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Towards wood dust collection during robotic grooving

Y. Dong^{1,2}, A. Bouali¹, N. Mechbal³, L. Bleron, T. Raharijaona^{2*}

Abstract—The wood construction industry has integrated the challenges of robotics and introduced the use of five-axis machining for more than 30 years. However, the wood dust and chips are often contaminated with different chemicals which causes health risks.

In this paper, we present an experimental analysis of the physical properties of chips by observing the motion behavior with a single high-speed camera. The experiments are led with an industrial gantry robot during the grooving process. The results show that we can estimate and quantify the velocity direction of wood chip emission in a range of 5m/s near the tool-material interaction. We also constructed two suction hoods and we experimentally show that chip collection is better when the tube is tilted near the tool.

I. INTRODUCTION

Wood manufacturing operations emit air pollutants and dust particles. When not properly removed, dust particles can cause problems in the machining systems: damage and immediate loss of performance [1]. Breathing dust particles also increases the risk of nasal cavity cancer and lung cancer among workers with cumulative exposure [2]. Thus, centralized aspiration systems have become mandatory in the wood industries. These systems efficiently remove dust particles from the traditional wood machining process, but still need improvements for Computer Numerical Control (CNC) machining [3].

Indeed, the efficiency of chip and dust extraction depends on the machining process. Dust creation in CNC drilling has been studied in [4]. The size of the obtained particles when drilling without a proper suction system might pose a potential risk to the health of woodworkers. The results are similar when considering sawing operations [5] and the milling process in [6]. Moreover, cutting parameters impact the dust emission and the surface quality during wood machining [7], [8]. It has been demonstrated that the shape, the size, and the amount of emitted particles during sawing process mainly depend on the form, physical and mechanical properties of sawed wood as well as on the shape, dimensions, type of machine, sharpness of the cutting blade, and technical and technological conditions of the sawing process [9].

When considering CNC machining, it is usual to see the suction hood fixed above the spindle. The efficiency of such a technique is limited due to the large workspace and the



Fig. 1: Picture of wood dust emission during the robotic grooving. We constructed an experimental setup composed of an industrial gantry robot to understand how dust particles are emitted for operational conditions such as feed speed and rotational speed.

complexity of the tool path that is allowed by using a 5-axis CNC. It has been demonstrated in [10] that the efficiency of the extraction system is usually limited.

Contribution: In this paper, we present an experimental setup dedicated to the observation of emitted particles during a woodworking process: robotic grooving.

The experimental setup is based on the use of a high-speed camera. The setup enables the observation of particles with diameters ranging from 0.1mm to 3mm. We succeeded in experimentally (i) determining the directions of emission of the wood chips, (ii) estimating the velocity magnitude of the particles, and (iii) building and testing a centralized suction system to improve dust collection near the tool. The suction system is tilted. While tilted, it succeeded in capturing an average of 50% of the emitted dust.

II. STATE OF THE ART

A. Origin of dust and chips

The expected quantity by volume of dust and chips produced in the unit time is determined by the width and depth of cut and the feed speed. The quantity by mass (kg/s) is obtained by multiplying the volume with the wood density [11]:

$$m_m = \frac{b \cdot e \cdot H}{60} \cdot \rho_m \quad (1)$$

where

b is the width of cut,

H is the depth of cut,

e is the feed speed in m/min,

ρ_m is the wood density.

