WEAR ASSESSMENT USING 3D SCANNING

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Abstract
The aim of this study was to develop and validate a methodology for wear detection using 3D scanning technology. The study included scanning of agricultural seed coulters before and after abrasive wear caused by operation. A 3D laser scanner EinScan HX and EXScan HX software were used to create digital models which were post processed in SolidWorks. Measurements using a wire method were also performed for comparison. Dimensional changes in the selected cross-section plane were determined, which enabled the wear rate to be characterized. Results confirmed the high precision and efficiency of 3D scanning for wear assessment.

Key words: *wear, 3D scanning, dimensional analysis, agricultural machinery.*

INTRODUCTION
Wear is a significant factor that influences the performance, reliability and service life of machine components *(Müller & Hrabě, 2013; Stachowiak & Batchelor, 2013)*. An intensive wear of changeable wearable parts occurs during soil processing *(Müller, Chotěborský & Hrabě, 2015)*. Traditional methods for evaluating wear, such as visual inspections and mechanical measurements, are often time-consuming and limited in precision *(Brusilová, & Gábrišová, 2014)*. 3D scanning technology offers a promising alternative, enabling detailed surface analysis and dimensional comparison over time *(Valigi, Logozzo & Affatato, 2017)*.
In recent years, 3D technologies have found wide application in reverse engineering, predictive maintenance, and quality assurance *(Afteni et al., 2022)*. These applications are particularly beneficial in agriculture, where field equipment is exposed to intensive wear mechanisms *(Cucinotta et al., 2019)*. As machine parts degrade over time, early detection and accurate assessment
It is worth mentioning that *Ťavodová et al. (2018)* applied an optical 3D scanning system with a laser projector and dual cameras to assess the wear of forestry mulching tools after approximately 80 hours of field work. The FlexScan3D system was used to scan both new and worn tools, and dimensional analysis was carried out in Geomagic Verify software. By overlaying the pre- and post-use models, they were able to visually and quantitatively assess material loss on the tool's working surface. This approach demonstrated the practical value of non-contact 3D scanning in evaluating functional wear in harsh operating environments.
In addition, their study explored the material's internal structure via metallographic analysis, confirming a ferritic-pearlitic base in untreated tools, and emphasized that appropriate heat treatment leading to a martensitic structure can significantly enhance wear resistance. Their findings support the integration of both material optimization and advanced diagnostic techniques for improving tool performance. 3D scanning not only supports qualitative evaluations but also enables quantitative comparisons by overlaying models captured at different time intervals *(Saadi, El-Damanhoury & Khalifa, 2023; Benfield et al., 2022)*.
This study focuses on validating a methodology for wear assessment based on 3D scanning using agricultural seed coulters as test components. It is the first approach using 3D scanning technology specifically for monitoring and quantifying operational wear on seed coulters in agricultural applications.

MATERIALS AND METHODS
The examined component was a seed coulter, subjected to abrasive wear during soil contact. Two coulters were analyzed - one new (Fig.1 up) and one worn (Fig. 1 down).
A laser 3D scanner EinScan HX (Shining 3D Tech Co., Ltd., China) was used for scanning, capturing up to 460,000 points per second with an accuracy of up to 0.04 mm. EXScan HX software (Shining 3D Tech Co., Ltd., China) processed the scans into STL files. Digital scans were aligned and merged. Model

was edited and the data were exported to meshed object format. This object was exported to STL format for usage of SolidWorks software (Dassault Systèmes, France). The procedure started with the calibration of the scanner using a dedicated calibration plate to ensure optimal accuracy. Subsequent steps involved scanning the components under controlled lighting conditions and at a fixed distance. The scans were post-processed to remove noise and align multiple views using reference markers. Measurements were performed using SolidWorks' slicing functions to obtain cross-sections at consistent locations on both models. The entire workflow of the 3D scanning process is illustrated in Fig. 2.

