Machine control systems for leveling areas for road investments

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Abstract. Earthwork is an essential stage in road construction. The proper and efficient performance of earthwork is a necessary condition of a successful execution of a road building project. Earthwork is carried out with suitable machines and implements, which allow mechanisation and acceleration of the task. In order to fully implement these machines, control systems are employed, as these improve the accuracy of the earthwork done, enable machine operators to carry out their work more easily, and support the processing of data. This article describes automated and laser systems used for this purpose. The situation on building sites where such systems are deployed has been analysed. The article contains the results of this analysis.

1. Introduction
In the road construction developments carried out nowadays, earthwork constitutes a large portion of the entire enterprise. Such jobs as making embankments, excavations, removal of the fertile soil level, and soil exchange are counted in millions of cubic meters. The performance of such tasks entails huge outlays and requires a large equipment base. Without completing the earthwork it is impossible to carry out further work, and although earthwork usually amounts of around 10 to 15% of the investor’s costs breakdown, it is the most essential stage in a construction process, as the well-designed and executed earthwork is the solid foundation for executing further tasks. Moreover, examples of construction enterprises where the cost of earthwork reaches 60% of the total value can be cited. Because of the large size of earthwork needed to be done in practically every road development project, a seamless and flawless execution of this stage is a very important component of the building work schedule. When large masses of earth are moved, it is almost impossible to image doing this work without whole sets of machines and implements. Mechanisation of earthwork is necessary, and an adequately selected set of equipment helps to ensure that high accuracy and quality of earthwork as well as its timely completion are attainable [1, 2, 3].

In the modern road building industry, one of the objectives is to accelerate the work, put the available equipment to the optimal use and limit the costs. Higher efficiency, accuracy, less time needed to perform building tasks and less money spent are the priorities of our time. Using control systems of operate construction machines facilitates the attainment of most of the above aims. Recent years have generated more interest in building machine control systems, which coincides with a great progress in the area of control systems. Such systems rely on highly varied technological solutions, are based on various measurement systems and employ diverse control methods [3].
Machine control systems affect the comfort of working conditions of a machine operator and a building engineer. The operator does not have to concentrate on manipulating the machine’s blade or digging bucket, which means he can pay more attention to matters which improve the safety of his working environment. Equipped with a machine control system, even less qualified staff can achieve better accuracy and efficiency. Control systems can be installed practically in all machines, and the capacities such systems have are highly varied. Manufacturers offer a wide range of machine control solutions. Possible applications of control systems will be discussed below using a bulldozer as an example.

2. Construction machine control systems – a review of literature

Construction machines are equipped with control systems representing different degrees of automation. And the solutions used in building practice allow one to monitor various parameters [4,5]. Control systems are divided according to two criteria:

a) degree of the automation of a road construction machinery control system:
- manual systems (indicator, simple),
- automatic (all steps fully automated and semi-automated),

where the automatic control of work means only the height of the working implement of a construction machine is automatically steered (fig. 1 and 2).

![Fig.1. Manual system (indicator)](image1)

![Fig.2. Automatic system (and semi-automatic)](image2)

b) 1D, 2D, and 3D systems, where the following can be controlled:
- 1D system – one parameter – height or slope position of the transverse working implement,
- 2D system – both height and slope of the transverse working implement are controlled,
- 3D system – the situational position as well as the height and slope of the transverse working implement require a numerical model of the building plan.

An indicator control system determines the position of a road construction machine’s implement relative to the plane of reference, after which it determines the necessary correction between this
position and the one designed in the building plan, and the result is displayed as a laser indicator or on a control panel seen by the machine’s operator. This system shows the height of a working element (1D system) or height and its position (2D system), and informs the machine’s operator what should be done (e.g. the digging bucket higher or lower, keep it this way, etc. – 1D system). The system’s elements are a rotation laser leveller (horizontal, single- or dual-grade) set up on a construction site, setting the reference plane, and laser sensors mounted on a construction machine, either directly on an electric boom, whose height can be regulated up to 0.1 mm accuracy [6,7].

