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Optimizing the making of written batik on mori cloth automatically using programmed canting motion with temperature and feed rate analysis

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Abstract

This study aims to optimize the technique of making batik writing on plain cloth using an automatic CNC machine with a regulated temperature and feed rate. Research methods were used. For testing the influence of variation in temperature (70 °C, 80 °C, and 90 °C) and feed rate against the quality of batik pattern and depth penetration of wax. Use of temperature sensors on electric ramps allows precise temperature control at a time-adapted rate, feeding for detection effects on thickness patterns and penetration wax. The result shows that improved temperature wax will increase its penetration in Mori, especially at a low feed rate, which produces a thicker pattern. Rate of displacement or a higher feed rate will speed up the process, but tends to reduce penetration wax and the thickness pattern. At a temperature of 90 °C and a feed rate of 450 mm/min. Quality is optimal for batik patterns and good wax. Balance between temperature wax and rate of displacement or feed rate is important to reach patterned batik results that are deep and consistent, which supports efficient batik production with still guard mark art.

Keywords:
Batik, Canting, Wax, Temperature, Feed rate, Optimization, Mori cloth.

1. Introduction

Batik is a work culture that is an inheritance from grandma's ancestors and has marked high art, with patterns and distinctive color schemes owned by the area that shows the identity nation [1-3]. Batik as an asset culture is an Indonesian product icon that has a mark of history and an exclusive image that describes the status of the user [4-7].

Batik, which is a product native to Indonesia, is one of the assets that countries are required to preserve. Batik has a long history in each motif; there is hidden meaning [8-10]. According to Keather Griffin and Margareth Hone (1990:4), batik is a "method of applying a coloring design onto textiles by waxing those parts that are not to be dyed". The definition in question is the batik applying method, a design dyeing technique in textiles with waxing on the part that is not dipped, so that this whole process produces certain batik motifs [2], [6], [11]

Along with the development of the times, shifts occur, meaning the use of batik as a fashion. Batik, which is cloth illustrated by the making done in a special way with writing or applying night (wax) on the cloth, and continued with processing and certain processes that have uniqueness. That is what ultimately made batik a part of the Inheritance Humanity for Masterpieces of Oral and Intangible Heritage of Humanity on October 2, 2009, which was later commemorated as National Batik Day [8], [12].

One of the reasons for productivity in the manufacturing industry in SMEs (Small and Medium Enterprises) in Indonesia is due to the production process being done manually[13-14]. With modern procurement machines, such as Computer Numerical Control (CNC) machines, SMEs are expected to be able to produce products with special geometry with high accuracy, increasing production process efficiency as well as increasing quality production results so that no one will lose competition with products from various countries [15-17].

Based on needs, it will improve efficiency and precision in the process of making batik. Traditional batik, especially those that use the canting technique, requires expertise and precision to produce consistent and detailed patterns. In addition, the factors like temperature, wax, and the speed of the movement of the canting (feed rate) greatly influence quality batik results, good from an aspect of accuracy pattern, and also the ability of wax to penetrate calico [18-20].

With CNC (Computer Numerical Control) technology, the batik process can be automated so that the resulting pattern is more consistent and time production can be trimmed in a way that is significantly. This batik CNC machine is designed to control temperature, wax, and feed-rate with precision, which is expected to produce more neat patterns as well as penetration even in wax [21-23]. Use a machine that is also expected to overcome the problem of frequent instability that happens in manual processes, such as different thicknesses of wax and trouble maintaining temperature with the wax during the process [24].

Therefore, research on the effect of wax temperature and feed rate on the results of canting and wax penetration patterns on white cloth is important so that the design of CNC batik machines can be optimized to increase the productivity of traditional batik by using technology according to the needs of the industrial world and still maintaining the characteristics of traditional batik art. [9], [12], [25].

