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Autopilot and Operator Assistance Systems for Wheel Loaders

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Hidromek

Abstract: In recent years, employing personnel for construction machinery operators has become challenging, requiring a lot of effort and experience. Meanwhile, personnel costs are increasing in Europe, Turkey, and other developed countries. The autopilot system facilitates the bucket loading and unloading process, among the most basic functions of wheel loader machines. It reduces the need for experienced operators and operator errors, increases the operational efficiency and productivity of the vehicle, and reduces fuel consumption and exhaust emissions to the environment. This study is about autopilot and operator assist systems and their benefits and advantages. It explains the working systematics, skid detection and prevention systems, mapping the earth, detecting people and objects, developments to increase vehicle efficiency and productivity, improving operator comfort level, etc. Even though some of the functions are carried out automatically, the vehicle still runs under the control and supervision of the operator in the cabin or a remote-control station.

Keywords: Autonomous construction machinery, Driving assistance for wheel loaders, Smart machines, Automated functions.

Introduction

Increasing fuel prices, global climate change, and the development of environmental awareness make the need for smart machines and systems operating at high efficiency indispensable. Similar and parallel to the automotive industry, intelligent and autonomous systems are developed and applied to machines in the construction machinery sector. Electronic control has been implemented for the systems and components of conventional construction machines, such as the powertrain, engine, hydraulic, steering, brake, etc. Meanwhile, due to the developments in GSM and Wi-Fi networks, large data transfers like video images have become possible. Therefore, automation and teleoperation of the machines have been applicable. Compared to autonomous passenger vehicles traveling on roads open to vehicle traffic and pedestrians, automation of construction machines can be easier and safer due to the restricted and defined working fields and less human density. Especially in teleoperated machines, operators are not in the cabin; thus, they cannot feel the machine and its operations. Therefore, machines can unnecessarily overload, productivity decreases, and tires wear out. If the main functions like loading and unloading run automatically, these kinds of failures and losses can be avoided. Operators' effort and fatigue are reduced drastically when the machine is controlled remotely. The exterior and interior view of Hidromek Opera, the remote-control station, is shown in Figure 1. & 2.

Overall System Layout

Conventional wheel loaders consist of the powertrain, work equipment, brake and steering systems, and machine control unit. Several devices, such as lidars, radars, thermal cameras, a touch screen, high-performance industrial computer and RTK GNSS antennas, have been added to the machine for these automated functions. The radars and lidars scan and detect the earth, gravel, obstacles, humans, and the environment. Thermal cameras detect the environment and distinguish between living things and objects. Even though there are omnidirectional cameras, thermal cameras significantly contribute to increasing safety levels for remote

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operations. The industrial computer processes the images from lidars, radars, and thermal cameras and matches them. Also, it sends commands to control and drive the machine automatically. The GNSS antennas detect the machine's position on the ground precisely. The touch screen shows the mapped earth, gravel, etc., provided by the industrial computer. The overall system layout is shown in Figure 3.

Figure 1. & Figure 2. The exterior and interior view of Hidromek opera, remote-control station.

