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Simulation of Short-Range Field of View for Agricultural Machinery Based on Standards Requirements

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The increasing demand for large and tall self-propelled agricultural machinery has raised important safety concerns. This development has significantly reduced the operators' field of view, increasing the risk of serious or fatal accidents for both them and nearby workers. It has therefore become essential to address visibility and safety issues related to the use of such machines.

In response to these challenges, this article proposes an innovative method to virtually analyze and verify the operator's field of view. By using a system based on ray tracing rendering, it is possible to assess the operator's visibility in accordance with both current ISO standards and the upcoming ones. In addition to ensuring compliance with these standards, the system also allows for the simulation of realistic scenarios involving interactions between agricultural machinery and nearby workers, thereby evaluating the operator's visibility in real tasks.

The proposed method enables the direct identification of issues during the 3D design phase, allowing for targeted interventions on components that cause masking effects. In cases where direct visibility is deemed insufficient, it also offers the possibility of virtually implementing indirect vision systems and evaluating their effectiveness in improving visibility.

Furthermore, the limitations of the current standard regarding the field of view near the tractor with rectangular boundaries will be discussed. In this regard, the virtual system can serve as a useful tool in defining criteria and limits to be adopted in future standards. The use of simulation and virtual prototyping of cabin to assure the correct Field of View from the driver's position can be effectively used to shorten early design stage of new tractors.

Keywords: Tractor, field of View, safety of agricultural machinery, standards requirements, simulation, ray tracing, virtual prototyping, visibility.

1. Introduction

Various standards lay down minimum safety requirements of agricultural, industrial and earth moving machinery field of view (FoV). Some manufacturers use tools such as video cameras and good practice that could require the site to be organized in advance or the presence of an external operator to coordinate the work, but the issue remains topical and can be improved through the use of new technologies. Data from INAIL highlights the critical issue of reduced field of view, particularly in areas closest to these machines

(INAIL, 2021). Tractor's structural components, along with other elements, can contribute to the creation of blind spots that are difficult to monitor. The issue of visibility in tractors is reported in the ISO 5721-1:2013 (ISO, 2013) and ISO 5721-2:2014 (ISO, 2014) standards that define the requirements and methods for evaluating the field of view, considering different areas: front, side, and rear. These standards, applicable to agricultural and forestry machinery, use similar procedures to identify and assess masking effects, but they differ in testing surfaces. Similarly, ISO 5006:2017 (ISO, 2017), which has the same goal but applies to earth-moving machinery, requiring checks on specific surfaces such as the Visibility Test Circle (VTC) and the Rectangular Boundary (RB), was adopted by CEN/TC 144-2:2022 (CEN, 2022) for self-propelled agricultural machinery. In any case, the test consists of installing lights on supports in strategic positions, placing them at a certain distance from the Seat Index Point (SIP), which is determined using a standardized device as described in ISO 5353:1998 (ISO, 1998). Subsequently, it is evaluated whether these lights are visible in a mirror positioned in specific areas of the test surface. This method allows for the detection of masked areas in a simple way, but it is neither very precise nor reproducible as it depends on the operator's skill (Landi et al.,2024). For this reason, recent studies have looked to improve the accuracy of the field of view evaluation using more advanced technologies. In one of these studies, Zvěřina et al., 2022 used a LiDAR (Light Detection and Ranging) scanning system placed on the tractor seat to simulate the operator's eyes, performing two scans (one for the right eye and one for the left) with reference spheres positioned in a semicircle located twelve meters in front of the machine. The data obtained from the scan are processed in 3D modeling software, where points above the working plane and beyond the reference distance are ignored, generating a graphical model of the field of view in .DXF format. This method offers high accuracy compared to ISO standards but involves high costs for equipment and analysis.

Another advanced approach was proposed by Bayran et al., 2015, who used a virtual simulation of the field of view based on a CAD (Computer Aided Design) model of the tractor. In this method, visibility is simulated using a digital human model inserted into the "Jack" simulation software, which allows for a 20 mm diameter sphere to be traced around the machine to identify masking areas. This virtual method is particularly useful in the design phase of the machine, as it allows for identifying and reducing masking effects before the production of physical prototypes. Similarly, Teizer et al., 2014 introduced the use of ray tracing algorithm to simulate and evaluate blind spots generated by forklift components. In this case, ray tracing allows tracking light paths to identify areas shaded by vehicle parts. The test was conducted on two models: the first obtained via CAD and the second from a LiDAR scan, comparing the results obtained from both systems. Thanks to the review of the current state of the art presented so far, a virtual simulator has been created based on the ray tracing algorithm to simulate the field of view during the design phase of tractors, as indicated in Landi et al., 2024. The results from this simulation have been compared with those from physical tests, showing greater accuracy compared to the methods currently described in the state of the art.