An automatic system compares the actual position of a working implement with the reference plane, determines the correction of the position and transmits the data to the operator’s display panel and to the unit which steers the hydraulic valves. Next, the working implement is set in the required position. The only thing that the operator must do is to steer the direction in which the construction machine moves. In a semi-automatic system, it is only the height, as the most important parameter, that is controlled automatically. In the construction industry, a semi-automatic guidance system is the one in which one lever suffices to set the working element of a road construction machine in the required position (e.g. an operator of an excavator must use three levers which steer the machine’s boom, arm and bucket, to set the working implement). The automatic functions of the systems can be switched off and manual steering can be switched on [8,9].

A 1D laser system is now the standard solution supporting the operation of building machines. This system is adjusted to work with graders, dozers, excavators and excavator-loaders. It consists of a rotation laser leveller and a sensor receiving a laser beam mounted on the machine. Based on the data from the laser, the leveller determines the reference planes, while the sensor mounted on a boom shows to the operator at what height he should set the machine’s working implement. The operator observes the data provided by the sensor, and correspondingly lowers or elevates the working implement. The system generates simple reports, which can read as follows: the blade too high – lower it down, the blade too low – elevate it, the blade on the correct height (this resembles a semi-automatic system) [6, 7].

A 2D laser system preferred for steering the work of an excavator is a more advanced variant of an indicator system. Same as a 1D system, a 2D solution is composed of a rotational laser leveller and sensors mounted on the working implement (the blade of a machine. In addition, a dozer has a system of hydraulic valves and a steering panel in the cab. The system lets the machine be positioned practically without any work done by the operator, so that both the height and position (angle) of the blade can be achieved according to the position fed by the laser leveller. The dozer’s operator is responsible for driving the machine and for pushing the earth load; at any time he can switch the automatic to manual mood of operation. The way an automatic control system works is by using a beam of laser light emitted by the laser levellers. Laser sensors mounted on the machine track the laser rays. The system collects data form the sensors and sends them to the steering panel. The system gathers signals from the sensors and transmits signals to the electric valve, which sets the blade very precisely at a required height and angle. In a 2D system coupled with an excavator, the sensors mounted on the machine transmit the data to a computer, which informs the operator about the depth and angle of the bucket; however, the operator of an excavator is unable to operate automatically the working implement, which is possible in graders or dozers (a semi-automatic system) [6, 7].

A 3D GPS (single antenna) system is supported by the GPS RTK (Real Time Kinematic) technology, and can be coupled with both the GPS and Glonass systems, which makes field work much easier. This is a system which ensures very precise control of the working implement of a machine with respect to three parameters: height, position and grade. The satellite receiver sets the position of a machine, compares it with the digital design entered into the steering panel, and the hydraulic valves automatically position the blade at the designed height. The operator focuses on driving the machine at an adequate speed, and all the other work is automatically guided by the system. The 3D GPS system allows the operator to achieve the required level after the first few passages of the machine. The system is equally effective in levelling the ground on curves and when moving straight ahead. The system is composed of two segments: a reference base and components mounted on the machine. The reference base consists of a GPS+GLONASS receiver, controller and a UHF radio modem for communication with the receiver on the machine. The base station and GPS receiver installed on the
machine compose a measurement system working in the RTK mode, that is determining the spatial position of a working implement in real time, in a set of 3 coordinates (x, y, z). Regardless of where a machine is situated at any given time, the system has the current and precise information about the position of the machine and blade (an automatic system) [10, 11].

3D (dual post) system is based on two GPS antennae, and it allows the operator to read data regarding the height, grade and position using the GPS references. The 3D Dual GPS system for controlling the work of a dozer is based on the GPS RTK technology, and can be connected with either the GPS or Glonass system, which greatly facilitates field work. The satellite receiver identifies the position of a machine, compares it with the digital design entered into the steering panel, and hydraulic valves automatically set the blade at the designed height (an automatic system); this system is similar to the one with a single antenna, but it is more precise [10, 11].

