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SYSTEM FOR AUTOMATED PRODUCTION OF CUSTOM MADE SHOE INSOLES

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Abstract: This article presents the development and implementation of the IPASIOU automated system for producing orthopaedic insoles. The IPASIOU system utilizes CAD/CAM technologies, digital scanning, and automated manufacturing processes to enhance the quality and availability of individually made orthopaedic insoles. The paper discusses the technological solution, results, and implications of the IPASIOU system, highlighting its potential for advancing the fields of orthotics and prosthetics.

KEYWORDS: Foot orthoses, O&P, CAD/CAM, CNC

1 Introduction

Foot-related problems such as joint pain, walking difficulties, sports injuries, arthritis, diabetic complications, and other conditions often require the use of orthopaedic insoles (Figure 1). A particular issue is the high proportion of the elderly population, for whom such aids help maintain physical activity and generally improve health status and quality of life. The demand for such custom made products is continuously growing, raising questions about maintaining quality and speed of production [1].

Fig. 1 Custom-made orthopedic insoles using CAD/CAM technology. Left: base of the insole made by direct processing of EVA material; Right: base of the insole made by thermoforming on a produced mold.

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The traditional process of manufacturing orthopedic insoles is time-consuming and resource-intensive, posing a challenge for both patients and healthcare systems [2-5]. Advanced digital technologies offer promising solutions to these challenges by simplifying the manufacturing process, improving the quality of orthopedic insoles, and reducing the time needed to produce such aids [4-10]. Orthopedic insoles, or foot orthoses, are medical devices designed to improve posture, support foot structures, alleviate pain in injured areas, and address other foot-related issues of various etiologies.

Custom-made and tailored insoles can significantly improve the quality of life for individuals with foot deformities or weaknesses. Approximately 60% of the population could benefit from orthopedic insoles in terms of improved posture, ease of movement, and increased work capacity, while 30% might experience therapeutic benefits. About 10% of users, due to the nature of their health condition, use orthopedic insoles as an indispensable aid. [11-16].

Despite the advantages of additive manufacturing (AM) technologies, the application of CAD/CAM systems in foot orthosis production remains of leading importance (Figure 2). Technical and technological parameters of machine tools play a crucial role in ensuring accuracy and productivity, while the stiffness of the spindle system directly affects the quality of machining and the profile of manufactured parts [17]. Although these systems may not achieve particularly complex surface geometries and internal product features as AM can, their application allows for rapid product or mold realization and a wider choice of materials with different characteristics. Specific technical solutions utilized by such systems are still desirable in the O&P industry [18-20].

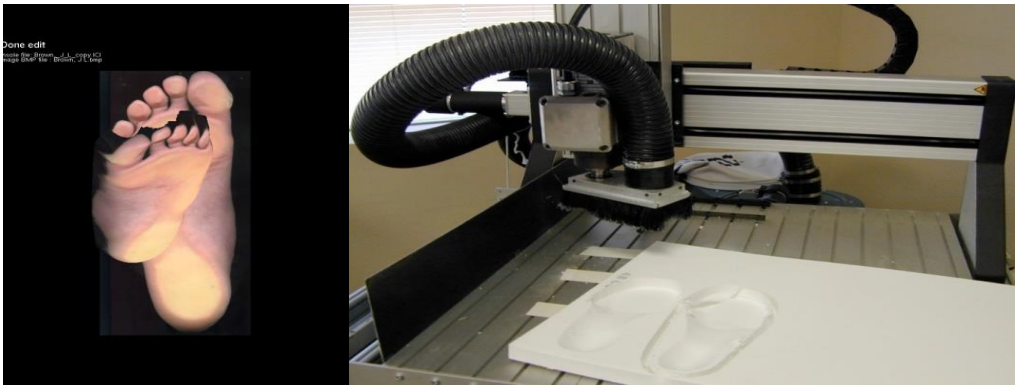

Fig. 2 Left – insole design based on the digitization results of the plantar foot surface; Right – three-axis CNC milling machine typically used for manufacturing the base of orthopedic insoles.

The technical solution presented in this work offers improvements in the acquisition process and production of orthopedic insoles, enabling their quick and high-quality realization with minimal need for additional human labor.

2 Technical Characteristics of the IPASIOU System (Technical Report)

The IPASIOU system was developed for automating and optimizing orthopedic insole production using digital technologies [21]. The use of 3D scanning techniques is integral in medical modeling, allowing for accurate reconstructions, which are essential for visualization, design and biomechanical analysis [22].

The system includes a developed 3D foot digitization assembly, a specially constructed 7-axis CNC machine tool, and accompanying software that enables its functionality (Figure 3). The fully automated process is initiated through the corresponding user interface, where the user selects the base material for the insoles, the number and type of shoes, and initiates the

digitization of the plantar foot surface. This is followed by computer-aided design (CAD) and computer-aided manufacturing (CAM) to produce a pair of individual insoles in one iteration. The system includes the following components:

1. Digitization Assembly for Automated 3D Scanning of the Plantar Surface of Both Feet: By using digital scanning technologies, precise foot measurements and the shape of the plantar surfaces of both feet are achieved, resulting in a detailed 3D model.