This article aims to deepen the analysis of the field of view in areas close to the tractor, which presents the greatest safety challenges for the operator, using the system described in the aforementioned research. By using the ray tracing-based simulation method, the masking effects in these areas will be analyzed in detail, with the goal of improving safety and contributing to the update of technical standards while optimizing the tractor design process and reducing the need for physical testing on prototypes.

2. Material and Methods

The Virtual System for Visibility Testing was developed following the procedure and guidelines of ISO 5006:2017, which sets the requirements to ensure that the operator of an agricultural machine has an adequate field of view from their seat, to work safely, minimizing blind spots and visual obstructions. Specifically, the standard requires the SIP, as defined by ISO 5353:1998, to be used as a reference point for positioning measurement tools and lights during visibility tests, which are performed on specific surfaces: the VTC and the RB. Using these guidelines, a virtual environment was created in Autodesk Inventor software (Autodesk Inc., 2024) to simulate and evaluate the field of view for agricultural machines, using an existing high-power tractor as a reference model, which we will henceforth refer to as Tractor D (Figure 1). However, the system is designed flexibly so that it can be adapted to any other agricultural machine and used on any testing surface. The virtual system relies on several key components, integrated into a parametric structure, which allows the test setup to be easily adjusted. The main component is the unified device for determining the SIP, which is added to the 3D model of the tractor and serves as the reference for calculating visibility from the operator's perspective. This device is placed parametrically, allowing for quick adjustments to fit the test specifications. Another essential part is the light support structure, which simulates the operator's binocular vision. Two light-colored sources are mounted on this support, one red and one green, to distinguish areas of monocular vision from areas of binocular vision. The structure is designed to rotate 360° around the vertical axis, allowing for full coverage of the field of view.

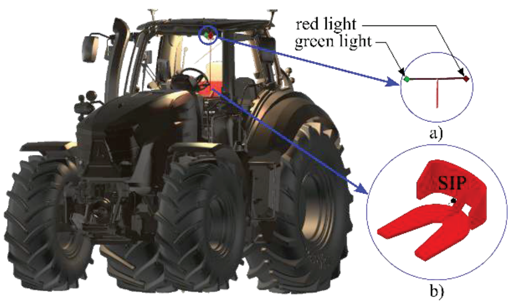

Fig. 1. 3D model of the test vehicle representing a high-power tractor. a) Lights support; b) ISO 5353:1998 unified device for determining the SIP.

The system accurately reproduces the test surfaces required by the ISO 5006:2017 standard. The first surface is the VTC, which is a circle with a radius of twelve meters drawn on the ground reference plane, with its center aligned vertically below the reference point of the lights (Figure 2b). The VTC is essential for identifying visibility areas that are blocked by the vehicle. The second surface, the RB, is a rectangle placed one meter from the edge of the machine, with height parameters that vary based on the type of vehicle being examined (Figure 2a). This surface allows for evaluating visibility at ground level, especially near the machine.
The simulation process is carried out using the Inventor Studio module of Autodesk Inventor, which employs ray tracing rendering to visualize masking effects. Areas with complete visibility are colored yellow (binocular vision), while areas with monocular vision appear red or green, and masked zones are represented as dark areas. This representation helps in identifying blind spots and critical areas of the field of view.

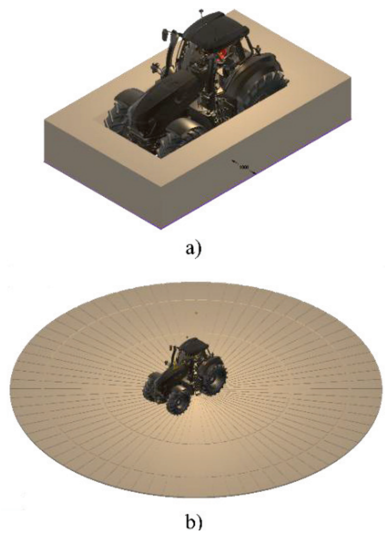

Fig. 2. Virtual test environment Tractor D. a) RB; b) VTC.