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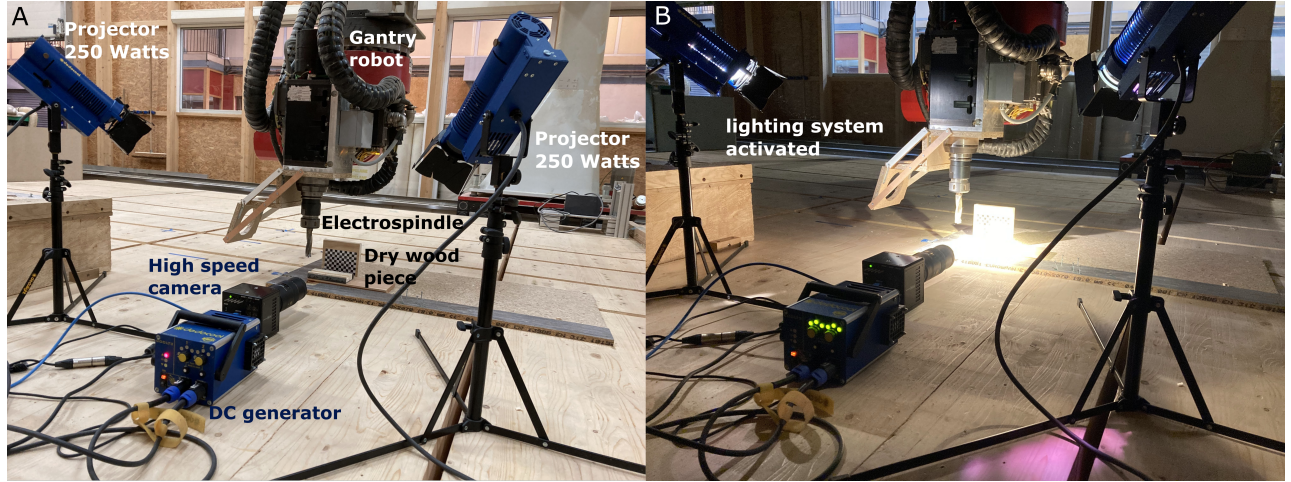


Fig. 2: Experimental setup dedicated to the analysis of the wood dust motion during robotic grooving. A) Picture of the experimental setup. It is composed of a multi-functional five-axis gantry robot. B) We used a lighting system and a high-speed camera to capture the motion of the ejected wood dust.

B. Dust and chip collection

The collection of dust is a very difficult task. It may impact the workroom pollution and energy costs of dust extraction. In this paper, we addressed the problem of dust collection during robotic grooving by analyzing the motion behavior of the thrown particles in the air as presented in Fig. 1. To analyze the motion behavior of a wood chip, the dynamics of the particle is modeled. As a first approximation, we can neglect the effect of gravity. The equation of motion reads [12]:

$$m \frac{dv}{dt} = c_e \cdot A \cdot \frac{\rho}{2} \cdot v^2 \quad (2)$$

Eq. (2) can be written such that:

$$\frac{dv}{v} = B \cdot dt \quad (3)$$

where,

$$B = \frac{g}{v^2} \quad (4)$$

v_{cr} is the terminal velocity. It is determined when the force due to air resistance is identical to the weight of the body. g is the gravitational constant.

If we assume the wood chip is a spherical body with a diameter d and a volume weight γ_m , the expression of v_{cr} is:

$$v_{cr} = \sqrt{\frac{4d\gamma_m}{3c_e\rho}} \quad (5)$$

An integration, with the initial condition $t = 0 \rightarrow v = v_0$, yields the expression:

$$v = \frac{v_0}{v_0 \cdot B \cdot t + 1} \quad (6)$$

$$s = \frac{1}{B} \cdot \ln(v_0 \cdot B \cdot t + 1) \quad (7)$$

where

s is the traveled distance,
 t is the elapsed time.

III. MATERIALS

A. Experimental Setup objective

We created an experimental setup to capture wood chips and dust generated during the robotic grooving. The setup included the following elements: a gantry robot, an electrospindle carrying machining tools, a high-speed camera, a lighting system with DC generator, and the wooden piece for manufacturing (see Fig 2).

B. Details of the experimental setup

1) *The robot*: WoodFlex32, the robot we used is a five-axis CNC platform. The robotic platform executes machining processes and is based on a multi-functional five-axis gantry robot. Thanks to Lot 1 engine, and the command software, we can pilot this robot easily with CNC ISO code.

2) *The machining tool and the electro-spindle*: A GIOR-DANO COLOMBO motor is mounted on the robot arm. It can provide a rotational speed of up to 18000rpm. A machining tool is selected to execute the grooving program, with the rotational speed up to 18000rpm and feed speed up to 10m/min. The path width was the same as the diameter of the tool.

3) *The high-speed camera*: To visualize wood chips and dust during manufacturing, we used a high-speed camera Photron mini UX 50, which provides a 1280*1024 full resolution and can give a frequency of 102400 frames per second with a duration of about 2 seconds. In addition, we used PFV4 software to pilot the camera and save videos.

