THE EFFICIENCY OF A 3-D BLADE CONTROL SYSTEM IN THE CONSTRUCTION OF STRUCTURE LAYERS BY ROAD GRADER – AUTOMATED DESIGN-BUILD OF ROAD CONSTRUCTION IN FINLAND

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Abstract: The paper reports on the research work in the domain of automated road construction. A new method and prototype of automated road grader has been developed in Finland. The working experiments show measurable influence and quality as well as economic profit to be achieved by the new technology.

Keywords: accuracy, automated construction, construction economics, design-build, economic efficiency, road grader, 3-D machine control

Introduction

Fast progress of teleinformatics, positioning technologies and 3-D-road design software has enabled to develop new blade control systems for road construction machinery. The major expectations of these systems are to increase productivity of the construction project and prefer quality of the end product. The objective is to build a complete digital link from design to layout. With the installation of centimeter accuracy guidance on board the earthmoving machines, the operator can fill and cut surfaces in relation to the road design. The goal of this development project is very challenging but if work is successful and reach objectives, economic benefit can be outstanding.

According to the publications of Finnish Road administration the capacity of traditionally controlled (without 3-D-machine control) motor grader on road finishing work is in practice about 7000 m^2/shift. While grader is doing for both spreading and finishing work method capacity is in normal road works about 2300 m3itd/shift (Work planning information for Road Construction 1-2, TVH).

Automatizing the total process of road construction

Since late 1990 there has come several internationally marketed motor grader 3-D machine quidance and control applications developed by such companies as Trimble, Leica and Topcon with their partners. In these applications, blade positioning needed is based on robot tacheometer or RTK-GPS. In Europe, some countries have also developed their own systems for 3-D machine control. Detailed research results about economic benefits and other experiences have very little been introduced and thus not available.

Total numerical working process of road construction consists of four part-systems. Helicopter laser scanning measuring system measures first terrain model. Measuring helicopter is positioned with GPS technology. Measuring data, terrain model which accuracy is 5-20 centimeters, is used for road structure design process. To produce steering data for the blade of construction machine we need 3-D road design software to produce 3-D design plan. In addition, the design plan has to translate to actual machine control data. (Fig. 1).

In the construction machine there must be a ”comparing-software” and blade controlling system unit, which compares the real time positioning data with the 3-D road-design and calculates the steering data for the blade controlling system. In the end of the cycle the blade control system steers blade to right elevation and slope. The construction machine and the blade must fit on with the slope-sensors to pinpoint the blade position in proportion to construction machine (picture). Controlling system includes also real time quality control system of as-built road structure. As-built height and slope accuracy and efficiency on work process is documented real time. Time and money can be saved even 50 % by reducing measuring costs and by more efficient grader at road construction site.

The object of our research and development project “Intelligent road construction” is set to develop a new numerical operation process for road construction. Measurements will be operated by advanced 3-D measurement technologies and computer aided design by 3-D CAD tools. 3-D design models will be control directly without delay automated measuring and construction machinery. Finally, the quality control will be executed through automated quality control tools.

In this paper, the first result of the intelligent road construction program – the automated road grader and its working experiments are described. The construction of the mecathronics of the road grader is solved by integrated total solution principle. Hence, the movement possibilities of the different parts of the machine are very extensive.

A new integrated total solution principle and the first practical implementation has been developed in Finland. In this system the sensors and developed software algorithms control all of the directions of blade’s movements. Developed system controls blade’s height, slope and driving line automatically but also gives the operator possibility to control all blade movements concurrently by one joystick. This function gives to an operator a possibility to control real time the movements of gravels. Robotic total stations are used as a positioning system. When operator opens the system it automatically starts to control robotic total station.

Furthermore the machine control system contains integrated quality control system for final height and slope of the road layer and also graders capacity measuring features. The control system is working in PC and thus the operator can utilize wireless data communication, which is also included in system. Road models, quality control and capacity data are carried forward by email or in addition by data card.