The renderings were precisely scaled and annotated within the software to ensure accurate measurement of the masked areas, allowing for a clear assessment of visibility limits as per the requirements of ISO 5006:2017.
The operation of this virtual system was validated in Landi et al., 2024, where it was also used to evaluate the field of view of another commercial tractor. In that study, the results from the virtual tests were compared with real-world field tests to verify the accuracy of the system. Specifically, the real tests were conducted following the same procedure outlined in ISO 5006:2017 and under controlled conditions. The visibility of the tractor was analyzed using both the VTC and the RB methods. The masking effects and blind spots identified in virtual simulations were compared with the physical measurements, confirming the system's reliability and accuracy. In this article, the same validated system was used to conduct tests on Tractor D, following the procedures outlined in ISO 5006:2017 (Figure 3). Additionally, the study further investigates the field of view in the areas close to the tractor, with the goal of enhancing operational safety by addressing the blind spots near the machine.

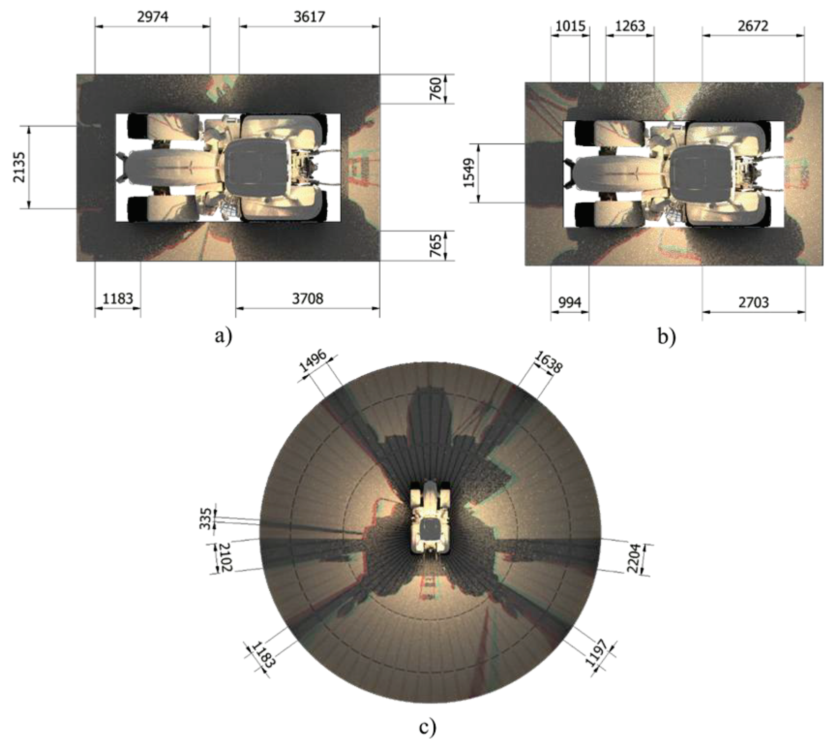

Fig. 3. Measurement in mm of the masking effects on different test surfaces, Tractor D. a) RB at a height of 1 m; b) RB at height of 1,5 m; c) VTC.

3. Results and discussion

3.1 Short-Range Field of View Further Analysis

As shown in Figures 3a and 3b, the field of direct visibility near Tractor D has completely shadowed areas. The visibility changes depending on the height: when the reference surface was placed at 1.5 m, 40% of the RB was masked, but when it was lowered to 1 m, the masked area increased to 60%. This suggests that shorter people or operators sitting down are much harder for the driver to see directly, and in some cases, it may even be impossible. To better understand this problem, we decided to test direct visibility not only as described in the ISO 5006:2017 RB test but also by using dummies or other test objects useful to represent workers on the ground while they perform typical tasks near a tractor. It has been decided to carry out some visibility tests using a dummy that follows the basic measurements from the ISO 7250-2:2011 standard, based on the 5th percentile female (ISO, 2011) and utilizing the "Human Dummy II," which represents the 50th percentile male. This approach allows for a more comprehensive assessment of the operator's ability to see people of different sizes and in different postures near the tractor. First, we placed two dummies in specific positions. In the first instance, the dummy representing the 5th percentile female (shortest, as it reflects a particularly challenging scenario) was positioned near the lift arms to simulate a worker performing an operation at the Power Take-Off (PTO) (see Figure 4). Meanwhile, the dummy representing the 50th percentile male was placed near the right wheel, simulating a worker ready to press the switches that control the lift arms (see Figure 5). These situations represent an operator connecting an implement, or when maintenance is required. Both figures include two images. Part a) shows the rendering from an angle near the rear window of the tractor cabin, allowing for an assessment of the illuminated portion of the dummy. Part b) shows the rendering made using a camera with a 120° field of view (corresponding to standard binocular visibility), positioned at the center of the lights support. It is important to note that in both figures, the dummy has been intentionally colored orange to make it easier for the reader to detect.