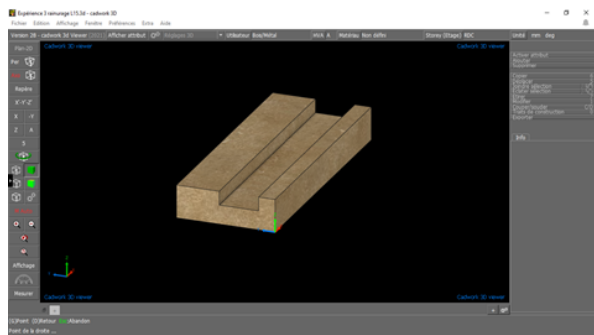


Fig. 3: Modeling the wood piece by Cadwork 70mm in width, 20mm in height, 150mm in length

4) *The lighting system:* We used two projectors COOLH dedocool as the lighting system, to light up the processing zone (see Fig 2). Each of them has a wattage of 250W and can provide 370000 Lux at 50 cm, with a supply voltage of 24V.

5) *The DC generator:* A COOLT3 generator powered two projectors. It can transform 240V to 24V.

6) *The wooden part:* The work piece part is a resinous wood. It is about 150mm long, 70mm in width, and 20mm in height. The work piece is fixed by the screw on the metallic support, to avoid the part from moving during machining.

IV. METHODS

In this section, we describe the methods and tools that will be employed, from camera calibration to the definition of the woodworking parameters. We also present a basic equation of motion for wood particles.

A. Camera calibration

The camera was positioned to have a large field of view and a deep film zone at the same time. We put the camera at 0.5m away from the machining origin.

To calibrate the camera, we used a checkerboard as the calibration reference. Each square of the checkerboard represented 10mm*10mm, so we measured and calibrated by using the software calibration function, and we obtained the following setting: 0.034mm/pixel.

We needed a high frequency to follow the wooden particles during machining, but the higher the frequency, the lower the resolution. Finally, we set the frequency at 5000fps. Consequently, we followed almost all wooden particles and, at the same time, had a good resolution.

To make the video as clear as possible, we needed a higher shutter speed, but we also needed a more powerful light. After several tests with the equipment, we set the shutter speed at 1/40000s.

B. Wood piece modeling and trajectory definition

We used the software CadWork for modeling the machining part (see Fig 3), and Lignocam to define the machining trajectory. We also used the software Lot 1 engine to generate ISO code and operate the robot. The

Machining parameters	Value	Unity
Rotational speed	18000	rpm
Feed speed	5	m/min
Feed width	24	mm
Feed depth	10	mm
Feed per turn	0.27	mm
Feed per tooth	0.093	mm

TABLE I: Values of the woodworking parameters

geometry of the wood piece was 70mm in width and 20mm in height mainly because it was the easiest form to find and process in the laboratory. The length of the part was 150mm, so we had enough length for a camera field of view and, at the same time, we minimized the machining time.

C. Definition of the woodworking parameters

The dust and chips are produced by different woodworking operations such as sawing, milling, molding, sanding, and grooving. In the article, we need to understand for grooving process how dust and chips are produced. We defined the woodworking parameters given in Table I and we identified that the production of dust and chips is determined by the width and depth of cut and the feed speed.

We analyzed the motion of dust particles whose size is over 100 μ m.

Moreover, the chips thrown by the tool are subjected to a drag force consisting of frictional forces and a force due to asymmetrical pressure distribution on the body [11].

This drag force is calculated from the equation below:

$$F_d = c_e \cdot A \cdot \frac{\rho}{2} \cdot v^2 \quad (8)$$

where

c_e is the drag coefficient,

A is the cross section of the body normal to the flow,

ρ is the flow velocity relative to the body,

v is the air density.

The drag coefficient c_e is determined for bodies of regular shapes (sphere, cylinder, disk) and are plotted on logarithmic coordinates as a function of Reynolds number Re . For the case study of the woodworking process, the chips have irregular shapes with a rough surface. Their drag coefficients depend on the instantaneous position and orientation. We can assume that the drag coefficients c_e may vary between 0.7 and 0.9.

V. EXPERIMENTAL RESULTS

Depending on the operational characteristics such as cutting speed, depth of cut, and on the mechanical properties of wood species (density, moisture content, resin content) different dust and chips may be obtained, concerning their size distribution and physical properties [11].

In the following experiments, we tested several operational conditions such as feed speed and rotational speed. All these factors influence the particle size distribution and the maximum particle diameter.