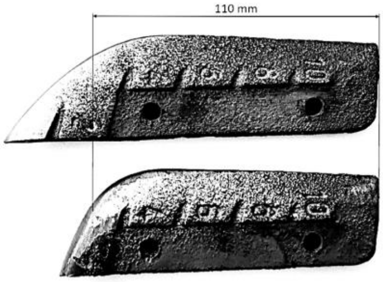

Fig. 1 Scanned objects – seed coulters, new (up) and worn (down)

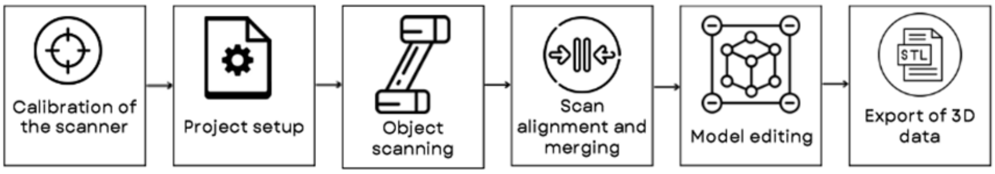

Fig. 2 Process workflow of the 3D scanning

Five dimensions (widths *S1*, *S2*, *S3,* length *L* and diameter *ØD*) were measured on each model (Fig. 3). These dimensions were measured in selected distance (110 mm) from base point of seed coulters (Fig. 1). They were designed to describe the essential wear features of the investigated seed coulters. Based on these values it was possible to evaluate and to compare the wear intensity of investigated objects.

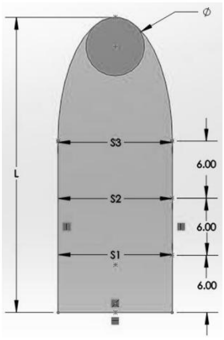

Fig. 3 Dimensions measured on cross section of the seed coulter

Measurements using a wire method were also performed. The wire method involved contouring the cross-section with a 1 mm copper wire at the selected distance from base point of specimen (Fig. 1) and measuring marked lengths on the created photo using ZENCore 3.0 software (Carl Zeiss, Germany). This method has been used as a reference sample to verify the accuracy of the 3D scan results.

RESULTS AND DISCUSSION

3D scanning allowed precise reconstruction of both new and worn coulter geometry. Digital slicing identified measurable material loss at a specific cross-section. The comparison indicated that 3D scanning showed dimensional deviations on the order of 0.1 mm compared to conventional wire method, with the advantage of faster data collection and better visualization. The wire measurement, while valid, was more sensitive to measurement errors (especially on rounded and irregular surfaces) and required higher skill needs due to manual handling.

The STL models exported from EXScan HX maintained high surface fidelity and were easily integrated into CAD software. Digital measurements showed significant changes in the selected dimensions (especially *L*, *ØD*) on the worn coulter (Fig. 4), aligning with expectations based on the abrasion mechanism during soil operation.

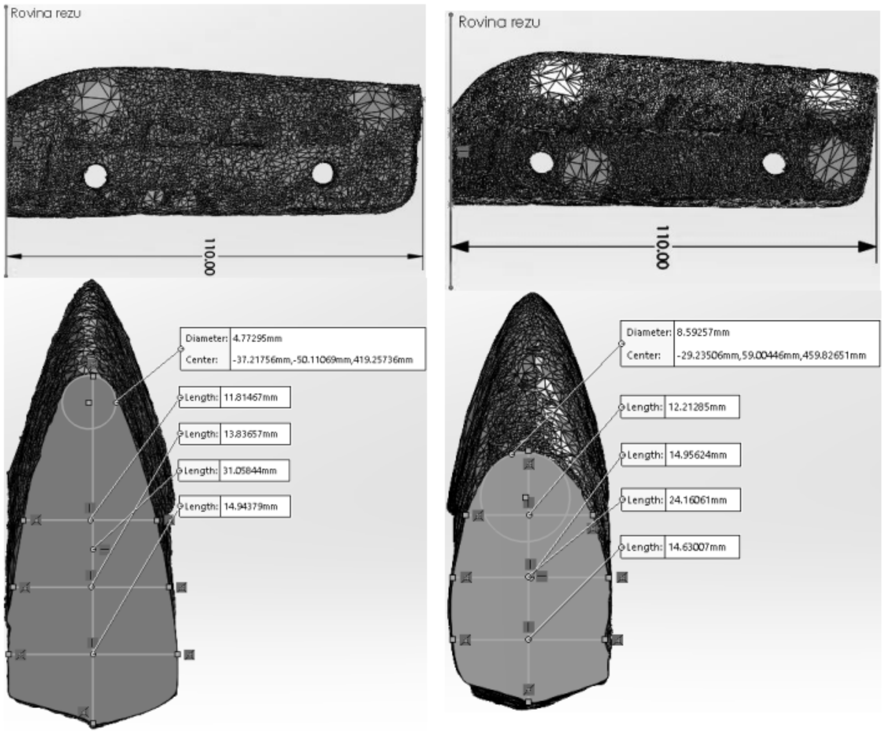

Fig. 4 Digital cross sections of the new seed coulter (left) and the worn seed coulter (right)