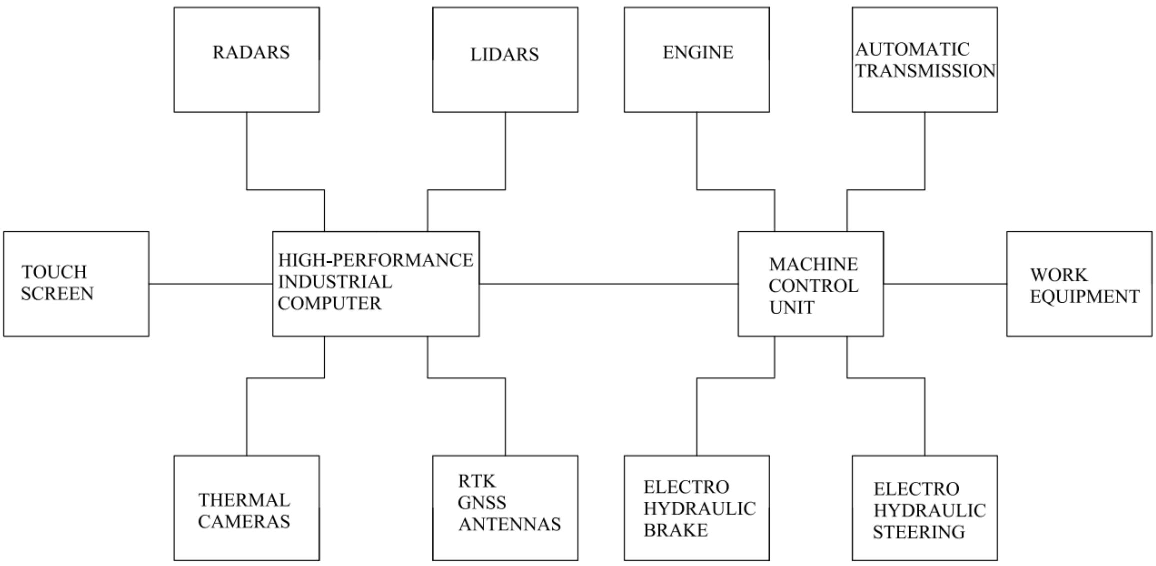

Figure 3. Overall system layout

Working Systematics

The working system consists of the preparation and implementation phases. At the preparation phase, the vehicle gets ready for the implementation phases such as loading and unloading the bucket. Firstly, the load and bucket types are determined by operators to obtain higher efficiency and productivity. Then, the driving assistance is activated. The preparation phase is shown in Figure 4. In the implementation phase, the machine loads the bucket automatically. The implementation phase is shown in Figure 5.