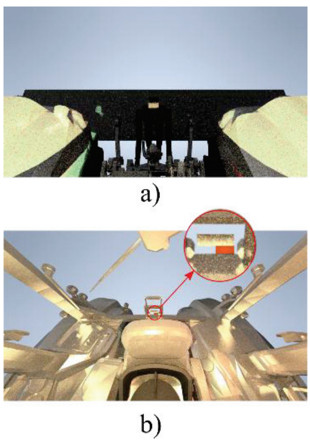

Fig. 4. Comparison of the field of view of a 5th percentile female dummy operating at the PTO through rendering. a) Evaluation of masking effects; b) camera view from the lights reference point.

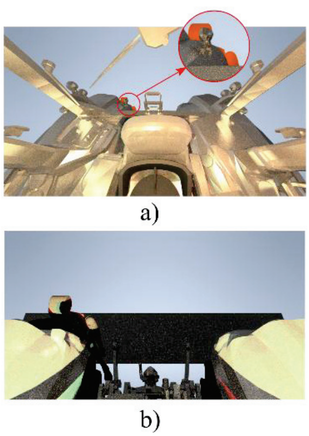

Fig. 5. Comparison of the field of view of a 50th percentile male dummy ready to press the switches through rendering. a) Evaluation of masking effects; b) camera view from the lights reference point.

This tests highlights two important aspects: on the one hand, the virtual system provides visibility information both through the analysis of masked areas and through the direct simulation of the operator's field of view; on the other hand, it shows that both images, despite using different approaches, present the same results, demonstrating that areas close to the tractor are heavily obscured by direct visibility, significantly limiting visibility and making the use of indirect systems necessary to improve safety. Additional tests were conducted following the guidelines of the ISO 18497-1:2024 standard, which addresses the safety of partially automated, semi-autonomous, and autonomous agricultural machines and tractors (ISO, 2024). This standard introduces the concept of a "hazard zone", defined as the area where, if an obstacle is present, there is a risk of injury. For demonstration purposes, we chose to define the hazard zone as the area outlined by the RB perimeter, as suggested by the ISO 5006:2017 standard regarding the field of view around the tractor. This zone includes the entire area enclosed by the smallest rectangle that can surround the machine's edge, with a one-meter outward offset. During the test, the dummy representing the 5th percentile female was positioned standing and moved so that, at first, the head was touching the edge of the RB perimeter and then the arm was touching the inner edge of the hazard zone, simulating movement around the tractor (Figure 6a-6b).

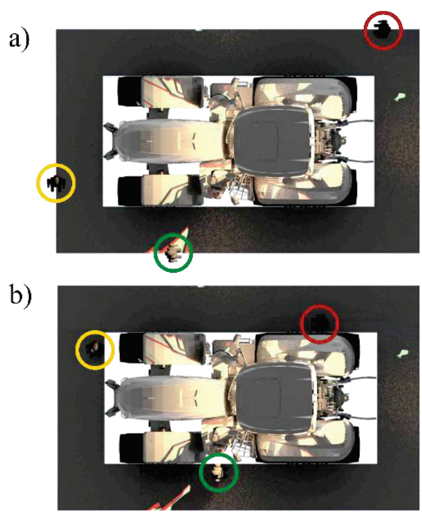

Fig. 6. Selected frames from the animated rendering tests, showing the dummy in three positions around the tractor. Different colored circles indicate visibility: yellow (head illuminated), green (head and at least another limb illuminated) and red (completely in the dark). a) Dummy at the edge of the RB perimeter; b) Dummy touching the edge of the tractor.

The animated renderings obtained from the tests were analyzed to define the visibility of the dummy during the previously described paths. A color-coding system was adopted to represent different visibility conditions: areas where the dummy is completely invisible are colored red, while those where only the head is visible are highlighted in yellow, and zones where both the head and at least one other limb are visible are colored green. Figure 6 illustrates, for clarification purposes, all three conditions for both paths, while Figure 7 presents the results derived from the evaluation of the animations.