To verify the accuracy of the dimensional measurements in digital cross sections (Fig. 3), measurements were made on the contours of the examined samples in a given section plane (110 mm from the base point – Fig. 1) obtained by the wire method. The results of the dimensional measurements using the ZEN Core software are shown in Fig. 5.

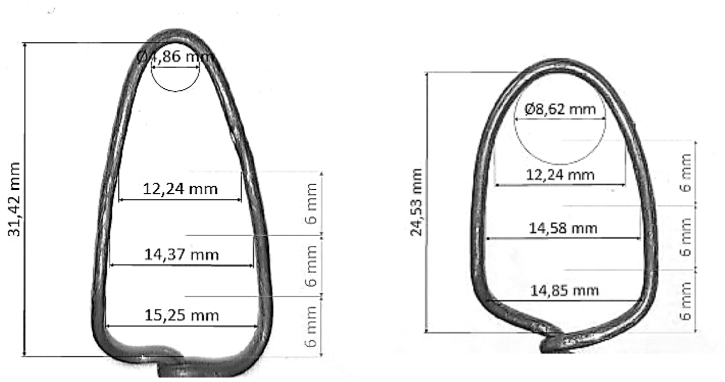

Fig. 5 Cross section of the new seed coulter (left) and the worn seed coulter (right) measured by wire method using ZEN Core Software

A comparison of the values of the seed coulter dimensions obtained using digital models and using the wire method (Fig. 6 and Fig. 7) shows that the deviations of the individual dimensions are in the order of 0.1 mm. The percentage differences were calculated relative to the reference values obtained from the digital model. In general, larger differences between the dimensions determined using the digital model and the wire method were recorded for the new sample (Tab. 1). The largest difference was found for the S2 dimension, which represented a difference of 3.83%. The differences between the dimensions determined by using the digital model and the wire method on the new sample did not exceed 4% in any case.

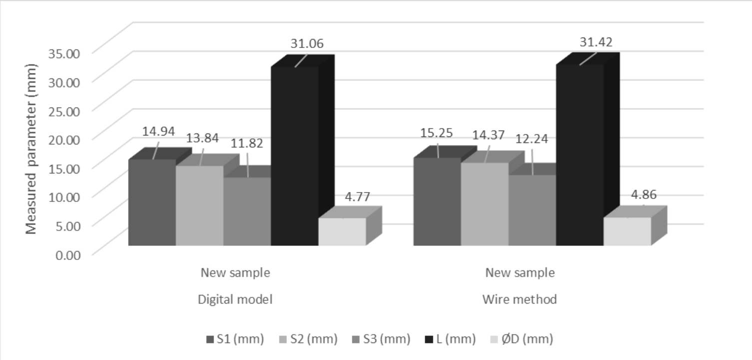

Fig. 6 Comparison of the new seed coulter dimensions obtained using a digital model with the dimensions obtained using the wire method

The wire method is simple and useful for basic geometry but sensitive to manual errors such as improper tensioning or inaccurate point marking.
3D scanning, on the other hand, produced more consistent and reliable results, especially for complex or worn surfaces. It also revealed fine details that may be missed by traditional techniques.
Another advantage of 3D scanning is its non-contact nature, which minimizes the risk of damaging delicate surfaces. It also allows archiving digital replicas for future reference or reproduction. The methodology demonstrated in this study may be generalized to other components exposed to similar wear conditions. Combined with CAD-based simulations, it also supports design optimization by identifying weak zones prone to degradation.

