics of Concrete Surface Grinding Work

Classification	Characteristics
Concrete Surface Grinding Work	Labor intensive
	Demands on the higher productivity
	Low work quality by unskilled labor
	Possibility of re-construction
	Accidents caused by lack of experience
	Hazardous working condition by concrete dusts
	Air and water pollution

3. Automated Concrete Surface Grinding Machine

The development of the automated concrete surface grinding machine is accomplished by developing and integrating the following five major system components.

- Concrete Surface Grinding Machine
- Graphical Control MMI
- Path Planning & Collision Avoidance System
- Remote Control Unit
- Quality Control System

The concrete surface grinding machine was designed by improving the conventional large scale concrete surface grinder so that it can be automated and remote-controlled by integrating the automation components. These five system components are explained in detail in the subsequent sections.

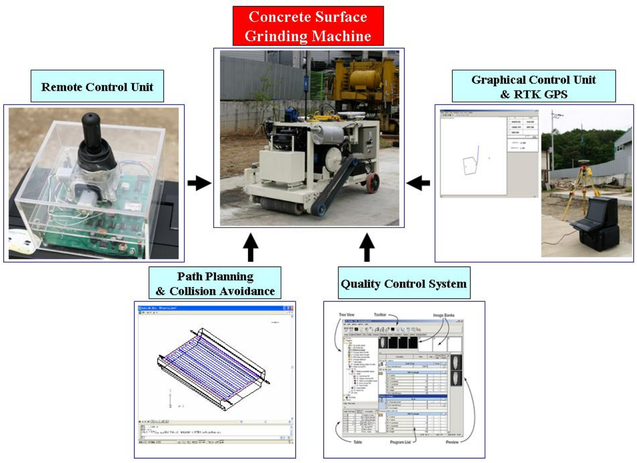

Figure 2. Concrete Surface Grinding Machine Components

3.1 Concrete Surface Grinding Machine

The main body of the concrete surface grinding machine is composed of a steel frame, four wheels, a grinding blade and a diesel engine and a battery to provide power to move the machine around the work site and to rotate the diamond grinding blade.

Other major components of the machine are two electrical motors and a generator for driving the machine, and a hydraulic system to control the vertical movement of the grinding blade.

A control box to secure the wireless communication system, GPS antenna, sensors for collision avoidance and quality control are attached to the machine for automated and remote control of the machine.

The grinding blade needs to be contacted with the concrete surface and rotated with fast rotational velocity and strong power, which makes the diesel engine with high torque to be selected as the power source.

Two electrical motors powered by the generator of the diesel engine drive the two rear wheel separately. The electrical motor is well suited for remote-control of the machine with its more precise control capability compared to engines. The change of direction with the motor is accomplished by differentiating the speed of the two motors.

Figure 3. Concrete Surface Grinding Machine

3.2 Graphical Control MMI

Graphical control MMI system is composed of Man-Machine-Interface Unit and GPS System. MMI Unit includes an industrial computer and a display monitor, and designed to provide the visual feedback of the position and orientation of machine as well as the work progress and quality control information. It is also an input/output tool for the path planning system.

GPS system is for data calculation/validation for graphic visualization of the real time position and composed of RTK-based unit and subsidiary communication equipments to increase an accuracy of GPS receiver attached to concrete surface grinding machine. And the supporting software handles designed CAD data of concrete surface, quality control information and GPS data in real time. So it displays position/direction of machine, planned path and progress of work on MMI monitor and helps avoiding collisions with objects in working environment through real time geometry analysis.

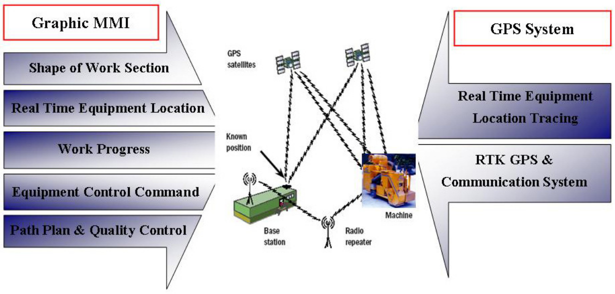

Figure 4. Graphic MMI for Concrete Surface Grinding Machine

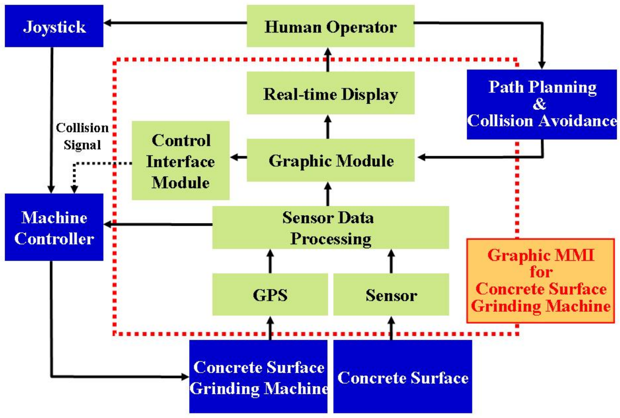

Figure 5. Architecture of Graphic MMI

3.2.1 Graphic MMI

The architecture of a graphical control interface varies according to its functionality in an equipment control system. In practice, however, graphical control interfaces can be divided into two architectural classes, active and passive [Seo et al. 2000].