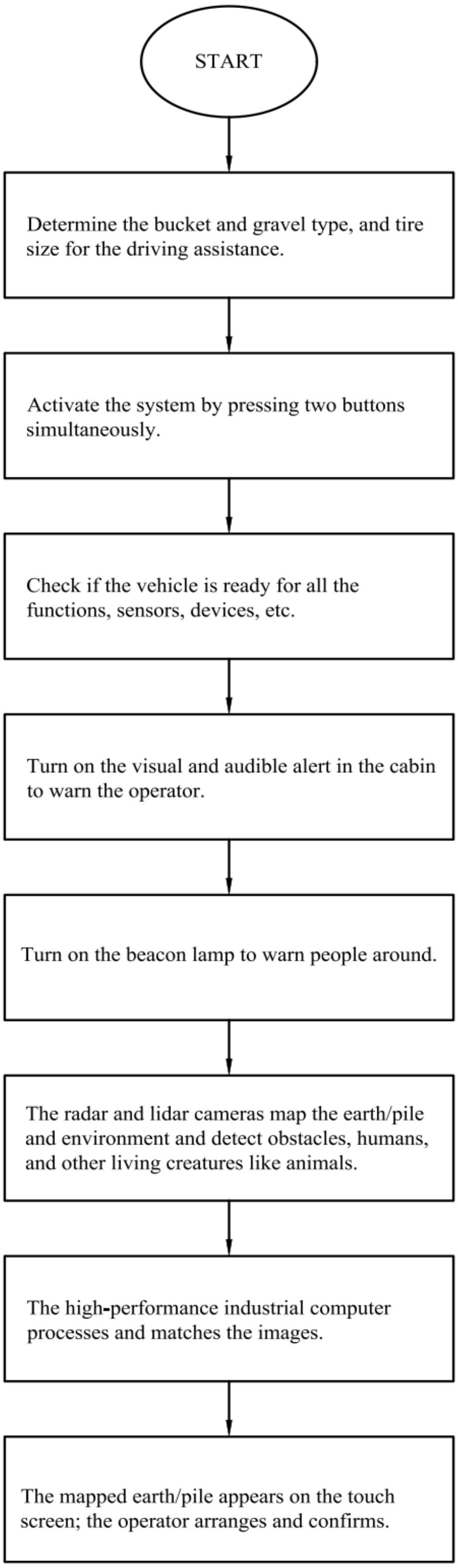

Figure 4. Preparation phase

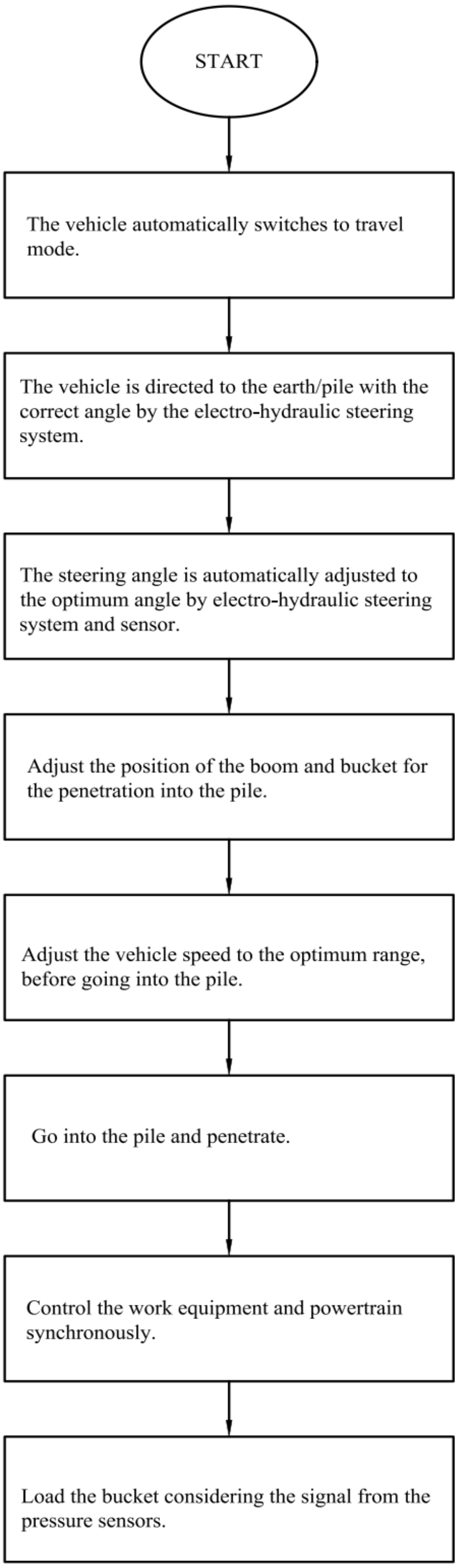

Figure 5. Implementation phase

Loading the buckets of wheel loaders is provided by the perfect harmony between the powertrain and work equipment. Both systems must work together synchronously. In order to load the bucket efficiently and fully, the vehicle must work without skidding and engine stall. When the machine skids, the energy of the engine converts into heat in the torque converter instead of the useful work. Skidding the wheels increases fuel consumption, damages the powertrain, heats up the transmission oil, and causes tire wear and operator fatigue due to the high vibrations. In this study, automatic loading and unloading systems, which is the state of the art, is explained.

The radars and GNSS RTK antennas determine the vehicle ground speed precisely. The lidar, GNSS antennas, radar, and thermal camera are shown in Figure 6. & 7. In closed areas, when the GNSS antennas cannot provide data, the speed data is ensured by the radars. Meanwhile, the wheel speed is determined by measuring the transmission output speed. Then, both data are compared to detect whether the wheels skid or not. If the system detects any wheels' skid, the engine speed and work equipment are controlled to prevent the skidding. Therefore, the bucket penetrates the excavation, pile, earth, etc. The skidding is not prevented by means of the differential lock or limited slip differential. It is carried out by running the powertrain and work equipment synchronously and simultaneously, which is provided by the system algorithms. The system controls the traction, bucket and boom cylinders together. The pressure sensors installed on the hydraulic lines of work equipment detect the load and send signals to submit status of the load percentage. When the loading is completed, the system warns with visual and audible alerts.