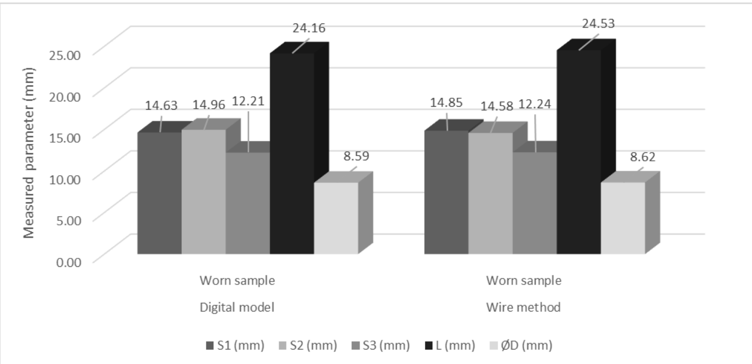

Fig. 7 Comparison of the worn seed coulter dimensions obtained using a digital model with the dimensions obtained using the wire method

Tab. 1 Parameter variation of new vs. worn seed coulters assessed via digital model and wire method

Difference in measured parameter	*S1* %	*S2* %	*S3* %	*L* %	*ØD* %
New sample	-2,07	-3,83	-3,55	-1,16	-1,89
Worn sample	-1.50	2.54	-0.25	-1.53	-0,35

The results of this study align with findings from other authors who applied 3D scanning to assess wear in various components.
Cucinotta et al. (2019) used an optical 3D scanner (ATOS Compact Scan 500-2M) to evaluate the wear of ploughshares. Through sectional analysis of the cutting edge, they identified worn areas visualized using RGB color mapping. Their results demonstrated similar effectiveness in detecting localized material loss as observed in this study.
Saadi, El-Damanhoury & Khalifa (2023) analyzed the wear of 3D-printed teeth using the InEos Blue Sirona scanner. Based on 3D models before and after wear, they evaluated volumetric loss using Meshmixer software. Similar to this study, they observed sub-millimeter differences, with the largest deviations occurring on rounded surfaces.

Benfield et al. (2022) tested the application of a 3D optical scanner for evaluating the wear of the human meniscus. Using structured light, they scanned 3D-printed replicas before and after one million cycles of simulated load. Their findings showed high accuracy in detecting material loss and confirm that 3D scanning is also effective for soft and irregularly shaped objects.
Valigi, Logozzo & Affatato (2017) demonstrated in a comparative study that 3D optical scanning is more accurate than traditional 2D techniques when assessing wear in railway components. Their measurement discrepancies remained within 5%, consistent with the differences measured in this study for the new seed coulter.
These results confirm that 3D scanning is a suitable method not only for metal components but also for complex, soft, or biological structures. In terms of accuracy, repeatability, and the ability to digitally archive models, this technology offers clear advantages over conventional methods.

ECONOMIC EVALUATION AND ROI ANALYSIS

The implementation of advanced technologies such as 3D scanning in agricultural production requires not only technical evaluation but also economic analysis. Return on investment (ROI) analysis provides concrete data on how quickly the investment will pay for itself and what impact it will have on operational efficiency and costs.
We took the following factors into account when calculating ROI:

- The price of the EinScan HX 3D scanner.
- Reduction in the time required for measurement and wear analysis.
- Faster identification of worn parts leads to more efficient maintenance planning.
- Early detection of wear allows for extended life of replacement parts.

The values used in the ROI calculation are based on a comparison of the traditional measurement method and 3D scanning:
Time savings of 4.17 hours per month → Traditional wire measurement takes ~40 minutes per component, while a 3D scanner takes only ~15 minutes →Assuming 10 components per month, the difference is approximately **4.17 hours**.
Reduction in downtime of **10 hours per month** → It is estimated that earlier detection of wear using a 3D scanner will reduce unplanned machine downtime by approximately **half the time** that the machine would be down using the traditional method.
15% increase in component life → More accurate wear monitoring allows components to be replaced in good time before they are completely worn out.
Assuming an hourly pay rate of 15 € and monthly maintenance costs of 1,000 €, the approximate savings are as follows:
Time savings: $4.17\ h \times 15\ € \approx 62.5\ €$ per month
Reduction in downtime: $10\ h \times 15\ € = 150\ €$ per month
Extended service life of parts: $15\%\ of\ 1{,}000\ € = 150\ €$ per month
Total monthly savings: $62.5\ € + 150\ € + 150\ € \approx 362.5\ €$
Annual savings: $362.5 \times 12 \approx 4350\ €$

$$ROI = \frac{Benefits}{Costs} \times 100 = \frac{4350\ €}{7300\ €} \times 100 = 59.6\%$$

$$Payback\ period = \frac{7300\ €}{4350\ €} \approx 1.68\ years \approx 1\ year\ and\ 8\ months$$

