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Development of an Alternative Approach for Estimating User Load due to Screw-in Torque in User Studies

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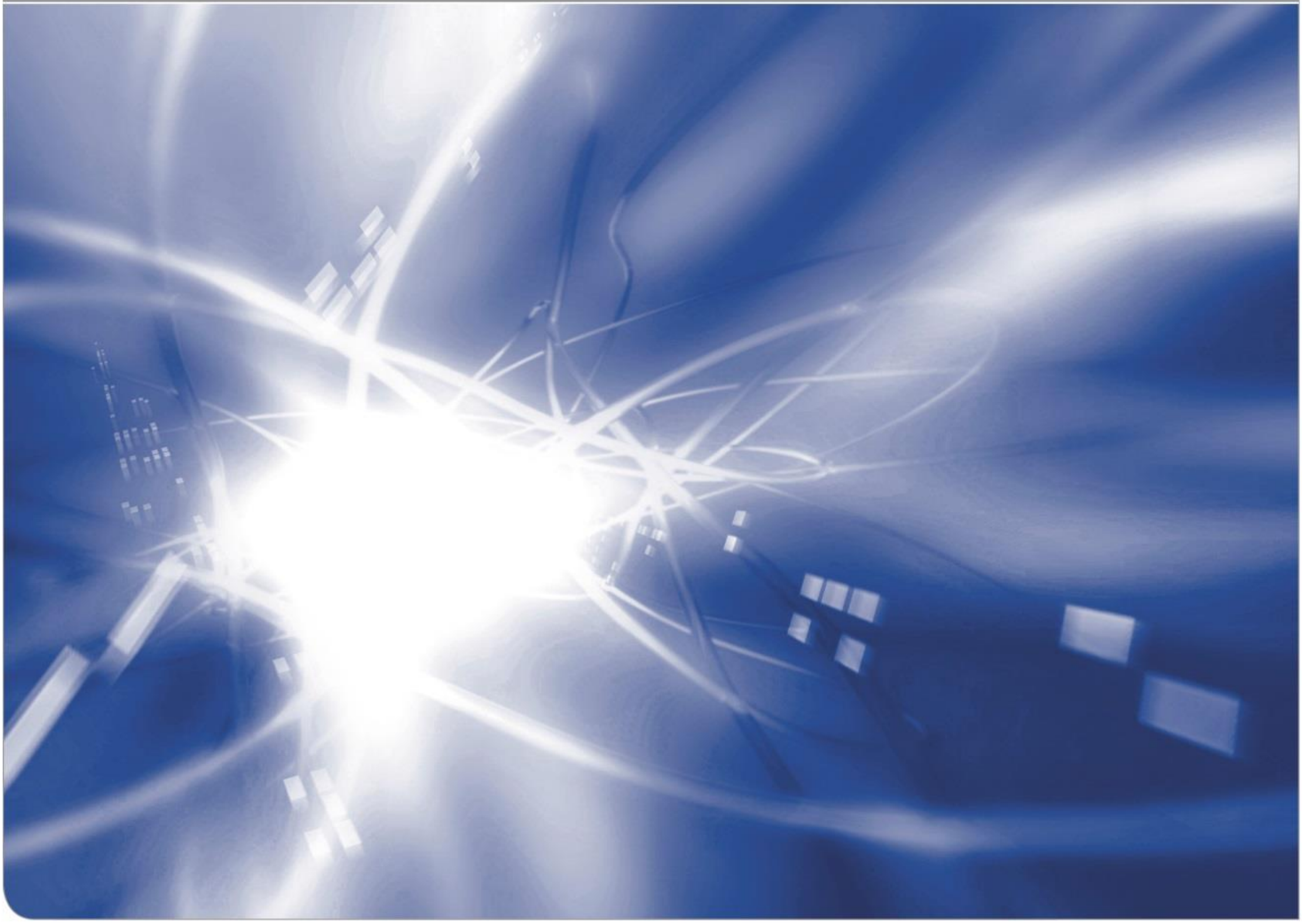

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Abstract

The proposed approach aims to estimate the screw-in torque load by utilizing the battery current of a cordless screwdriver. This approach is particularly designed for user studies involving cordless screwdrivers, enabling accurate estimation of user loads. By measuring battery current and establishing the correlation between battery current and screw-in torque, user load can be estimated effectively.

The experimental setup includes a two-degree-of-freedom testbench, allowing a fixation of the cordless screwdriver and restricting its movement. The screwdriver is mounted on the screwdriver collar and attached to a slide mechanism for linear movement along the drilling axis and rotational movement around the axis. Data from ten consecutive screw-in processes were collected, including measurements of screw-in torque, screw-in depth, and battery current. It was observed that torque varied across different sections of the screw-in process, with an increase in torque as the screw is screwed deeper into the wood.