The purpose of this study was to analyze the wax temperature on the quality of the batik pattern canting results on plain fabrics and to determine the effect of federation or the speed of the canting movement on the level of wax penetration on calico fabrics and to identify the interaction between wax temperature and federation on the canting pattern and wax penetration [26-29]

2. Research Methods/ Materials and Methods

The research variable system is illustrated as shown in Fig. 1

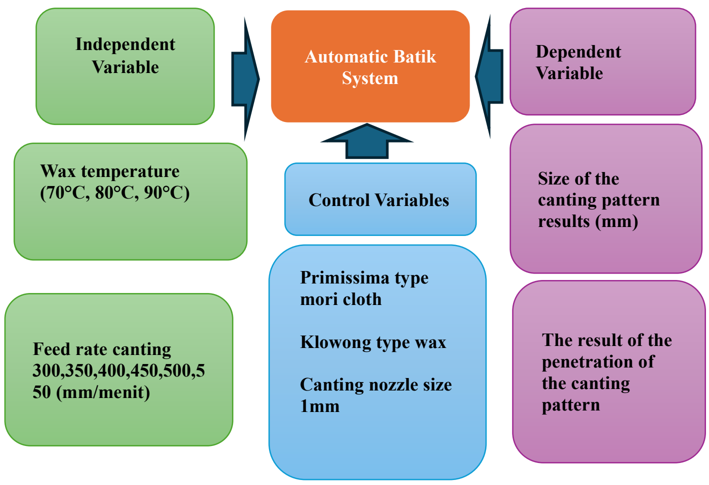

Fig. 1. Research Variable System

Preparation is done by preparing cloth with the same size for each experiment. Prepare wax with the various temperatures that have been determined. Canting Process: Use canting with the same size nozzle. Canting at different speeds in accordance with the design.

Batik patterns are used with designing the Alone batik pattern that resembles flowers that represent Batik patterns in general. Batik patterns are designed and changed to become vectors on Mastercam software. After that, they are set up with the toolpath and made into G-code. And the G-code: We move to the GRBL software for operating device canting movement. Experimental design as shown in Fig. 2.

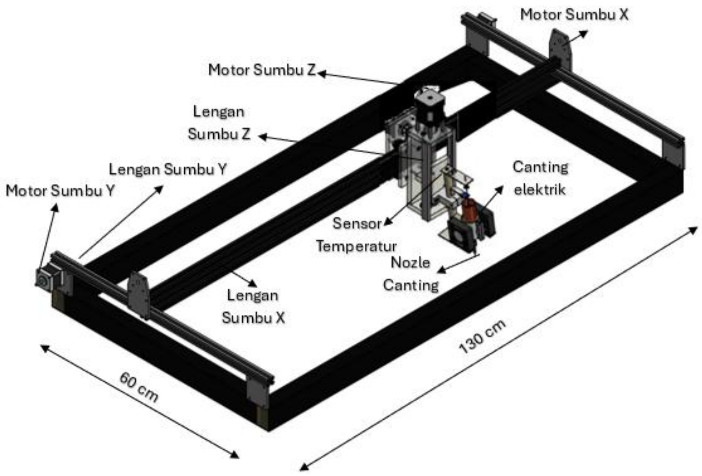

Fig. 2. Experimental Design

Setting up heating temperature wax on the canting. Using a temperature sensor with a variation of temperature 70 ^{0}C, 80 ^{0}C, 90 ^{0}C. To prepare for the program that wants to be executed, the GRBL software is run. Formerly the third namely x, y, and z. After axis Can move normally prepared mori cloth and set on the z-axis so that the needle can press cloth and liquid wax can come out. Electric canting is shown in Fig. 3.

Fig. 3. Electric canting with 1mm nozzle

Measurement: Measuring results of the batik pattern using imageJ software line thickness and clarity pattern. Usage of imageJ is done. First, install the program, then enter the image to be measured and calibrated picture, namely create a line of the desired size. The same with the image, then enter the number size in the analysis. Then enter units in the ImageJ program. With do the ImageJ software calibration Already Can do the measurement. ImageJ software is shown in Fig. 4.

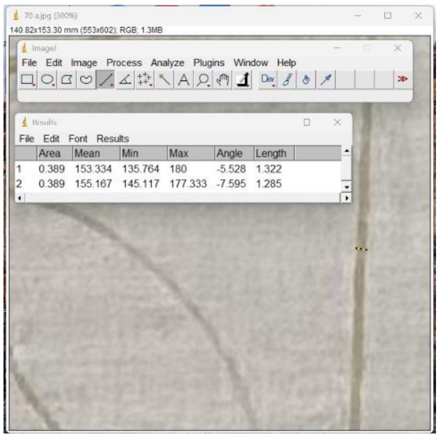

Fig. 4. ImageJ software ~~For~~ to measure

Take notes results measurement canting and penetration patterns wax for every combination of temperature, wax, and speed, canting movement, or feed rate. Do it every experiment several times to ensure consistent results (replication).