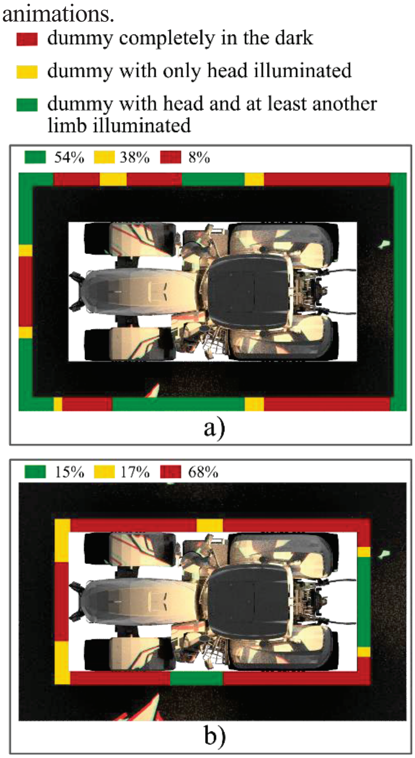

Fig. 7. Results from the visibility assessment of the animated rendering tests. A) Dummy at the edge of the RB perimeter; b) dummy touching the edge of the tractor.

3.2 Implementation of Indirect Vision Systems and Sensors in the Virtual Environment

As highlighted in the previous chapter, the adoption of indirect vision systems (IVS) in large agricultural machinery is essential to enhance operator visibility. These systems can be effectively simulated using ray tracing rendering technology, with the only requirement being to know the FoV of the IVS to be simulated.

The authors implemented this simulation by introducing a hollow parallelepiped into the virtual environment, with a parameterized opening that can be adjusted based on the specified FoV (Figure 8a).

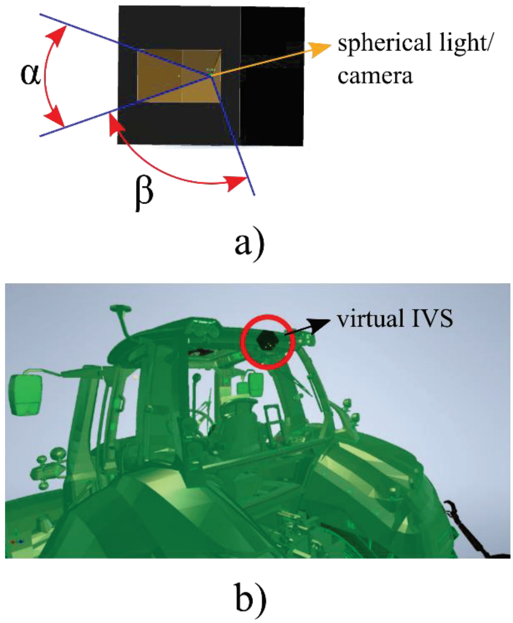

Fig. 8. Virtual IVS implementation: a) geometry of the virtual IVS, with the parameters α for the vertical FoV and β for the horizontal FoV; b) example of virtual IVS positioning.

This approach enables an analysis of the contribution of IVS to increasing the field of view. By placing a spherical light source at the center of the virtual model and performing the rendering, it becomes possible to measure and evaluate the visible areas through the analysis of illuminated zones (Figure 9).

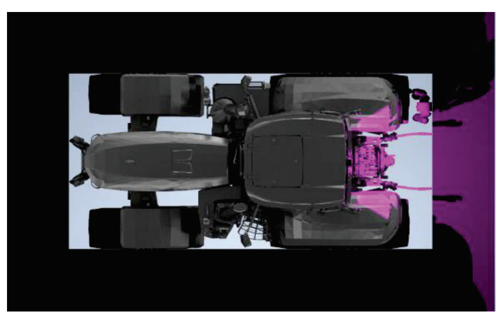

Fig. 9. Example of detection of illuminated areas by a virtual IVS.

Moreover, in the virtual IVS, it is possible to directly insert a camera in Inventor Studio, allowing the evaluation of the IVS's FoV through an image of the area captured by the IVS, as shown in Figure 10.