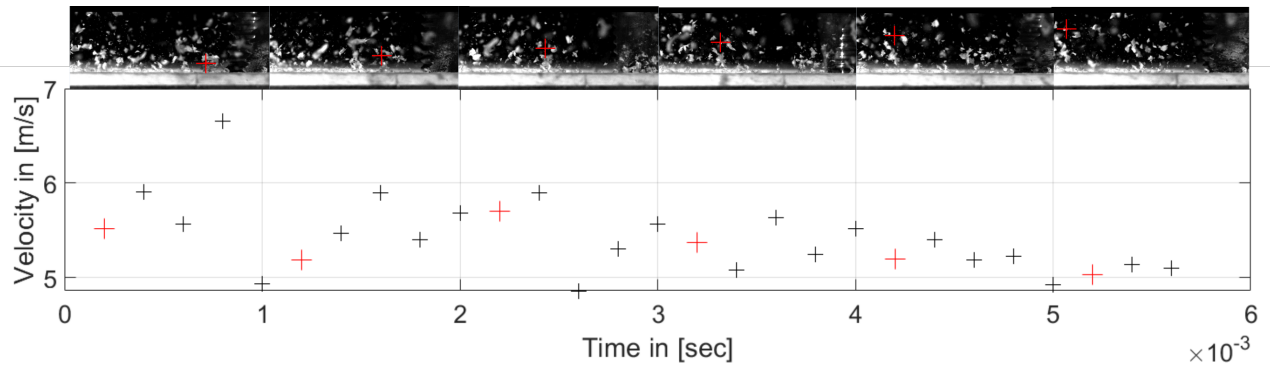


Fig. 4: Experimental estimation of the wood chip velocity magnitude. Knowing the position of the wood chip for each frame, we estimated the instantaneous velocity magnitude versus time along thirty images.

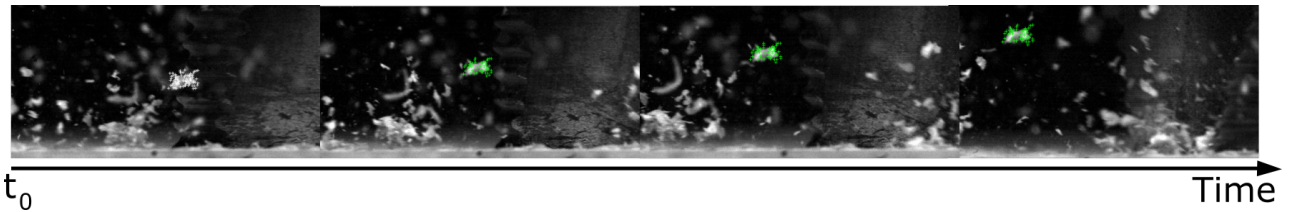


Fig. 5: Automated trajectory tracking of a wood chip. We assumed that the selected wood chip moved in the vertical plane. We manually initialized points to track and set the initial video frame. We estimated the motion of the wood chip by using Kanade-Lucas-Tomasi (KLT), feature tracking algorithm. Since the wood chip changed its shape along its trajectory, we used this algorithm for short-term tracking (ten frames).

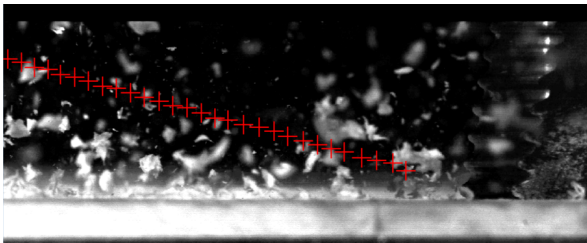


Fig. 6: Trajectory tracking of a wood chip offline. We used the images acquired at high frequency (5000fps) and manually tracked the wood chip during thirty frames.

A. Motion estimation of wood chips by using offline image processing

In the following experiments, we acquired video frames at 5000fps to track the wood chip in the plan of the camera. From Fig. 4, one can see the instantaneous velocity versus time along thirty frames. The magnitude of the velocity is about 5m/s.

In Fig. 5, we automated the trajectory tracking of a wood chip, assuming that the selected wood chip moved in the vertical plane. Firstly, we manually initialized points to track and set the initial video frame. Secondly, we estimated the motion of the wood chip by using Kanade-Lucas-Tomasi (KLT), feature tracking algorithm.