3. Results and Discussion.

3.1 The results of the canting pattern at a wax temperature of 70 ^{0} C

Collection at temperature 70 ^{0}C. Wax with a 1 mm nozzle needle canting is obtained results batik like shown in Fig. 5 and breakout shown on cloth Fig. 6 on the plain cloth. That the higher the feed rate set on the tool, the result is that the batik patterns are thinner and the penetration is less frequent. This is because the wax liquid comes out less compared to the speed of moving the canting. Likewise, with the temperature used, namely 70 0 C, the wax is less than the maximum on the canting or the wax still has lumps and at that temperature there is wax penetration on plain cloth but thin.

Fig. 5. The results of the canting pattern at a temperature of wax 70 ^{0} C with feed rate 300 mm/ min

Fig. 6. The result of the penetration canting pattern at temperature wax 70 ^{0} C with feed rate 300 mm/ min

3.2 The results of the canting pattern at a wax temperature of 80 ^{0} C

Wax at a temperature of 80 0 C with a 1 mm canting nozzle needle, the batik results shown in Fig. 7 and the translucent results shown in Fig. 8 are obtained on plain cloth. The higher the feed rate set on the tool, the thinner and more translucent the resulting batik pattern. It's starting to look clear. This is because the wax liquid that comes out is less compared to the speed of moving the canting as shown in table 4.1.2. Likewise, with the temperature used, namely 80 0 C, the wax on the canting has begun to melt and there is less penetration into the mori cloth. The pattern has begun to appear.

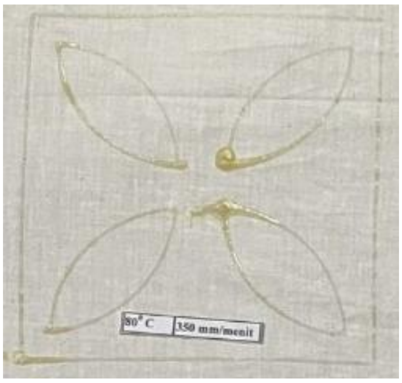

Fig. 7. The results of the canting pattern at a temperature of wax 80 ^{0} C with feed rate 350 mm/ min

Fig. 8. The result of the penetration canting pattern at temperature wax 80 ^{0} C with feed rate 350 mm/ min

3.3 The results of the canting pattern at a wax temperature of 90 ^{0} C

wax at a temperature of 90 0 C with a 1 mm canting nozzle needle, the results of the batik pattern in Fig. 9 and the penetration of the pattern shown in Fig. 10 on plain cloth are obtained. The higher the feed rate set on the tool, the thinner and more translucent the batik pattern is clearly visible, as shown in the picture. Likewise, the temperature used is 90 0 C to the wax in the canting is liquid so that there are no lumps in the canting and the penetration on the mori cloth is the same as the pattern.

Fig. 9. The results of the canting pattern at a temperature of wax 90 ^{0} C with feed rate 450 mm/ min

Fig. 10. The result of the penetration canting pattern at temperature wax 90 ^{0} C with a feed rate 450 mm/ min

3.4 Influence Variation Wax Temperature Against Quality of Batik Canting Pattern Results on Mori Cloth

Based on the data retrieval obtained, the average results of size at several temperatures and feed rates are in Table 1.

Table 1. Measurement results average size data collection on several temperature and feed rate

No	Canting Nozzle Size	Feed rate (mm/ min)	Temperature		
			Average 70 ^{0} C	Average 80 ^{0} C	Average 90 ^{0} C
1	1mm	300	0.87	1.15	2.18
2	1mm	350	0.80	1.02	1.81
3	1mm	400	0.74	0.97	1.30
4	1mm	450	0.71	0.92	1.08
5	1mm	500	0.66	0.84	0.82
6	1mm	550	0.64	0.69	0.85