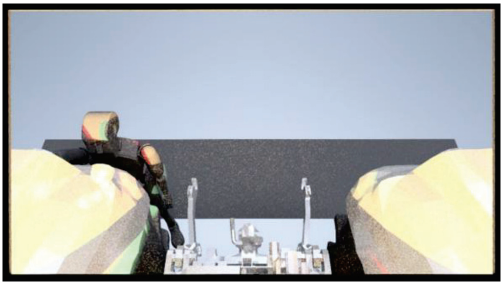

Fig. 10. Example of detection of areas framed by the virtual IVS through rendering performed with a camera positioned at its center.

Both methodologies, although with different results, are useful in determining the correct positioning and angling of the IVS, in order to achieve the desired FoV.

3.3 Limitations of Current Standards and Proposals

As described in the introduction, current standards require the validation of the operator's FoV by analyzing the number and size of obscured areas at specific heights and in certain zones (such as RB and VTC according to ISO 5006:2017). These masked areas are defined by the zones that are blocked from the light emitted by bulbs positioned from the machine's SIP. However, as previously highlighted, the placement of lights during physical tests is often challenging. Using the virtual system, we examined the close-range field of view of the Tractor D within the RB perimeter, not only under ideal conditions with correct lights placement (Fig. 3b), but also simulating a SIP lowered by 10 and 20 mm. These variations are commonly observed in physical testing. The analysis of the results in Figure 11 compared with Figure 3a shows that even small deviations in the positioning of the light support can lead to significant differences in masking, with a maximum variation, in our specific case, of 246 mm.

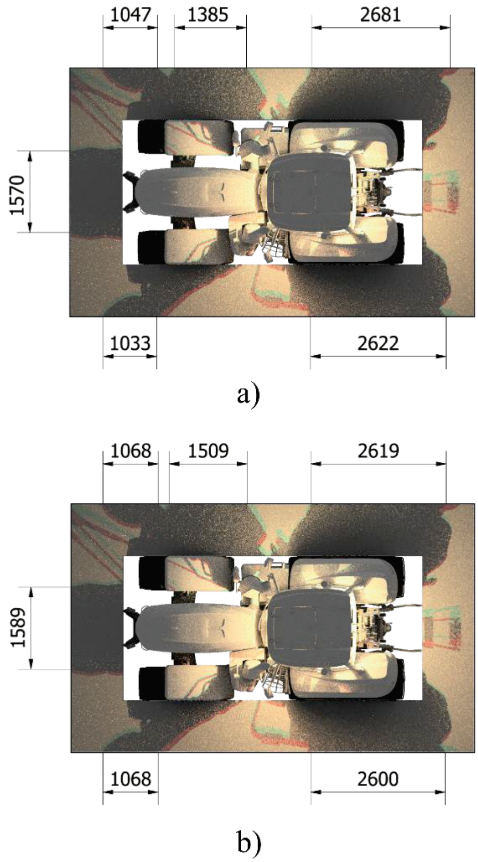

Fig. 11. Measurement in mm of the masking effects on RB with different SIP heights. a) SIP lowered by 10 mm; b) SIP lowered by 20 mm.

This shows that current tests rely heavily on the operator's skill and how even minor positioning errors can significantly impact results, leading to considerable variations in visibility assessments. Additionally, a purely numerical approach may be less effective, as it could indicate that a part of the operator's body is visible but not necessarily recognizable. Therefore, in the future, it might be more useful to adopt a system that verifies whether a minimum portion of the operator's body is clearly identifiable, rather than just visible.

4. Conclusions

This article introduces a virtual system for checking the field of view of agricultural and forestry machines, using ray tracing rendering. This system allows visibility to be evaluated during the design phase, helping designers to improve the FoV before the physical machine is built.

The visibility tests performed on a representative tractor, following ISO 5006:2017 for the VTC and RB zones, showed that areas close to the machine are particularly problematic. Further tests confirmed that these zones have the greatest visibility limitation. Additionally, it was found that measuring the masked areas in millimeters can be inaccurate due to the difficulty of precisely positioning the testing equipment. Moreover, this approach can be misleading, as some body parts may be visible but not easily recognizable. For this reason, future standards could consider new methods, such as assessing a specific body part of a dummy that should be visible. Despite these limitations, the system presented in this article can be effective also in early design stages of new tractor, as it allows different environments and configurations to be easily simulated, helping to create safer machines. It is clear that full safety for operators working near large machines can only be ensured through the use of indirect vision systems. In this context, ray tracing technology can simulate their behavior by knowing the FoV characteristics of the IVS to be installed, thus allowing the optimal positioning of the system to be determined during the design phase.

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