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Assessment of the Effectiveness of Thermographic and Computer Vision Techniques in Analyzing Thermal Phenomena during Drilling: Wood-Based Materials Perspective

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Abstract: A new direction related to research in the wood industry may be thermal imaging together with computer vision techniques. In this work, an attempt was made to use these to record temperature phenomena during drilling in wood-based materials, using MDF as an example. For this purpose, a CNC station was created with a built-in high-resolution thermal imaging camera (260x200 px). Two drill bits were examined – sharp and dull. The temperatures generated by them during drilling were compared. It was shown that the phenomena which can be recorded during the drilling process can be associated with changes in the tool geometry, and therefore can be used for research related to heat during drilling. The presented results open many new and interesting directions in research in wood-based materials technology.

***Keywords**:* computer vision, thermal imagine, woodworking, machining

INTRODUCTION

In the era of rapid technological development, engineers and scientists are constantly looking for innovative methods and technologies that can contribute to improving production processes as well as the efficiency and quality of products. A potential direction in the mechanical wood processing industry may be thermal imaging techniques, with particular emphasis on thermal imaging cameras and computer vision. These are tools that appears to become interesting from a scientific and industrial point of view.

The article *Infrared Thermography for Temperature Measurement and Non-Destructive Testing* [Usamentiaga et al., 2014] provides an excellent introduction to infrared thermography (IRT) and discusses the use of this technology in various fields, including medicine, diagnostics and building inspection. IRT uses infrared radiation to measure the temperature of objects and provides thermal images that can be useful in many applications, from monitoring temperature in industrial processes to detecting faults in materials. The article presents the theoretical basis of IRT and describes how temperature measurement is carried out using this technology. Image processing and data analysis methods are also discussed. Additionally, the article provides an overview of IRT applications in non-destructive testing, including the detection of defects in materials and the analysis of subsurface structures, citing numerous sources and studies.

In medicine, thermal imaging is widely used in the context of drilling, especially during orthopedic and implant surgeries. For example, it was found that when drilling bovine cortical bone samples, the temperature increased with the pressure force and also varied depending on the drilling direction, which was related to the anisotropy of the thermal properties of the bones [Abouzigia and James 1997]. In other studies, high-speed drilling was shown to produce less heat, which was associated with a faster healing process and higher quality of new bone formation compared to lower-speed drilling [Iyer et al. 1997]. Temperature measurement also made it possible to conduct research on the influence of drill geometry on heat production during drilling. It was found that the drill geometry had a significant impact on heat production, and drills with specific geometries were characterized by lower temperatures even after repeated use [Chacon et al. 2006]. This also applies to other cutting parameters [Belleville et al. 2013].

In the woodworking industry, examples of the use of thermal imaging in scientific research aimed at understanding thermal processes and their impact on various properties of wood materials or tools also can be found. In papermaking, heat transfer measurements were performed for various cellulose fiber suspensions flowing through a pipeline. It was found that heat transfer was dependent on various fiber properties, such as length, and elasticity, as well as various mechanical and chemical processing methods [Kazi et al., 2015]. In another study, an experiment was carried out on the thermal performance of underfloor heating systems on a scale model. These studies aimed to understand the impact of the presence of furniture on the efficiency of the underfloor heating system and the ambient temperature [Fontana, 2011]. Other research allowed for the development of a new analytical method allowing to obtain the solution of equations describing changes in the internal and surface temperature of the building over time, which may be used in wooden construction [Lü et al. 2006].

Computer vision is a field of computer science that deals with image processing and the analysis of visual data using computers. In the woodworking industry, computer vision is used in both scientific and industrial research contexts, enabling the analysis of various parameters and optimization of production processes. Computer vision can be used to analyze drill wear when machining chipboard, a material commonly used in furniture production. This study focuses on adjusting the loss function in the XGBoost algorithm to improve drill wear classification accuracy [Bukowski et al. 2024]. In another study, the authors examine the impact of different feature extraction methods on the effectiveness of tool condition classification in the case of tool condition monitoring [Antoniuk et al. 2023]. Microdrilling studies were carried out on *Sapindus mukorossi* seeds, which are commonly used in the production of handicrafts. The authors analyze the influence of drilling parameters on drilling force, hole diameter and hole morphology to optimize the drilling process [Zhao et al. 2023]. A new method for measuring the shape of assembly holes under the influence of changes in the humidity of wooden elements has been described [Sydor et al. 2023]. Computer vision can also be used to measure the position of holes with small diameters [Król and Szymona, 2021; Król et al. 2022; Król and Koczan 2023].