The application of the EinScan HX 3D scanner in agricultural production brings not only technical advantages but also important economic benefits. The investment will pay for itself in approximately 1 year and 8 months, with more precise and faster measurements reducing time, downtime and maintenance costs. These model calculations demonstrate the practical value of the technology and offer motivation for its implementation.

CONCLUSIONS

The results of the study confirm that 3D scanning represents an accurate, repeatable, and efficient method for assessing the wear of machine components, particularly those with complex or irregular geometries. By comparing digital models of new and worn seed coulters, it was possible to quantify material loss at a specific cross-sectional plane with a precision of up to 0.1 mm. Compared to the traditional wire method, 3D technology demonstrated higher reliability and lower error rates, especially on rounded and uneven surfaces. Additionally, it enabled detailed visualization of wear and digital archiving of the geometry for future analysis. The verification process showed that dimensional differences between the two methods did not exceed 4%, confirming the high accuracy of the proposed methodology. This technology has proven to be suitable not only for metal components in agriculture but also for a wider range of applications requiring the monitoring of functional changes over time. Moreover, besides financial and time savings, their key advantages include repeatability, precision, archiving capabilities, and the ability to perform detailed calculations and statistical analyses, which clearly demonstrate the return on investment (ROI). The findings can be generalized and applied to the wear assessment of other types of tools or components exposed to similar operational conditions.

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REFERENCES

1. Afteni, C., Paunoiu, V., Afteni, M., & Teodor, V. (2022). Using 3D scanning in assessing the dimensional accuracy of mechanically machined parts. In *OP Conf. Ser.: Mater. Sci. Eng.*, 1235, 012071.
2. Benfield, C. T., Chen, M., Moskal, G., & Kearney, R. S. (2022). Quantification of meniscal wear using 3D optical scanning. *Journal of Biomechanics, 133*, 110939.
3. Brusilová, A., & Gábrišová, V. (2014). Methodology of wear profile analysis. *Manufacturing Technology, 14*(2), 137–143.
4. Cucinotta, F., Catarinicchia, A., & Mazzoleni, P. (2019). Evaluation of ploughshare wear using 3D optical scanning. *Measurement, 134*, 356–364.
5. Müller, M., & Hrabě, P. (2013). Overlay materials used for increasing lifetime of machine parts working under conditions of intensive abrasion. *Research in Agricultural Engineering*, *59*(1), 16–22.
6. Müller, M., Chotěborský, R., & Hrabě, P. (2015). Application of overlay material on soil processing tools for purpose of increasing their abrasive wear resistance [Aplikace návarového materiálu na nástroje zpracovávající půdu za účelem zvýšení jejich odolnosti vůči abrazivnímu opotřebení]. *LCAŘ*, *131*(9–10), 279-283.
7. Saadi, M. M., El-Damanhoury, H., & Khalifa, N. (2023). Volumetric wear assessment of 3D printed teeth using 3D scanning. *Dental Materials, 39*(1), e30–e37.
8. Stachowiak, G. W., & Batchelor, A. W. (2013). *Engineering Tribology* (4th ed.). Oxford: Butterworth-Heinemann.
9. Tóth, T., & Živčák, J. (2014). Optical measurement systems in mechanical engineering. *Applied Mechanics and Materials, 611*, 202–209.
10. Ťavodová, M., Kalincová, D., Kotus, M., & Pavlík, Ľ. (2018). The Possibility of Increasing the Wearing Resistance of Mulcher Tools. *Acta Technologica Agriculturae*, *21*(2), 87–93
11. Valigi, M. C., Logozzo, S., & Affatato, S. (2017). Accuracy evaluation of 3D optical scanners for wear detection. *Wear, 376–377*, 788–796.
12. Valigi, M. C., Logozzo, S., & Affatato, S. (2020). 2D versus 3D assessment techniques in railway component wear. *Measurement, 164*, 108059.

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