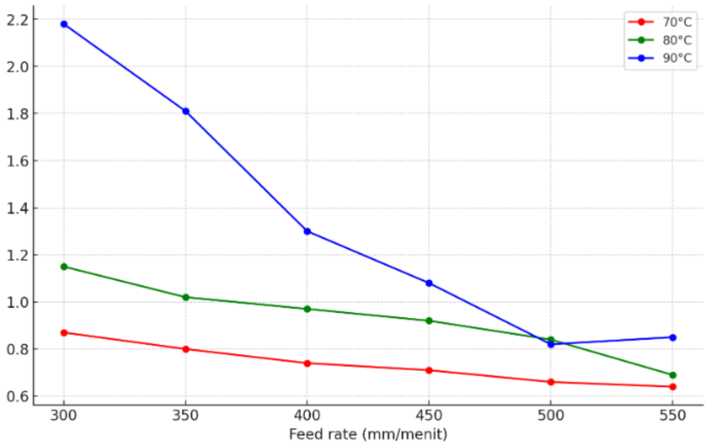

Fig. 11. Graph feed rate and average temperature wax

Based on Table 1 is obtained picture graph 11. In Graph 11 each level temperature (70 °C, 80 °C, and 90 °C), there is a consistent trend: increasingly tall feed rate, the lower average penetration wax. This is more significant at higher feed rates high, especially at temperatures of 90 °C. Temperature of waxes are also has an important role in determining the depth penetration of waxes.

Based on Table 1 at the same feed rate, the increase temperature wax causes improvement penetration of waxes. As for example, at a feed rate of 300 mm/min, penetration wax increases from 0.87 at 70 °C, to 1.15 at 80 °C, and reaching 2.18 at 90 °C. This shows trend of consistency in all level feed rates, although more penetration low at lower feed rates.

The temperature of more waxes tall produce lower wax viscosity, make wax easier to seep in to fiber cloth at a higher feed rate tall.

3.5 Feed rate Or Speed The Movement of Canting Affects Penetration Waxs Against Making Batik on Mori Cloth

Based on Table 1 at a temperature wax 70 °C, a faster feed rate canting, and a value average penetration wax tend decreased. At feed rate (300 mm/min), penetration wax ~~of~~ is 0.87, while at the highest feed rate (550 mm/min), penetration wax is down to 0.64. This shows that the faster the canting moves, the faster A little time wax to penetrate fabric, especially at a lower wax temperature.

Based on Table 1 at a temperature of 80°C, the penetration wax tends to decline with increasing feed rate. At a feed rate of 300 mm/min, wax penetration is 1.15, while at a feed rate of 550 mm/min, the average value is only 0.69. Although there is a little improvement wax penetration compared to that with temperature of 70 °C, increasing feed rate still causes wax cannot be absorbed perfectly to fabric at this temperature.

Based on Table 1 At the highest temperature (90 °C), increasing wax temperature makes wax more liquid and its viscosity reduced, so that penetration wax increases significantly at low feed rate. At a feed rate of 300 mm/min, wax penetration reached 2.18, which is marked the highest. However, the increase of feed rate still causes wax penetration declines significantly. For feed rate of 550 mm/min, it only produces 0.85. This is to signify that although wax at high temperature tall more can easily penetrate cloth, canting speed remains constant as a delimiter factor.

Based on Table 1 and Fig. 11, it is found that the feed rate has a direct influence on the ability of the wax to penetrate the fabric. At low feed rates (300 mm/min), the wax itself has a longer time to absorb into the fabric fibres, resulting in deeper wax penetration. Conversely, at lower feed rate heights (500-550 mm/min), the contact time of the wax with the fabric is reduced, which causes the wax to be poorly absorbed, even at higher temperatures.

The feed speed of the canting greatly affects the penetration of the wax on the calico fabric. At low feed speeds, the wax can penetrate better into the fabric, especially at higher wax temperatures. On the other hand, at higher feed speeds, the contact time of the wax with the fabric becomes too short, so the penetration of the wax is significantly reduced, even if the wax temperature is increased. To obtain optimal batik pattern results, a higher feed speed should be used at a lower rate, especially if the wax temperature used is not too high.

3.6 Interaction between Wax Temperature and Feed Speed or Canting Movement Speed Affects Pattern Yield and Penetration of Batik Making Wax on Mori Fabric

The data in table 1 shows a significant interaction between wax temperature and feed rate on wax penetration results. At higher temperatures, i.e. 90°C, wax penetration tends to be greater at higher and lower feed rates. For example, at a feed rate of 300 mm/min, the wax penetration reaches the highest value of 2.18 at 90°C. However, at higher feed rates of 550 mm/min, there is a drastic decrease, with an average penetration of only 0.85.