These examples illustrate various applications of computer vision in scientific and industrial research in the wood industry, which can contribute to improving production processes and improving the quality and efficiency of manufactured products.

In connection with these reports, it can be concluded that the use of thermal cameras and computer vision techniques in the analysis of temperature phenomena during drilling in wood-based materials may be an interesting research area. This article aims to present the potential of these technologies and demonstrate their practical use in research related to the mechanical processing of wood on the example of MDF.

MATERIALS AND METHODS

CNC drilling

A standard MDF board was used for the tests (average density 752 kg/m³, Brinell hardness HBW 4.3, thickness 16 mm). The holes were made with a standard HSS drill for metal with a diameter of 3 mm (Klimas Wkręt-Met NWKA0300, DIN 338). The first series (consisting of a 12-time repetition of the drilling program of 320 holes) was made using a new drill, while the second series was made using a worn drill. Drill bit was blunted manually with grind stone.

No mechanical or vacuum chip removal was applied. Chips were removed from the camera lens manually by directing compressed air into the lens. The liquid-cooled spindle speed of 7500 RPM, feed 3m/min. A *shutter device* was connected to the CNC machine at the *Coolant* output, whose task was to reveal a warm point in the camera's field of view. The warm spot was directed at the camera using a mirror.

The holes were made at the same intervals (time and location) in a 16x20 arrangement. Drilling gcode used for one hole was:

```
G90 G1 Z3 F3000
G90 G1 Z-1 F3000
G91 G1 X-5 F3000
M8      ;coolant on
G4 P0.2 ;wait 0.2s
M9      ;coolant off
```

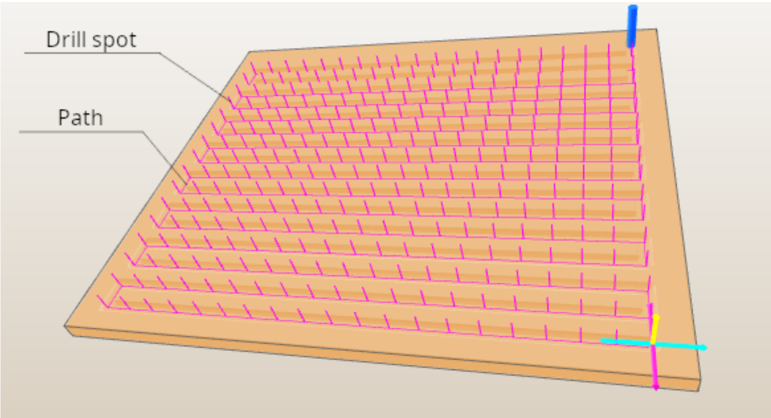

Figure 1. Visualization of gcode of a single sample.

Images acquisition

The thermal imaging camera (Maant Super IR CAM, 260x200 px) was placed in a fixed position relative to the drill and the XY axes and in a fixed position relative to the Z axis (Fig. 2). Video records began before the drilling program was started and ended after its completion. Software used was provided with camera – MaAnt IR 1.03.3 Win32 Eng.

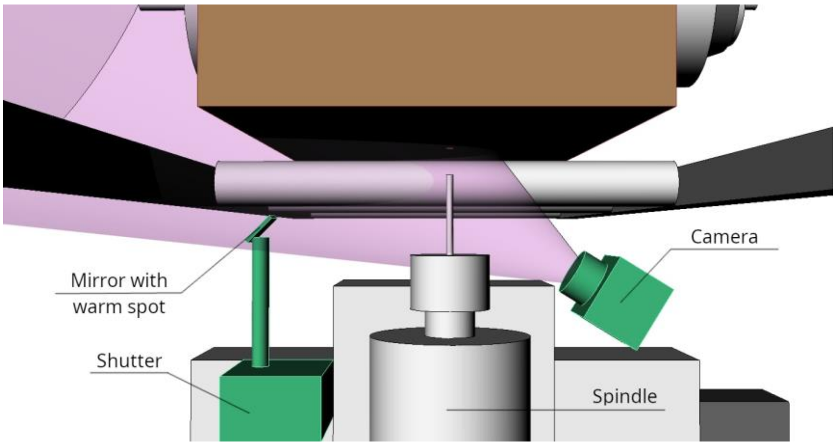

Figure 2. Diagram of the measurement station.