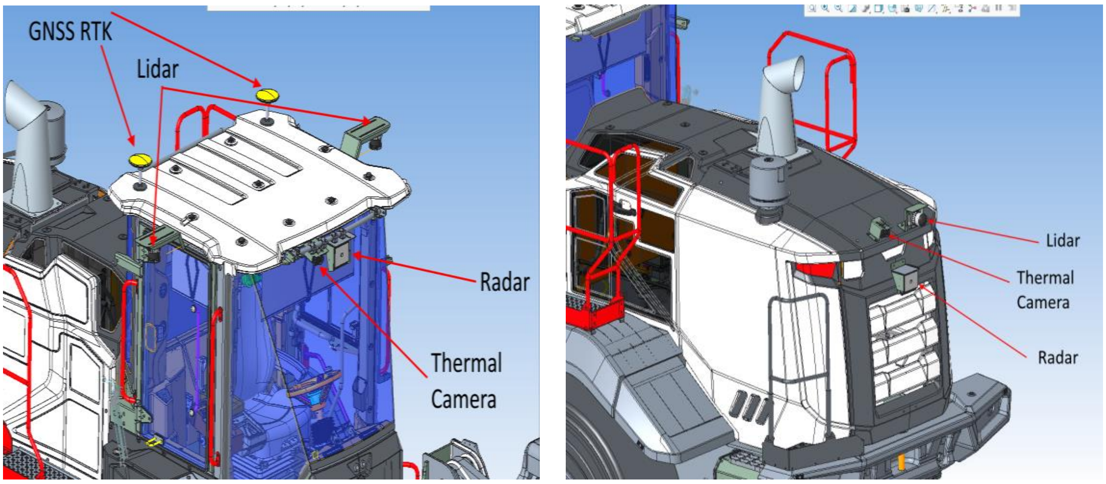

Figure 6. & Figure 7. GNSS RTK antennas, lidars, radars, and thermal cameras

The system algorithms are designed for the engine, torques converter and pumps to run in the efficient ranges by considering the machine's requirements. The engine and vehicle speed are controlled by automatically. Besides, the engine is driven at the stabile speed to increase the efficiency. Diesel engines have different efficiency characteristic in different speed range and load conditions. The fuel map of the engine is shown in Figure 8.

After loading the bucket, the bucket is positioned to the carry condition. The machine is driven to a truck or anyplace manually. When the boom raises and the bucket dumps, since the hydraulic cylinders reach the end of the stroke, the shock loads occur on the machine and cause fatigue on machine and as well as operators. The automatic bucket unloading system provides the boom raising in a controlled manner by angle sensors preventing from shock movements at end of the stroke. Meanwhile, the transmission clutch cut-off system activates automatically to provide more power to the work equipment and increase the efficiency of the operation. When the machine switched to the driving mode, it disactivates automatically as well. While dumping, the system shakes the bucket to make bucket fully unload without shocking the machine by controlling the hydraulic system automatically.

For dumping the bucket, how much the bucket is empty designates the efficiency of the operation. After dumping, the boom and bucket reach the carry position automatically. In the conventional machines, lowering the boom can cause shock loads and vibrations on the machine and operators, which can also cause damages on the machine and fatigue of the operator. In the automatic mode, the shock loads are prevented and the smooth movements are provided. In the meantime, as lowering, the gravity provides the sufficient force, therefore, the engine throttle is reduced to minimum level to increase the efficiency.

Mapping of Earth

4D radar and ultra-wide view high-resolution lidar cameras are used to map the earth, pile, excavation, etc. The images from the radar and lidar are matched and processed in the industrial computer to increase accuracy and precision. Lidar has higher resolution and can provide accurate, consistent results. However, it cannot measure long distances, and its performance reduces depending on the weather and ambient conditions, such as in rain or dusty environments. Radar can identify things in long-range, adverse weather and ambient conditions.