This phenomenon indicates that at higher temperatures, the wax becomes thinner, making it easier to absorb into the fabric. However, the high speed of canting movement limits the contact time of the wax with the fabric, which in turn reduces the penetration of the wax.

The interaction between wax temperature and canting feed rate shows that to obtain an optimal batik pattern, a balance between the two factors is required. Higher wax temperature can increase wax penetration and produce clearer patterns, but this effect is highly dependent on the feed rate. At both higher and lower feed rates, a high wax temperature gives better wax penetration.

In batik making, the setting temperature and feed rate must be considered to produce consistent and precise patterns. At low feed rates, the wax can penetrate deeper, which can result in patterns with thicker and clearer lines. However, if the wax is too hot, the pattern may become less detailed as the wax is too thin and difficult to control.

Conversely, at high feed rates, the wax has a harder time penetrating the fabric, which can result in thinner or insufficiently consistent patterns. Proper feed rate and temperature settings are essential to produce the desired batik pattern.

From the graph in Fig. 11, it can be concluded that good wax temperature and feed rate have a significant influence on the pattern and wax penetration on white cloth. For optimal batik results, a balance between wax temperature and canting movement speed is required. High wax temperature and low feed rate tend to give better wax penetration.

4. Conclusions.

Variations in wax temperature affect the quality of batik canting pattern results on plain cloth. At low temperatures, the wax tends not to be liquid enough, resulting in less optimal patterns and no wax penetration into the fabric. In contrast, at 90°C, the wax melts well, reaches maximum viscosity, and produces more precise canting patterns and better wax penetration into the fabric.

Feed rate affects the thickness and size of the canting pattern as well as the penetration of wax on the fabric. The higher the feed rate, the size of the canting result tends to decrease, indicating that the canting transfer rate negatively affects the thickness of the result. Higher feed rates produce thicker patterns, while better feed rates produce thinner patterns. At the right feed rate, the wax is able to penetrate the mori fabric well, especially at higher temperatures. The interaction between wax temperature and feed rate plays an important role in determining pattern quality and wax penetration on the mori fabric. At a higher temperature (90°C) and feed rate of 450 mm/min, the canting results are close to the nozzle size and wax penetration reaches 70%. This combination produces optimal pattern quality and deep wax penetration, making it efficient in the batik making process with better quality results compared to other temperature and feed rate conditions.

References.

[1] D. Rahmad, "TESIS FORMULASI DAN ANALISIS KUALITAS MALAM BATIK TULIS DARI BAHAN DAUR ULANG FORMULATION AND ANALYSIS OF HANDWRITTEN BATIK WAX QUALITY FROM RECYCLED MATERIALS Dipersiapkan dan disusun oleh." [Online]. Available: http://etd.repository.ugm.ac.id/

[2] O. Harmsen, "Strand 2. Art Nouveau and Politics in the Dawn of Globalisation Batik-How Emancipation of Dutch Housewives in the Dutch East Indies and 'Back Home' Influenced Art Nouveau Design in Europe." [Online]. Available: https://en.wikipedia.org/wiki/The_History_of_Java

[3] S. Lestariningsih, "PEMBUATAN PROTOTYPE CANTING ELEKTRIK 'CANTRIK' BERDASARKAN KARAKTERISTIK KEBUTUHAN PENGGUNA DENGAN METODE QUALITY FUNCTION DEPLOYEMENT (QFD)," 2017.

[4] N. N. Mulyaningsih, I. Yona Okyranida, Q. Maghfiroh, and F. Widiyatun, "ANALISIS FISIKA KUALITAS LILIN BATIK YANG SUDAH DIGUNAKAN BERULANG." [Online]. Available: https://journal.ikippgriptk.ac.id/index.php/snpp/article/view/7030

[5] D. Rahmad, M. Kusumawan Herlianysah, A. Sudiarso, and A. Haerudin, "Performa: Media Ilmiah Teknik Industri Formulation and Analysis of Handwritten Batik Wax Quality from Recycled Materials," vol. 23, no. 1, pp. 62–76, 2024, doi: 10.20961/performa.22.1.83540.