The 3-D system has graphical interface from where the operator can see blade position compared to design. The digital design of the road layer is created with Terra Street design software. New company Roadsys Ltd has started to market the 3-D blade control system. The trade name is Robot Grader (Fig. 2).

Site tests

Two experiments were executed in two road construction sites as parts of motorway construction –projects in Tornio-Kemi and Salo in Finland, 2000-2001.

<u>Results</u>

The detailed results of the work studies executed are introduced in tables 1-5. In the tables, the term “basic capacity” is determined to be machines work achievement per basic working time, which is the time when machine is all time working. The term “method capacity” means machine’s work achievement per method working time, which includes basic time and other time used in efficient working for example setting times of tacheometer, waitings of truckers, etc.

According to the tests (table 1) the standard deviation of the 3-D blade control system in unbound base course is about 17 mm in height direction. According to the specifications of Finnish Road Administration the tolerance for that work phase and product part is ± 20 mm. All of the slope measurements (table 2) fulfill the tolerance requirements. According to the work studies (tables 3-4) the economic benefits grew best up more than 50 %. It is also essential to notice that the needs for measurement crew as well as the costs are decreased.

Conclusion

The practical functionality of the operation principle was verified by the experiment results. The adequacy of accuracy was proven to be sufficient. Economic benefits by automation were observed.

The road and traffic design and construction techniques are developing rapidly worldwide. Teleinformatics and positioning technologies play important part in this process. Finland is one of the countries in developing these new technologies and also suitable operating environment for testing them. Construction industry should without prejudice start to use and take advantage of these new technologies.

Intelligent Road Construction Site IRCS is a Finnish research and development programme been started in Finland. The programme consists of several different research and development projects. The entirety is scheduled 2001-2005 and it collects about twenty infra companies and other parties of road construction process. The total investment for research activities is about 2 M€.

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REFERENCES

Heikkilä, R. (1996) The Applicability of an Electro-Optical Coordinate Measuring Technique to the Dimensional Control of Precast Concrete Facade Panel Production. Oulu, Acta Universitatis Ouluensis, Technica C 86. Doctor's thesis. 87 p. + Appendixes.
Heikkilä, R. & Jaakkola, M. (1999) New Automation Possibilities for Road Construction Methods. Košice, the 3rd Scientific Conference with International Participation "Building and Energy" in Košice, 8-9 September 1999.
Heikkilä, R. & Jaakkola, M. (2000) Planning Future Activities for Road Construction Automation Purposes. Construction Economics News, 1/2000, p. 6-9.
Jaakkola, M. & Heikkilä, R. (2000) Liikkuvan työkoneen ohjaus tienrakentamisessa. Tiehöylän ja murskeenlevittimen CAD/CAM-järjestelmät. Tienrakennusautomaatio. (Controlling mobile work machines in Road Construction. CAD/CAM systems for road grader and mass spreader. Automated Road Construction. Project Report. Confidential. Oulu, University of Oulu.
Jaakkola, M. & Heikkilä, R. (2001) Automatizing a road grader for Finnish Road Company – Development Phase I. Project Report. Confidential. Oulu, University of Oulu.
TVH 733892 (1983). Tien tekemisen työnsuunnittelutiedot 1-2 (Work planning information for Road Construction 1-2). Finnish Road Administration.

SOURCES FOR PRODUCT INFORMATION

www.leica-geosystems.com
www.topconlaser.com/MC_Products
www.trimble.com/bladepro3-D.html
www.mikrofyn.com
www.precisesurvey.com
www.roadsys.fi

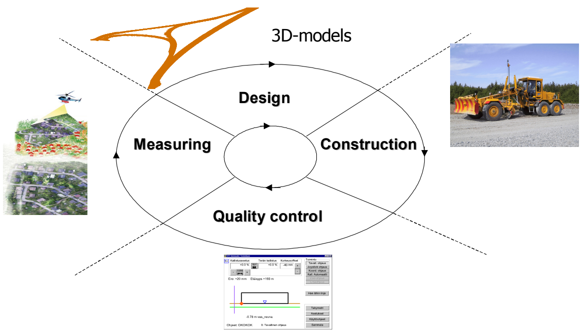

Figure. 1: The principle of the numerical working process of road construction.