In practice, the shape of a wooden ship is irregular, so the experimental determination of the velocity is not a

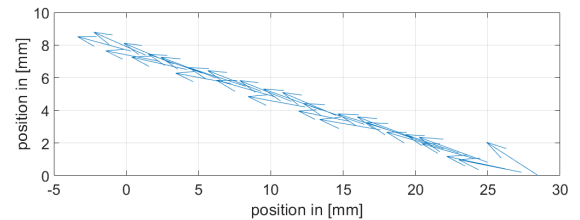


Fig. 7: Estimated velocity vector of a single thrown wood chip

simple task. Therefore, we used this algorithm for short-term tracking (ten frames).

Figure 6 shows the trajectory tracking of a wood chip. The tracking is processed manually frame by frame. One can remark the straight path of the wood chip.

Figure 7 plots the estimated velocity vector of one wood chip along its trajectory.

To collect most of the chips thrown by the tool, it seems to be better to place the collecting tube such that the flying chips directly get into the tube.

B. Construction of a centralized suction system for proximal aspiration and tests of two aspiration modes (vertical tilted)

The placing and construction of suction hoods depend on the tool and operation design. For the woodworking machines, the suction hoods usually are not placed in the

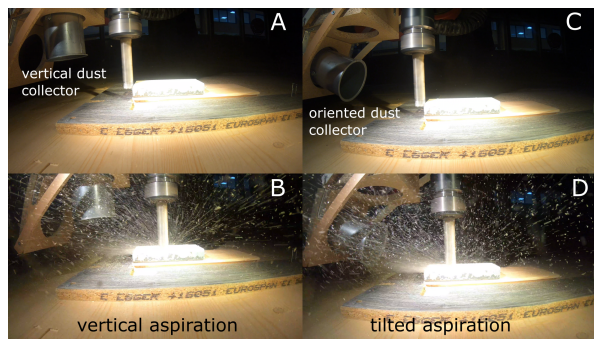


Fig. 8: Tests of the wood dust collection near the tool-material interaction. We constructed two mechanical devices connected to the gantry robot to test the efficiency of the wood dust collector while tilted. A) the device is vertically oriented, B) the device is tilted on the side of the electro-spindle.

N° test	Aspiration mode	Weight of dust [g]
Test 1	without aspiration	6.2588
Test 2	without aspiration	6.3847
Test 3	vertical aspiration	4.2752
Test 4	vertical aspiration	4.0799
Test 5	vertical aspiration	5.2196
Test 6	tilted aspiration	3.6749
Test 7	tilted aspiration	2.7766
Test 8	tilted aspiration	2.3449

TABLE II: Values of the woodworking parameters

proper position to catch more wood particles. In this paper, we constructed a centralized suction system to experiment with the benefit of aspiration of wood particles near the tool-material interaction. Two mechanical devices were connected to the gantry robot to test the efficiency of the wood dust collector while tilted.

Figure 8 presents both configurations of the suction hood. In Table II, we give the aspiration modes and the collected dust weights.

We found out the efficiency of vertical aspiration was 29.6% (configuration shown in Figs 8A and 8B). It means that 29.6% of the total amount of wood dust emitted during grooving is collected by vertical aspiration. The efficiency of the titled aspiration revealed a better result with 54.4% (configuration shown in Figs 8C and 8D). This preliminary observation showed that extracting the wood particles near the tool-material interaction improves dust capture efficiency.

Summary of experiments: Experiments have demonstrated that (i) we can assess realistic velocities of wood chips in direction and norm during robotic machining by using a high-speed vision system, and (ii) placing the suction hood near the tool-material contact improves the dust capture efficiency.

VI. CONCLUSION AND PERSPECTIVES

Wood dust is known to be a human carcinogen. The exposure levels to hardwood dust are usually below $3\text{mg}/\text{m}^3$.

However, over 0.5 million workers may be exposed to a dust level exceeding $5\text{mg}/\text{m}^3$. To improve dust capture efficiency during woodworking grooving, we analyzed the physical properties of chips by observing the motion behavior with a single high-speed camera.

Moreover, a proper hood design placed near the tool seems to improve the capture efficiency.

In a further study, we aim at designing a robotic hood that will enable dust capture near the tool.

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