[6] N. N. Mulyaningsih, I. Yona Okyranida, Q. Maghfiroh, and F. Widiyatun, "ANALISIS FISIKA KUALITAS LILIN BATIK YANG SUDAH DIGUNAKAN BERULANG." [Online]. Available: https://journal.ikippgriptk.ac.id/index.php/snpp/article/view/7030

[7] A. Haerudin dan Vivin Atika Balai Besar Kerajinan dan Batik and J. Kusumanegara No, "KOMPOSISI LILIN BATIK (MALAM) BIRON UNTUK BATIK WARNA ALAM PADA KAIN KATUN DAN SUTERA Composition of Biron Wax for Natural Dye Batik Products on Cotton And Silk Fabrics."

[8] S. Sutyasmi, E. Kasmudjiastuti, and R. S. Murti, "The effect of oil on the making batik leather with chrome aldehyde combination to written and stamped batik," in *IOP Conference Series: Earth and Environmental Science*, Institute of Physics Publishing, Nov. 2019. doi: 10.1088/1755-1315/355/1/012101.

[9] H. Bowo Cahyono Balai Riset Dan Standardisasi Industri Surabaya Surabaya and R. Yuliastuti Balai Riset Dan Standardisasi Industri Surabaya Surabaya, "Aplikasi Canting Listrik pada Industri Batik Tulis untuk Mendukung Implementasi Industri Hijau pada Industri Tekstil Pencelupan, Pencapan dan Penyempurnaan Use of Electrical Canting in Handwritting Batik Industry to Supports the Implementation of Green Industry Textile, Dyeing and Improvement Textile Industry," 2020.

[10] F. Affan, "Catharsis: Journal of Arts Education Batik in the Joint Business Group of Sidomulyo, Tegal: A Case Study of the Ornamentation, Function, and Inheritance," 2019. [Online]. Available: http://journal.unnes.ac.id/sju/index.php/catharsis

[11] D. N. Aini, D. W. Arisanti, H. M. Fitri, and L. R. Safitri, "Pemanfaatan Minyak Jelantah Untuk Bahan Baku Produk Lilin Ramah Lingkungan Dan Menambah Penghasilan Rumah Tangga Di Kota Batu," *Warta Pengabdian*, vol. 14, no. 4, p. 253, Nov. 2020, doi: 10.19184/wrtp.v14i4.18539.

[12] W. Wibawanto, R. Nugrahani, J. S. Rupa, F. Bahasa, and D. Seni, "Indonesian Journal of Conservation INOVASI PENGEMBANGAN MOTIF BATIK DIGITAL BAGI IKM BATIK SEMARANG," 2018. [Online]. Available: http://journal.unnes.ac.id/nju/index.php/ijc

[13] P. Studi, D.-I. R. P. Mekanik, and S. Vokasi, "RANCANG BANGUN ALAT PELOROTAN LILIN PADA KAIN BATIK TULIS DI KUBE PUTRI KAWUNG," Pleburan, Kec. Semarang Selatan, 2022.

[14] W. Widyaningrum, Y. Aris Purwanto, and S. Mardjan, "Design of Control and Monitoring System of Air Condition at Controlled Atmosphere Storage Based on Arduino Uno Microcontroller," *Jurnal Keteknikan Pertanian*, vol. 6, no. 1, pp. 77–84, Apr. 2018, doi: 10.19028/jtep.06.1.77-84.

[15] A. Afkhamifar, D. Antonelli, and P. Chiabert, "Variational Analysis for CNC Milling Process," in *Procedia CIRP*, Elsevier B.V., 2016, pp. 118–123. doi: 10.1016/j.procir.2016.02.164.

[16] A. M. Shrif, A. A. Gouda, and M. A. Razek, "Comparative study among constrained application protocol eXtensible messaging, and presence protocol of IoT," *Indonesian Journal of Electrical Engineering and Computer Science*, vol. 27, no. 1, pp. 546–554, Jul. 2022, doi: 10.11591/ijeecs.v27.i1.pp546-554.

[17] S. N. Grigoriev and G. M. Martinov, "Research and development of a cross-platform CNC kernel for multi-axis machine tool," in *Procedia CIRP*, Elsevier, 2014, pp. 517–522. doi: 10.1016/j.procir.2014.03.051.