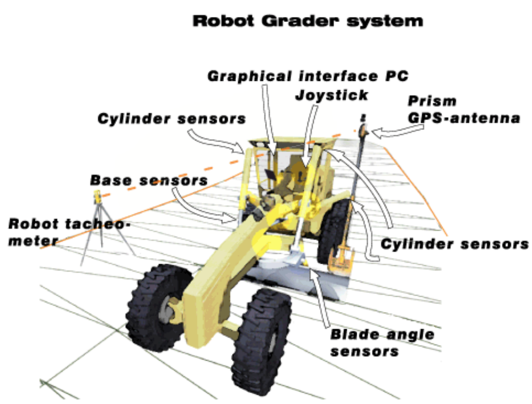

Figure. 2: Robot grader. A new 3-D blade control system principle for road grader.

Figure. 3: The 3-D surface model created for the tests. The model was designed by Terra Street CAD application and used directly to control the blade of grader.

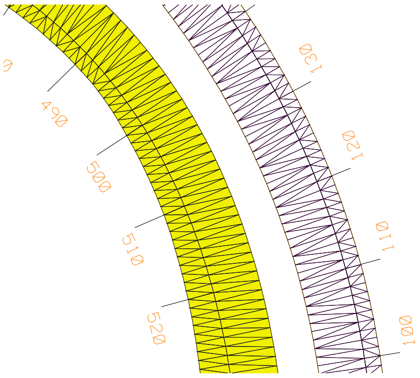

Figure 4: An example of 3-D surface model of Tornio-Kemi motorway.

Figure 5: The user interface for the 3-D blade control system with wireless data communication system.

Figure 6: The site tests of the 3-D blade control system.

Table 1. Automated road grader experiments. The height results of Tornio-Kemi site tests.

Site number	Average [mm]	St.dev. [mm]	Min [mm]	Max [mm]	Count [number]	Accepted [%] *)
E5R1	- 23	19	-64	22	33	66
E5R3 Jakava	-31	19	-60	19	27	50
E5r4	-19	17	-53	22	48	81
E5R3 Kantava	-21	16	-59	10	36	61
MO plv 16860-17780	-8	17	-50	41	146	87
MO plv 15620-16240	-3	10	-30	10	90	99

*) Road structures vertical position tolerances were ± 20 mm

Table 2. Automated road grader experiments. The slope results of Tornio-Kemi site tests.

Site number	Average [%]	St.dev. [%]	Min [%]	Max [%]	Count number	Accepted %
E5R1	-	0,26	-0,4	0,4	15	100 %
E5r4	-	0,56	-0,8	1,2	14	85 %
MO 16900-17780	-3,07	0,25	-0,6	0,5	46	100 %

Table 3: Automated road grader experiments. The capacity results in adjustment tasks.

Site number	Basic [m2/h]	Method [m2/h]	Area of object [m2]	Adjusted aggregate [t]
mo plv 18760-19020	1282	803	3120	-
mo plv 18600-18820	2258	1650	2860	-
E5r4	2444	2005	2240	18
E5R1	715	677	2100	71

Table 4: Automated road grader experiments. The capacity results in grade tasks.

Site number	Basic [m2/h]	Method [m2/h]	Method of work [t/h] / [itdm3/h]	Adjusted aggregate [t]
E5R4 jakava	617	579	162 / 108	590
E5R3 kantava	368	308	238 / 159	1358
mo plv 17360-17580	550	491	217 / 145	989
mo plv 17200-17460	1613	1366	747 / 498	1445
mo plv 17920-18600	1678	1498	87 / 58	457