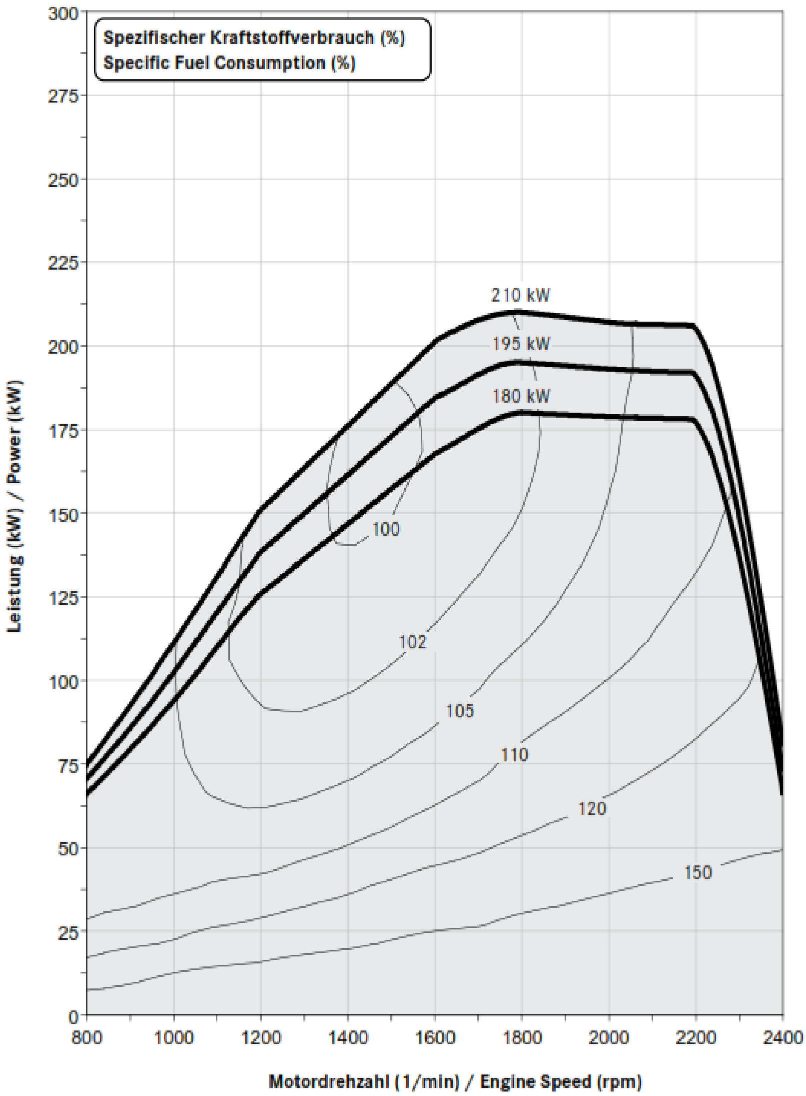

Figure 8. Fuel map of the engine

Conclusions and Recommendations

In this study, a commercially viable semi-autonomous system is explained where operator presence and control are still present. This study provides a valuable approach to next-generation fully autonomous construction machinery. Switching from conventional machines to semi-autonomous ones can be safer and more economical than switching to fully autonomous. However, we might see construction machines with artificial intelligence and machine learning capabilities in the near future. It is recommended to switch to automated machines gradually to avoid safety issues and the rise of the unemployment rate in the construction sector. One of the handicaps of fully autonomous construction machines is the high initial investment cost. Processing and matching the images necessitates high technology and deep know-how and, therefore, is quite expensive. Cloud-based machine learning can reduce overall costs and drastically speed up and improve AI learning. It can use the data from other machines with similar working fields and conditions. Thus, machines can gain experience faster and increase efficiency and productivity.

The operator's experience and feelings come to the fore in conventional machines controlled inside the cabin. In remote-control machines, since the operator's feelings cannot constitute or can stay at low levels, the operators' adaptation or synchronization is not at the desired level. The autopilot and driving assistance systems eliminate these kinds of deficiencies and not only raise the overall efficiency, productivity, and functional safety but also extend the lifespan of the machines and reduce operator fatigue, fuel consumption, and carbon emissions.

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM Journal belongs to the authors.

Acknowledgements or Notes

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