While certain limitations exist, such as the constant push force applied during experiments and specific conditions, the proposed approach presents a practical solution for estimating screw-in torque in manual tasks and accurately assessing user load in user studies.

Introduction

In the field of support systems product development, assessing the impact of exoskeletons on user ergonomics typically involves user studies incorporating representative manual tasks. While efforts are made to maintain a consistent load on the user during these tasks, achieving consistent load is not always feasible due to factors like screw type or inhomogeneous characteristics of the wood used. Furthermore, the direct measurement of the screw-in torque is challenging in user studies. Consequently, an alternative method is needed to estimate the user load due to the screw-in torque in these tasks.

Previous research has already explored the process of screwing wood screws into softwood. These studies have demonstrated the significant influence of both the screw and the wood on the resulting screw-in torque (Blaß & Siebert, 1999). In their investigation, Blaß and Siebert used a screw-in testbench equipped with a cable-connected screwdriving machine (Blaß & Uibel, 2012).

Steck et al. derived load models of the screw-in process based on manual screw-in tests, which are used for drive testbenches (Steck, Gwosch, & Matthiesen, 2019). These models generate maps that relationship between screw-in torque and the corresponding screw-in angle.

The proposed approach for determining the screw-in torque involves estimating the torque load based on the battery current of the cordless screwdriver. This approach can be effectively employed in studies involving cordless screwdrivers, such as the research conducted by Sänger et al. (Sänger et al., 2022). By utilizing this approach, it becomes possible to assess whether all participants in the user study experienced a consistent load during the screw-in task, thus enhancing the accuracy and reliability of the findings.

Approach und Methods

Testbench for screw-in tasks

To conduct the screw-in tasks, a test bench with two degrees-of-freedom (DoFs) was developed (see Figure 1). This test bench enables the fixation of a cordless screwdriver while restricting single DoFs. The cordless screwdriver is securely mounted on the collar of the screwdriver to a slide mechanism that can be moved along the drilling axis using a linear guide (linear DoF). Additionally, the rotation of the screwdriver around the drilling axis is enabled (rotational DoF). The workpiece is clamped onto a material rest and the screw-in process is performed tangentially into the wood (Höfferl et al., 2016).

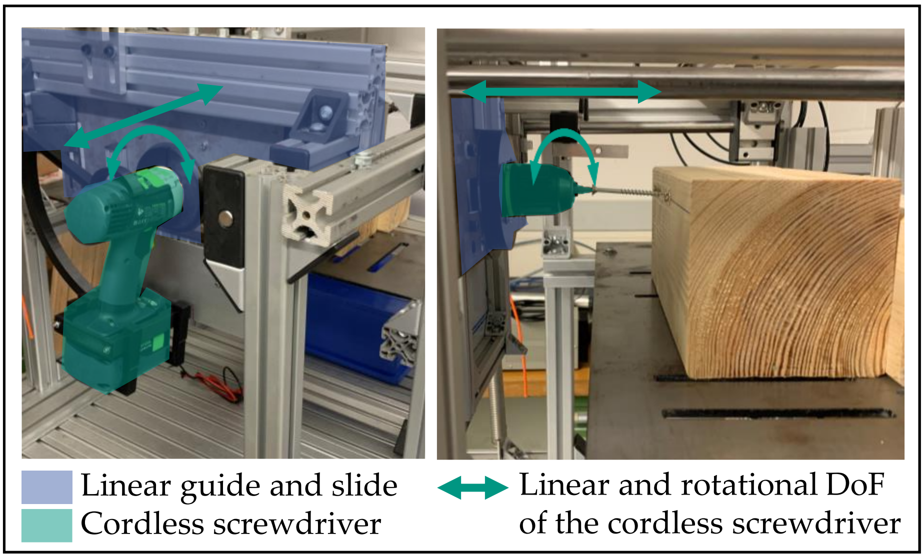

Figure 1: Testbench including linear guide and slide mechanism, providing a linear degree of freedom (DoF) along the drilling axis and one rotational DoF for the cordless screwdriver.

The push force applied by the user was kept constant at 100 N by visual force feedback shown on a display. The trigger of the screwdriver is pressed 100% during the screw-in process. The torque, screw-in depth, and battery current of the screwdriver were measured with the measurement systems shown in Table 1. Ten consecutive screw-in processes were performed with the same user.

Detailed information on the materials used for this setup can be found in Table 1.

Table 1: Used Materials in the study.