During the drilling process, a thermal imaging camera tracks the movement of the drill and takes an image in the form of a video. After the drill is removed from the material, the spindle remains in position for 0.2 s and the shutter opens, revealing a warm spot in the camera's field of view.

Image analysis

An example image recorded for further analysis is shown in Figure 3. The first 3 stages of image analysis are presented in the diagrams (Figure 4-6), the code is available at https://github.com/PMK-rol/IRCamDrill/tree/v1.0. The scripts were run on Octave GNU Octave software, version 5.2.0, in the Kubuntu 20.04 environment.

Figure 3. Example screenshot during the test.

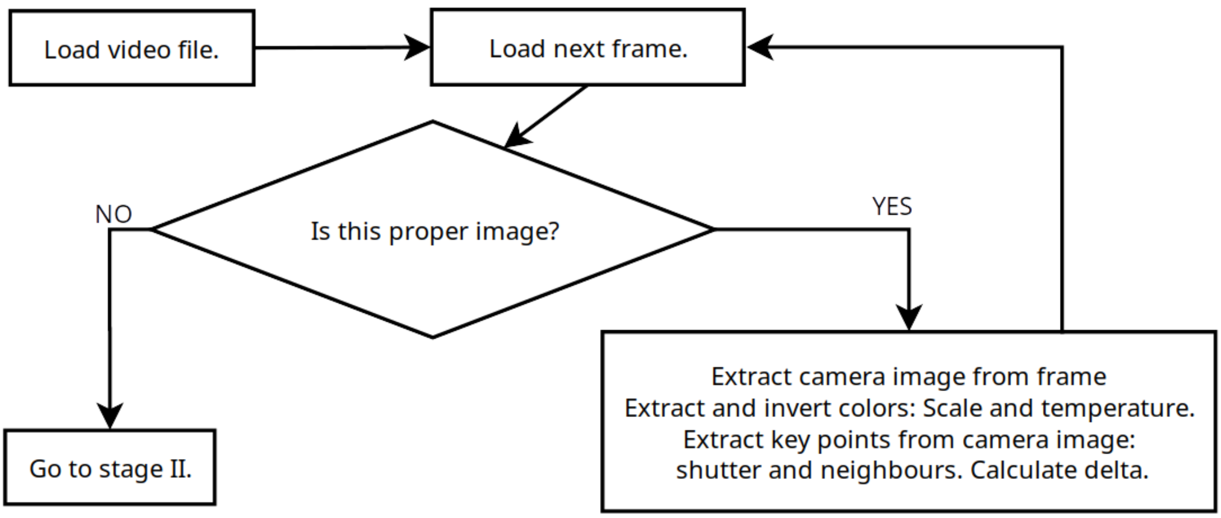

Figure 4. Stage I of image analysis. The result is a series of frames and calculated numerical values (time and brightness difference between the *warm spot* and the surrounding area).