An active graphical control interface system forms a part of an equipment control system. With this type of graphical interface, the operator can perform real-time simulation and task planning by manipulating graphical models. The simulated or planned commands are verified and then passed to the equipment through the controller interface module. The operation can then be monitored with the real-time updated graphical models or live views while the graphically generated motion commands are automatically executed [Sheridan 1992].

On the other hand, graphical models are updated as the status of equipment and work environment change, but no task planning or simulation with graphical models are employed in passive graphical control interface. The operator gets enhanced visual feedback from a graphical display, but the operator controls equipment directly through the equipment controller. Therefore, a controller interface module is often not required, or minimal interactions between the controller interface module and the controller, such as emergency stop signals, exist. This type of graphical interface helps the operator's decision making simply by providing an additional source of visual feedback to a direct line of sight or closed circuit television (CCTV) feedback. More than that, it also acts as a measurement system and a recorder of progress and work completed.

In the concrete surface grinding machine case, with the passive graphical control interface employed, the operator could improve the manual operation by intermittently comparing the graphically presented position of the grinding machine's position and orientation along with the work progress and quality control information.

Therefore, passive type interface is more appropriate to concrete surface grinding and the operator must monitor live visual feedback frequently with path planning and collision avoidance system.

3.2.2 RTK GPS

Concrete surface grinding machine needs RTK (Real Time Kinematics) GPS for remote control in order to bring position information to operator. RTK positioning is based on at least two GPS receivers, a base receiver and one or more rover receivers. The base receiver takes measurements from satellites in view and then broadcasts them, together with its location, to the rover receiver. The rover receiver also collects measurements to the satellites in view and processes them with the base station data. Typically, base and rover receivers take measurements at regular 1 second epochs (events in time) and produce position solutions at the same rate. The key to achieving centimeter-level positioning accuracy with RTK is the use of the GPS carrier phase signals, so RTK is suitable to use its data for remote-controlled concrete surface grinding machine Trimble 2003].

RTK GPS is organized at the base station and the mobile station. The mobile station, which is the remote-controlled concrete surface grinding machine, is composed GPS receiver, transmitting radio modem, antennas and attached concrete surface grinding machine in field. GPS receiver receives the satellite signals through antenna and calculates the coordinate data of grinding machine based on the revised data by communicating with the base station. The receiver, subsequently, sends the revised coordinates data to control center through the radio modem. Control center, which is composed receiving radio modem, control computer and program, receives the final positioning data and change it to graphical information for operators to monitor concrete surface grinding work.

3.3 Path Planning & Collision Avoidance

Concrete surface grinding machine is used to finish the mission within the confirmed work space such as bridge decks, airport runways and etc. Therefore, it needs to devise path plans before operation and to use position data of path planning to attain the satisfactory grinding work. Figure 6 shows the structure of the path planning and collision avoidance system [Moon and Bernold 1997].

The path planning and collision avoidance system is currently being developed under a commercial CAD environment. 3-D CAD data of the machine and the work environment are used by the decision making module to create collision free and optimized path plan.

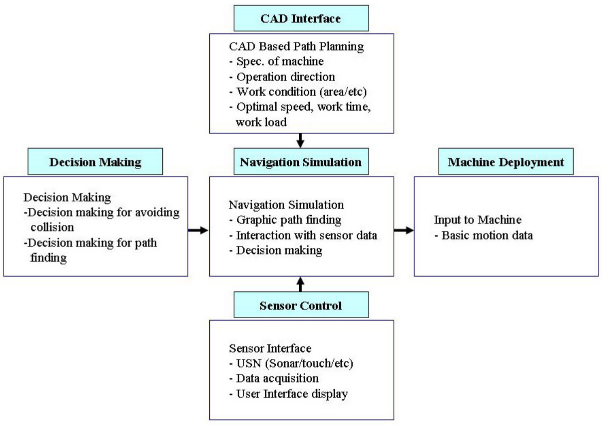

Figure 6. Path Planning and Collision Avoidance System

Path planning devised on CAD environment and CAD drawing of work environment and equipment will migrate into the graphical MMI system. Collision avoidance system utilizes sonar and touch sensors to help recognizing unplanned and/or unexpected objects and adjusting path plans to work safely without interruption.

3.4 Remote Control Unit

The concrete surface grinding machine is remotely controlled through the graphical MMI which is a high-level communication tool between the operator and the machine. The remote control unit explained in this section takes care of the wireless communication of the sensor data from the machine to the operator and the control command data from the operator to the machine. This remote control unit is composed of the main control and the supportive control as shown in Figure 7.