Material	Description
Screw	Wood screw (10 × 100 mm, TX40, Fischerwerke GmbH & Co. KG, Waldachtal, Germany)
Wood	Solid structural timber (solid softwood)
Screwdriver	Cordless screwdriver Festool PDC 18/4. (Festool GmbH, Wendlingen a.N., Germany) Settings: Speed stage 1 (0-400 rpm) Torque stage 12 (11.5 Nm) Trigger: 100%
Datalogger	Electric battery current and voltage of the screwdriver (Dörr, Ries, Gwosch, & Matthiesen, 2019)
Torque, rotational position, and speed sensor	Typ-4501A020HA (Kistler Instrumente AG, Winterthur, Switzerland)
Linear position sensor	LRW2-F-100-S (WayCon Positionsmesstechnik GmbH, Taufkirchen, Germany)

Approach to estimate the screw-in torque based on the battery current

To determine the correlation between battery current and screw-in torque, the following approach is suggested (see Figure 2).

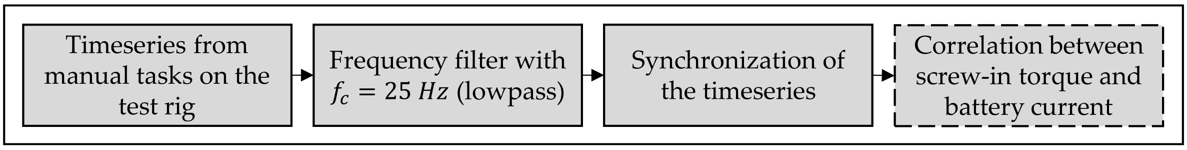

Figure 2: Approach to estimate the screw-in torque based on Steck et al. (Steck et al., 2019).

Due to high noise in the torque and battery current signal, the signals were first smoothened by a lowpass filter with a cutoff frequency of $f_c = 25\ Hz$ before being synchronized. For the battery current signal, the initiation of the screw-in process was defined as the moment when the current exceeded the idle current, indicating that the screw starts threading into the wood and started tightening (Steck et al., 2019). The end of the screw-in process was set when the battery current reached its maximum. The duration for each screw-in process was calculated from these two timestamps. It was assumed that a maximum battery current signal causes the maximum torque. For the torque signal, the end of the screw-in process was determined by detecting the maximum torque. The start of the torque signal was then identified using the screw-in process duration. After interpolating all signals to the same data length, the mean, maximum, and minimum values of battery current and torque were calculated across all ten repetitions. The torque values were plotted against the screw-in depth.

Results

Figure 3 shows the synchronized battery current and torque signal of one screw-in process.

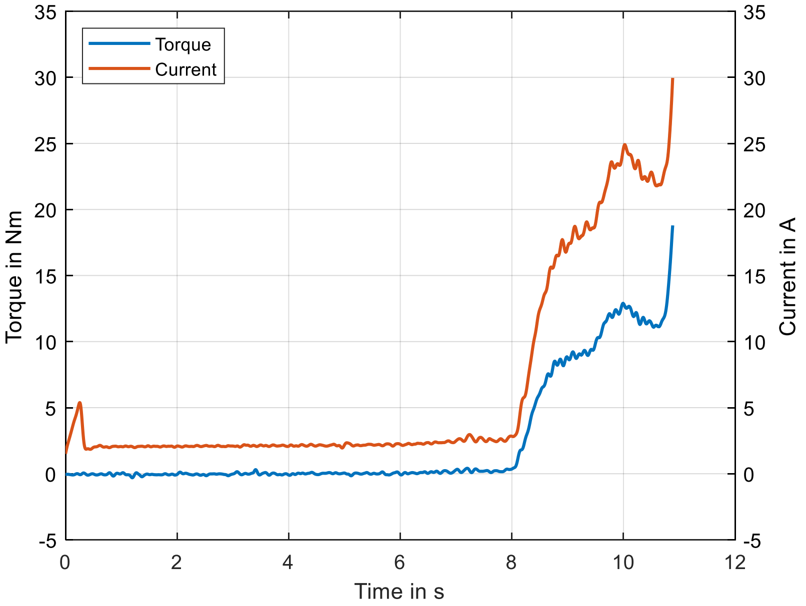

Figure 3: Synchronized screwdriver torque and battery current signal against time during the first screw-in process.

The maximum, mean, and minimum values of torque signals against the screw-in depth were analyzed for all ten screw-in processes. The respective data is shown in Figure 4.