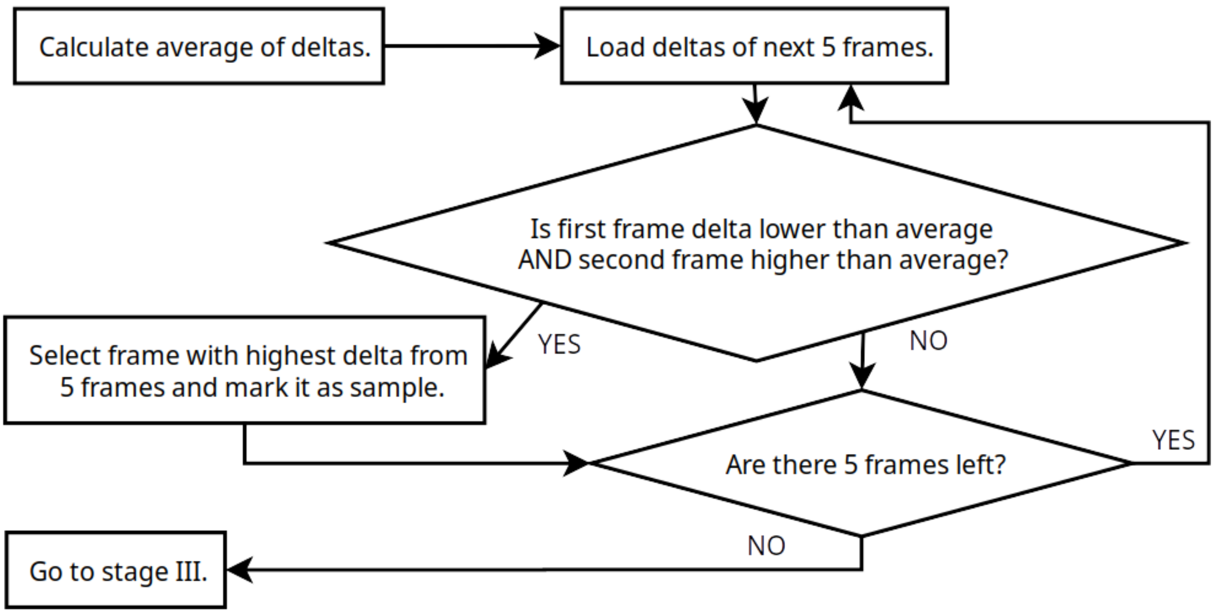

Figure 5. Stage II of image analysis. The result is a series of frames in which a warm spot appears.