3. Research method and aim

On account of the importance of earthwork as a stage in road construction, sixteen road building enterprises conducted over the past four years in north-eastern Poland were submitted to analysis. The study included the determination of the value of earthmoving work, costs of delays or acceleration of earthwork, and possibilities of certain improvement of this stage owing to the implementation of automation. The research also included a review of the literature and documentation from the road construction projects, as well as field trips to the construction sites. Studies into the use of control systems comprised dozers typically used to carry out earthwork while building roads. The first step was to analyse the documentation, and to determine the percentage of earthmoving costs in the total costs breakdown of a road building investment. In most of the analysed cases, the documentation was complete, but there were several amendments to original designs due to the changing scope of works, including earthwork. The collected data are presented in Table 1.

Most of the analysed road construction projects were within the range of statistical average data. In two cases, the contribution of earthwork to the total road building costs was less than 10%, whereas in three cases it exceeded 30%. This means that in most of the analysed cases the earthwork performed corresponded to 10 to 30% of the total costs. The importance of earthwork was therefore verified. Apart from the costs, another significant consideration is the timely completion of earthmoving, as this is the first step in a building process, and subsequent stages in a construction process cannot be started until it is finished.

| No | Share of earthworks (%) | No | Share of earthworks (%) |
|----|-------------------------|----|-------------------------|
| 1. | 6                        | 9. | 45                      |
| 2. | 15                      | 10. | 12                     |
| 3. | 25                      | 11. | 14                     |
| 4. | 12                      | 12. | 5                      |
| 5. | 35                      | 13. | 16                     |
| 6. | 14                      | 14. | 25                     |
| 7. | 14                      | 15. | 34                     |
| 8. | 20                      | 16. | 42                     |

**Table 1.** Share of earthworks in the entire investment

| No | Share of earthworks (%) | No | Share of earthworks (%) |
|----|-------------------------|----|-------------------------|
| 1. | 6                        | 9. | 45                      |
| 2. | 15                      | 10. | 12                     |
| 3. | 25                      | 11. | 14                     |
| 4. | 12                      | 12. | 5                      |
| 5. | 35                      | 13. | 16                     |
| 6. | 14                      | 14. | 25                     |
| 7. | 14                      | 15. | 34                     |
| 8. | 20                      | 16. | 42                     |

Average value 20,87

It was demonstrated in the sixteen analysed cases that the implementation of a fully automated and reliable control system considerably accelerated the earthwork, facilitated quality checks, and eliminated the need to carry out snagging work. In ten cases, the equipment used was fitted a semi-automatic control system, and in five the machine guidance systems were automatic. No machine control systems were used on three building sites. On the construction sites which used automatic or semi-automatic machine guidance systems the earthwork was found to have been accomplished much more efficiently, with the minimal amount of snagging work and less workforce employed in comparison with the other building sites. The costs of compensation paid for failing to meet deadlines
was reduced (in some cases down to zero). Figure 3 illustrates a dozer with a system of machine control performing some earthmoving. Table 2 presents advantages and disadvantages of using control systems to operate machinery used to carry out earthwork.

![Figure 3. Bulldozer with a control system on a road construction (own photographs)](image)

**Table 2. Summary table**

| No. | Type of control system | Advantages | Disadvantages |
|-----|------------------------|------------|---------------|
| 1   | Machines without a control system | - possibility of servicing by people who do not know automation  
- no failure of electronic systems | - low accuracy of performed works  
- frequent necessity to carry out correction works  
- delays in robots |
| 2   | Machines with a semi-automatic system | - greater accuracy of work  
- acceleration of works | - the need to manually handle the blade  
- correction work |
| 3   | Machines with an automatic system | - timely work  
- reduction of employment  
- reducing the cost  
- eliminating penalties for late payment | - occasional failures of electronic systems |

**4. Summary and conclusions**

Control systems are applied to the work of various machines employed on construction sites. These solutions enable an investor to improve the efficiency of machines and the work safety of the workforce. This study confirmed that machines fitted with control systems work faster, more accurately and more efficiently, which is extremely important in the case of earthwork involved in road construction because this stage of earthmoving to a large extent decides about the time it takes to complete a road development project. With GPS-based systems it is possible to work at night, in difficult field conditions, with fewer land surveyors, and – in large road construction investments – such control systems are necessary to meet the deadlines. It is therefore justifiable to use machine control systems on road construction sites, as this can generate tangible economic profits.

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