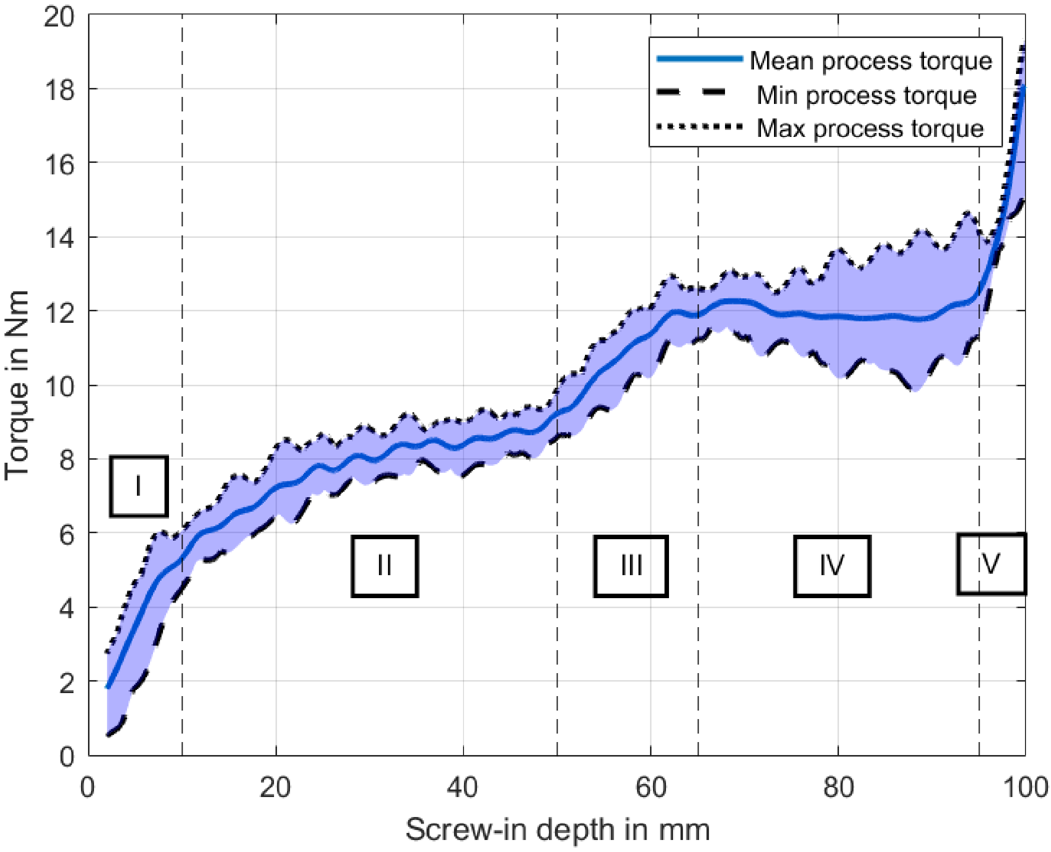

Figure 4: Maximum, mean, and minimum values of process torque for ten screw-in processes against screw-in depth (0 mm = start of screw-in process, 100 mm = screw head is flush with the surface). The screw-in process is divided into five sections (I-V) and the process torque show a comparable characteristic compared to the state of research (Steck et al., 2019).

The screw-in process is divided into five sections (I-IV) which represent different depths of the screw inside the wooden beam. For the first 10 mm of the screw (I), the mean value of torque increases from 2 to 5 Nm. The torque signal increases stronger than in the second section (II) from 10 to 50 mm. Here, the mean value of torque rises from 5 to 9 Nm. A kink is detected at 50 mm. From here to 65 mm, the torque increases to 12 Nm in section III, stronger than in the section IV, where a plateau at 12 Nm can be seen. The torque signal increases sharply for the last 5 mm in section V. The mean value of torque maxes out at 18 Nm. The maximum and minimum values envelope the mean-torque curve with a maximum offset of 2 Nm.

The results of the process torque and battery current is limited by the constant push force of 100 N applied by the user during the experiment. A constant push force on the testbench does not match with reality, as the study by Sänger et al. (2022) has shown (Sänger et al., 2022). These specific results are also only applicable for the specific screwdriver, screw type, and the wood mentioned in Table 1.

Discussion

The mean torque progression (see Figure 4) shows the typical curve for wood screws in wood (Blaß & Siebert, 1999; Steck et al., 2019). Steck et al. plotted the screw-in torque against the screw-in angle. Since screw-in angle and screw-in depth directly corelate with the screw pitch, the two illustrations are equvilant. A detailed explanation of the torque progression is given in (Steck et al., 2019).

The proposed appraoch offers a practical procedure for determining the screw-in torque during manual tasks. By analyzing the data from the study, a correlation between the battery current and screw-in torque can be established. This correlation can be used e.g. in user studies to estimate the torque load acting on the user. Particularly in user studies involving cordless screwdrivers, this approach allows for estimating the actual loads exerted on users. By utilizing the presented method, it becomes possible to measure only the battery current in user studies and utilize the established correlation to estimate the user load accurately. This streamlined process offers a practical solution for assessing user loads.

Aknowledgements

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