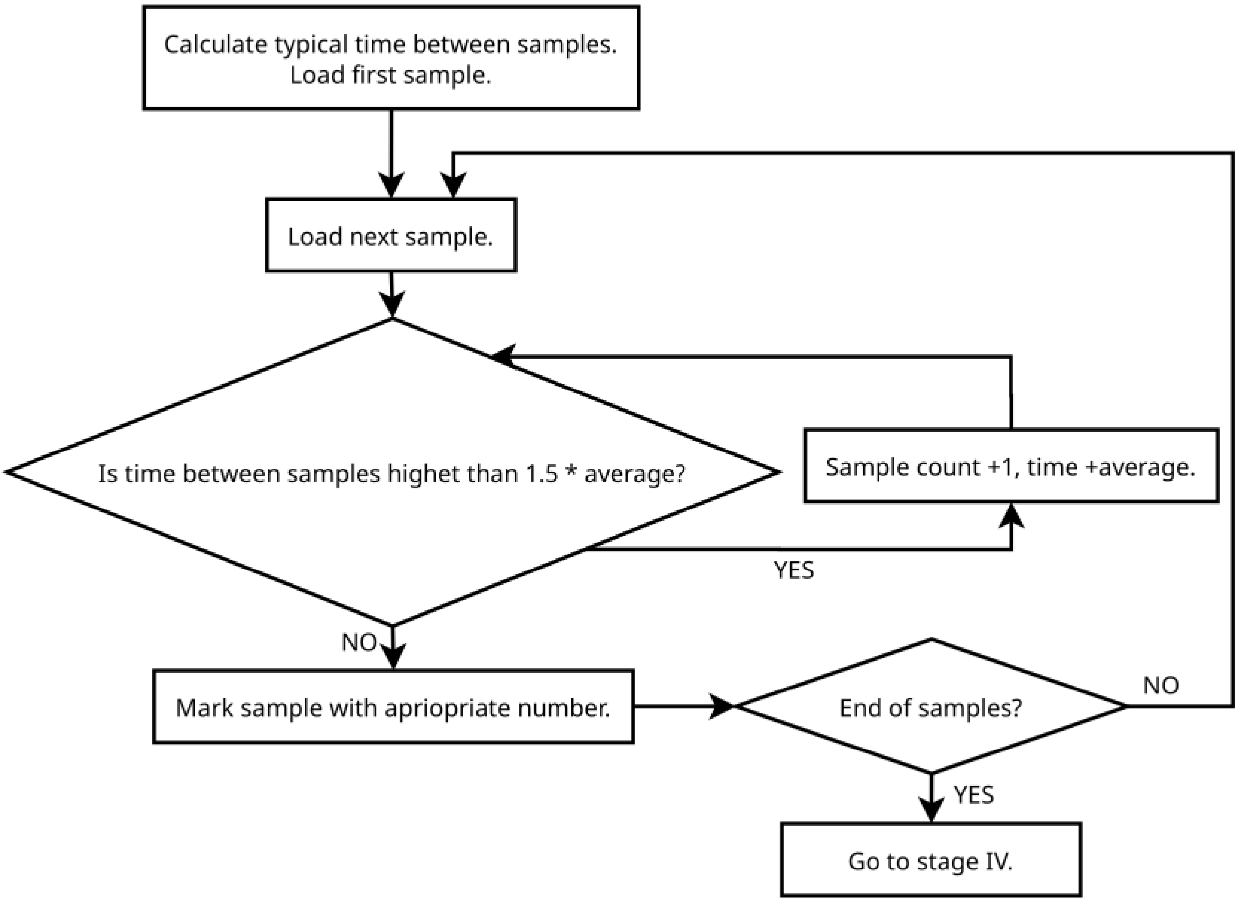

Figure 6. Stage III of image analysis. As a result, frames are obtained for further image analysis with the sample number marked. This level aims to possibly predict the number of missed frames.

The simplified image analysis process can be described as selecting frames from a film with a warm spot (stages 1-2), correcting sample numbering (based on the time between measurements, stage 3), reading the maximum temperature using OCR tools (gocr 0.52 20181015, built-in text analysis disabled, analysis based on a manually created database).

Calculations (average) and preparation of charts were performed using the LibreOffice 6.4.7.2 package.

RESULTS AND ANALYSIS

The test results are presented in charts: average temperatures obtained for both stages of drill wear (Fig. 7), raw data for selected (first, middle and last) series of holes with a new drill (Fig. 8) and raw data for selected (first, middle and last) series of holes with a worn drill (Fig. 9). Breaks in the series are related to the unfavorable properties of the thermal imaging camera used.

The analysis of averages allows to conclude that the temperature of the drill, immediately after making a hole, changes with tool wear. The average results indicate that the temperature increase in the first phase (heating the drill to a constant temperature) occurs faster in the case of a worn drill. This seems to be consistent with literature data and intuition.