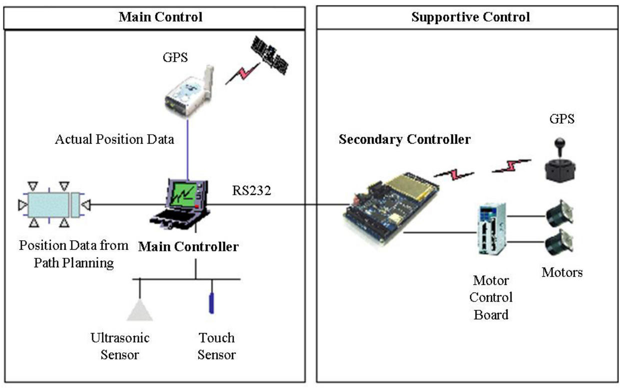

Figure 7. Control Plan for Concrete Surface Grinding Machine

3.4.1 Main Control

The navigation information of the machine is tracked against the planned path and the work environment information by transferring the path planning information and the GPS data to the main controller.

The ultrasonic sensor and the touch sensor data acquired by DAQ (Data Acquisition Board) are presented to the operator through the graphical MMI system via the main controller. The operator is then able to make decision regarding the operation based on the GPS and other sensor data.

3.4.2 Supportive Control

The operator manipulates the joystick shown in Figure 8 to send the control command to the machine. Two electrical motors to drive the rear wheels are controlled by the control command from the joystick control board which processes the joystick control signal.

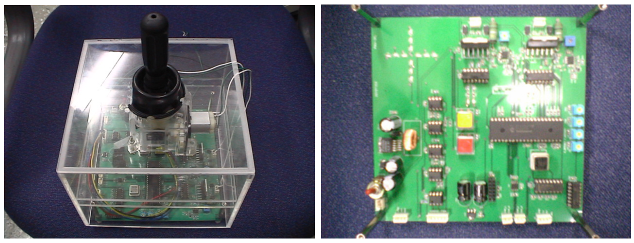

Figure 8. Remote Control Joystick Controller

3.5 Quality Control System

The results of flatness measurement show that concrete surface flatness quality varies significantly according to work conditions during the construction of concrete facilities. Especially, it is necessary to grind concrete surface at concrete pavement joints.

In the works where needs a certain level flatness of the quality standard, real time quality control system helps concrete surface grinding machine to observe, understand and execute work conditions.

Quality control system is being developed and composed of the measurement system using the 3-D image and other sensing system and data processing unit. Using the surface information from the image system, the quality control system measures the grinding depth and width and creates data for work planning. And then, it compares the quality standard for remote control of the machine.

4. Test and Evaluation

For the test of the machine, the remote-controlled concrete surface grinding system was composed of a remote-controlled grinding machine, a temporary control center and GPS base station as shown in Figure 9. The grinding machine was controlled on the rough concrete surface by remote control. The operator controled the machine through graphical interface using position data from GPS in the control center located in a safety environment.

Figure 9. Concrete Surface Grinding System

The developed prototype system without the finished control station and the quality control system was tested at a test bed with concrete surface as shown in Figure 9.

To operate the concrete surface grinding machine, the grinding machine was placed on 10m × 3m on the concrete surface and GPS base station and the temporary control center with an industrial control computer and joystick were prepared. And then the operator could start concrete surface grinding work.

Controlling the grinding machine was accomplished by manipulating the joystick with the graphical interface support which displays condition of the machine and the test bed.

Currently the operators can remote-control a forward/ backward movement, rotation and grinding depth through changing the elevation of the machine.

According to a test result, the diamond grinding blade, powered by 140 HP diesel engine, could grind the concrete surface satisfactorily and the performance of the concrete surface grinding machine including the maneuvering capability was satisfactory.

Figure 10. shows the tested concrete surface before and after of the grinding work. Only the very first operation of the prototype system have been tested yet and the more detailed tests on the positional accuracy, collision avoidance as well as the quality control system along with other features are planned within the near future.

Figure 10. Comparison of Surfaces

5. Conclusion

Current concrete surface manual grinding work has high level of safety and quality concerns caused by the lack of skilled workers. Moreover hazardous work conditions cause industrial disaster and environmental pollution. Therefore development of the remote-controlled concrete surface grinding machine, which supports decision-making of the operation in relation to the work progress and the work quality, would contributes to overcome limitations of productivity and safety of the current conventional operation.

In addition, the developed automation skills (e.g. real time position detecting, optimal path planning, collision avoidance and quality control system) would be able to offer knowledge foundations which can apply to automated earthwork system, piling machine, crane, concrete pump, dredging machine and etc. Furthermore successful development of remote-controlled machine contributes image raising and promotes the circumstance for research revitalization of automation.

Acknowledgments

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