[18] A. Leonardo and W. Sugianto, "Simulation of automatic fan with LM35 temperature sensor using ATMEGA8535 microcontroller in Proteus application," *Journal of Engineering and Applied Technology*, vol. 1, no. 1, pp. 43–50, 2020, [Online]. Available: https://journal.uny.ac.id/index.php/jeatech

[19] E. Prianto and H. S. Pramono, “Eko Prianto: Proses Permesinan CNC Dalam Pembelajaran Simulasi CNC PROSES PERMESINAN CNC DALAM PEMBELAJARAN SIMULASI CNC.” [Online]. Available: http://journal.uny.ac.id/index.php/jee/

[20] A. Goeritno *et al.*, “IMPLEMENTASI CONTACTING CONDUCTIVITY SENSOR DAN THERMISTOR BERBASIS MIKROKONTROLER ATMEGA32 UNTUK PENDETEKSIAN AWAL KUALITAS AIR,” 2016.

[21] S. Utama, A. Mulyanto, M. A. Fauzi, N. U. Putri, F. Teknik, and I. Komputer, “Implementasi Sensor Light Dependent Resistor (LDR) Dan LM35 Pada Prototipe Atap Otomatis Berbasis Arduino,” vol. 2, no. 2, pp. 83–89, 2018.

[22] A. W. Wardhana and D. T. Nugroho, “Pengontrolan Motor Stepper Menggunakan Driver DRV 8825 Berbasis Signal Square Wave dari Timer Mikrokontroler AVR,” *JURNAL NASIONAL TEKNIK ELEKTRO*, vol. 7, no. 1, p. 80, Mar. 2018, doi: 10.25077/jnte.v7n1.530.2018.

[23] W. Eka Sari, E. Junirianto, and G. Fatur Perdana, “System of Measuring PH, Humidity, and Temperature Based on Internet of Things (IoT),” *Buletin Ilmiah Sarjana Teknik Elektro*, vol. 3, no. 1, p. 72, Jan. 2021, doi: 10.12928/biste.v3i1.3214.

[24] X. Yang and K. Cheng, “Investigation on the Industrial Design Approach for CNC Machine Tools and Its Implementation and Application Perspectives,” in *Procedia Manufacturing*, Elsevier B.V., 2017, pp. 1454–1462. doi: 10.1016/j.promfg.2017.07.276.

[25] L. Maulana Hakim, “Batik Sebagai Warisan Budaya Bangsa dan Nation Brand Indonesia,” 2018.

[26] I. Malik, S. Riyadi, J. Teknik Mesin, P. Studi Teknik Mesin Produksi dan Perawatan, P. Negeri Sriwijaya, and J. Srijaya Negara Bukit Besar, “PENGARUH SPINDLE SPEED, FEED RATE, DAN DEPTH OF CUT TERHADAP AKURASI HASIL PERMESINAN PADA MESIN CNC ROUTER 3 SUMBU,” *JURNAL AUSTENIT*, vol. 11, no. 2.

[27] A. Nugroho, R. Prathivi, and A. F. Daru, “ANALISA METODE VALIDASI SENSOR SUHU UNTUK APLIKASI INTERNET OF THINGS (ANALYSIS OF VALIDATION TEMPERATURE SENSOR METHOD FOR THE INTERNET OF THINGS APPLICATION),” *Pengembangan Rekayasa dan Teknologi*, vol. 15, no. 1, 2019, [Online]. Available: http://journals.usm.ac.id/index.php/jprt/index

[28] I. P. Okokpujie, C. A. Bolu, O. S. Ohunakin, E. T. Akinlabi, and D. S. Adelekan, “A review of recent application of machining techniques, based on the phenomena of CNC machining operations,” in *Procedia Manufacturing*, Elsevier B.V., 2019, pp. 1054–1060. doi: 10.1016/j.promfg.2019.06.056.

[29] J. I. Mahmood, M. S. Hilmi, and P. Krishnan, “Design and development of a modular computer numerical control (CNC) machine manipulator for automation,” *International Journal of Innovative Technology and Exploring Engineering*, vol. 9, no. 1, pp. 58–62, Nov. 2019, doi: 10.35940/ijitee.A3916.119119.