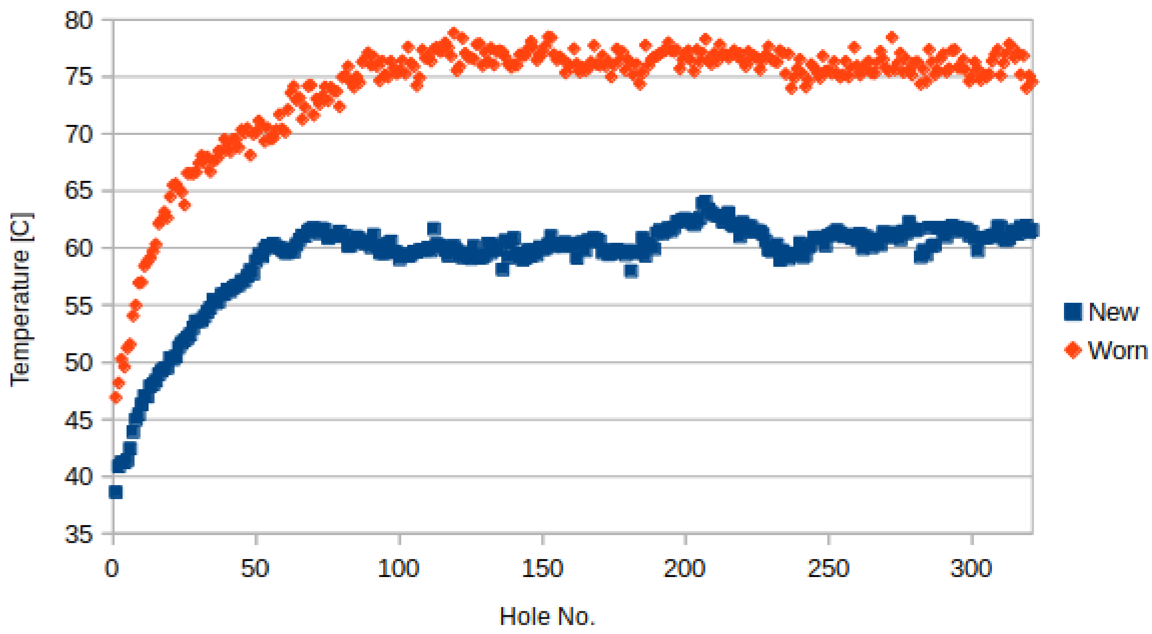

Figure 7. Average temperatures (for subsequent holes) for a new and worn drill.

The graph showing the course of subsequent series in the case of a new drill shows the trend of temperature increase (both the rate and the maximum value) with each subsequent course (i.e. after a series of 320 holes). The reason for these changes may be the rapid wear of the HSS tool when cutting MDF boards, resulting in a change in its geometry and an increase in friction between the board material and the drill surface - these results are consistent with literature data [Chacon et al. 2006]. The indistinct but recurring oscillatory nature of the graphs may be related to the distribution and order of drilling the holes (heat transmission from the holes drilled in the previous line).

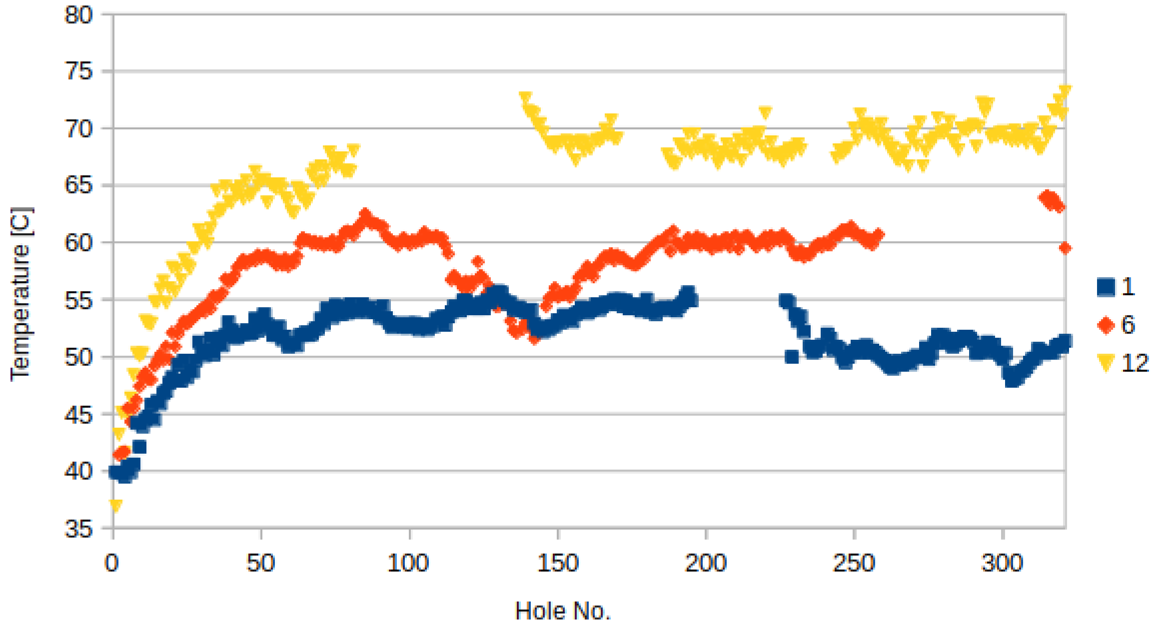

Figure 8. Temperature of the new drill during subsequent series of measurements (selected).

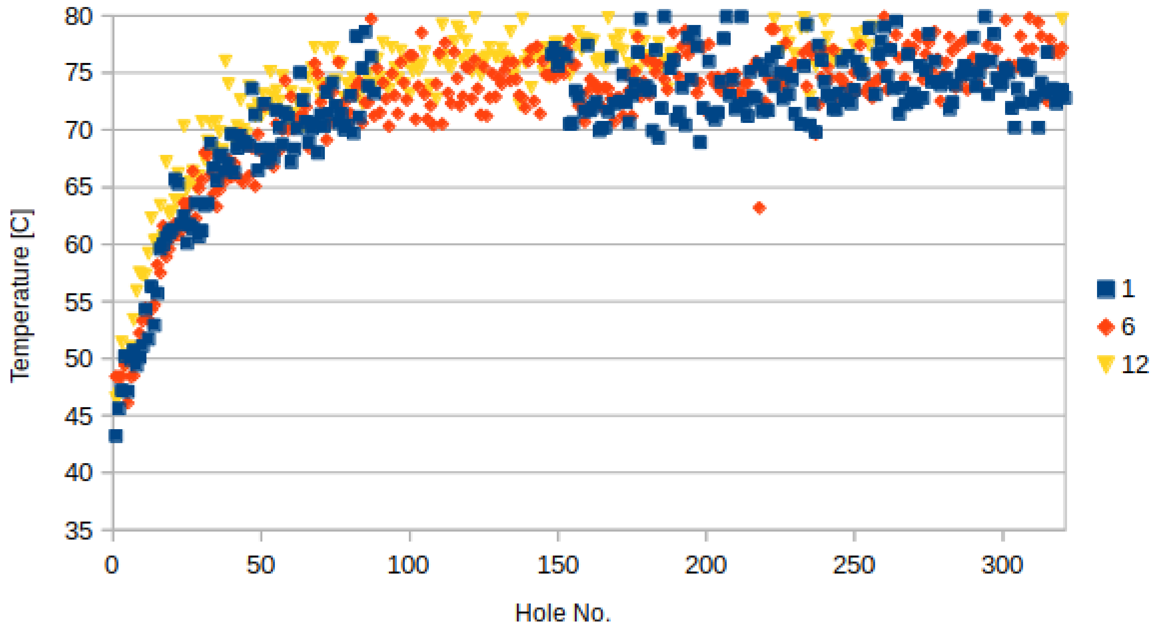

Figure 9. Temperature of the worn drill bit during subsequent series of measurements (selected).

In the case of the temperature course of a worn drill, no clear difference is visible between subsequent attempts (subsequent series of 320 holes). This suggests no clear change in the drill geometry or a change that does not have a clear impact on temperature phenomena.

CONCLUSIONS

The study of temperature phenomena using computer vision and thermal imaging techniques seems to be an interesting analytical direction in the wood materials industry. This study shows that the temperature phenomena can be registered during the drilling process. Observed temperature changes are associated with a change in the tool geometry caused by wear. This is consistent with the literature data [Chacon et al. 2006].

The results show that this may be a promising direction. Although the method requires several refinements and research with in-depth analysis, in the future, the proposed method may be used to study the influence of various cutting parameters, type of boards (their composition), process parameters (cooling, hole drilling sequence) on temperature phenomena and wear rate during the drilling process.

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Streszczenie: *Ocena efektywności technik termowizyjnych i widzenia komputerowego w analizie zjawisk termicznych podczas wiercenia: perspektywa materiałów drewnopochodnych.* Nowym kierunkiem związanym z badaniami w przemyśle drzewnym może być termowizja wraz z technikami widzenia komputerowego. W niniejszej pracy podjęto próbę ich wykorzystania w celu rejestracji zjawisk temperaturowych podczas wiercenia w materiałach drewnopochodnych na przykładzie MDF. W tym celu stworzono stanowisko CNC z wbudowaną kamerą termowizyjną o dużej rozdzielczości (260x200 px). Zbadano dwa wiertła – nowe oraz zużyte i porównano wygenerowane przez nie temperatury podczas wiercenia. Wykazano, że zjawiska możliwe do zarejestrowania podczas procesu wiercenia można powiązać ze zmianą geometrii narzędzia, a więc mogą posłużyć do badań powiązanych z ciepłem podczas wiercenia. Przedstawione wyniki otwierają wiele nowych i ciekawych kierunków w badaniach w technologii tworzyw drzewnych.

Słowa kluczowe: wizja komputerowa, termowizja, obróbka drewna, obróbka skrawaniem

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