2. Automated CAD Design: The digital model is used to design the insole, taking into account the foot geometry and specific requirements. The result of this automated process allows the formation of a custom orthopedic insole model, with the top surface facing the plantar aspect of the foot and the bottom surface adapted to the shoe into which the insole is applied.

3. Automated CAM Production: The achieved design is translated into machine instructions for automated production using a specially developed CNC machine.

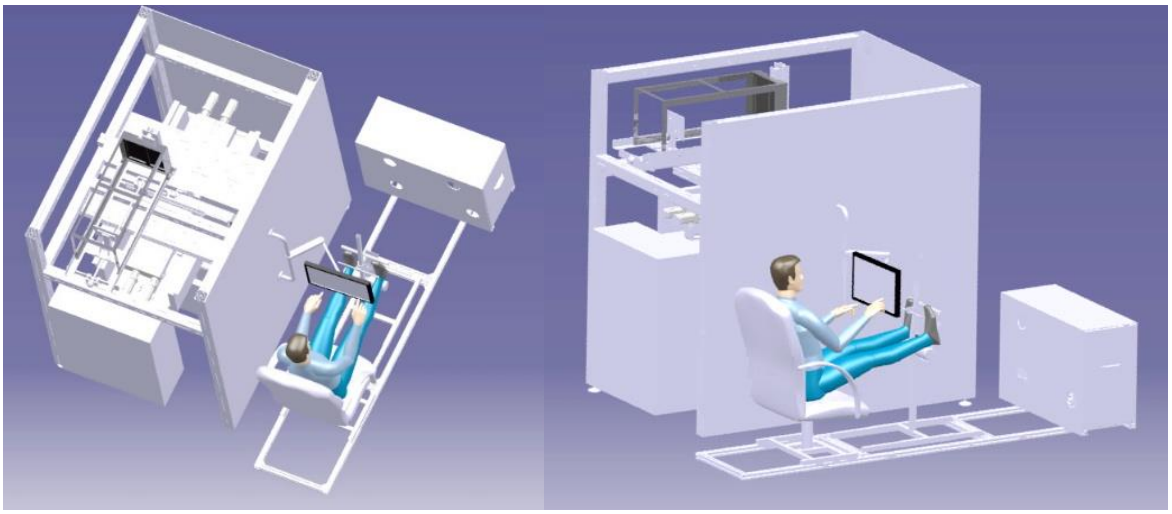

Fig. 3 Illustration of the practical application of the IPASIOU system.

The project, which realized the system, included several phases, including the development of a proof-of-concept (POC) prototype, followed by iterative improvements leading to the creation of the industrial prototype (IPASIOU).

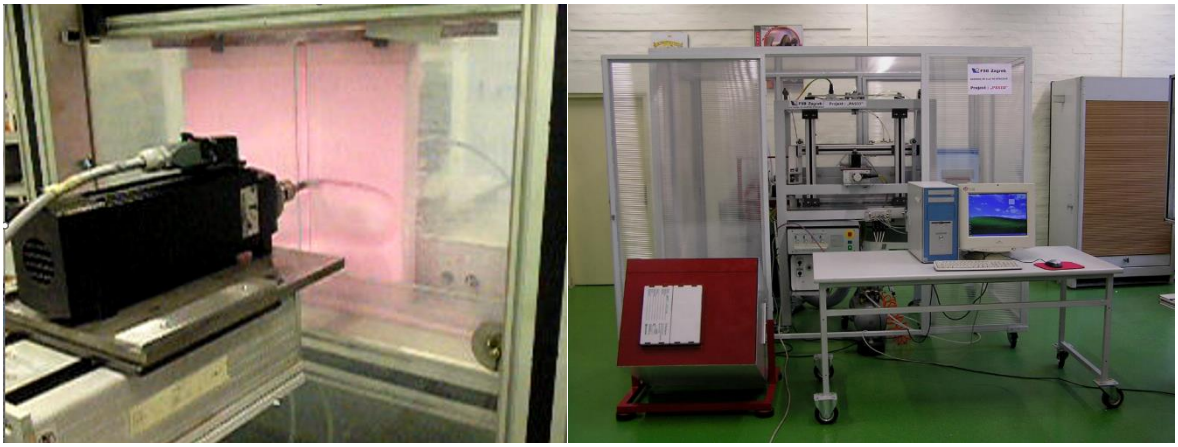

Fig 4 POC prototype of the automated system for producing customized shoe insoles.

The realized POC prototype demonstrated the feasibility of the IPASIOU system, achieving significant improvements in production speed and precision (Figure 4). The initial version allowed for surface modification of the insole and application to a finished design, producing a pair of insoles in approximately 9 minutes. Further development focused on improving the automation of the process and increasing production efficiency.

3 Industrial Prototype (IPASIOU)

The industrial prototype integrated advanced features such as simultaneous production of a pair of insoles, improved digitization, and automated design adaptation (Figure 5).

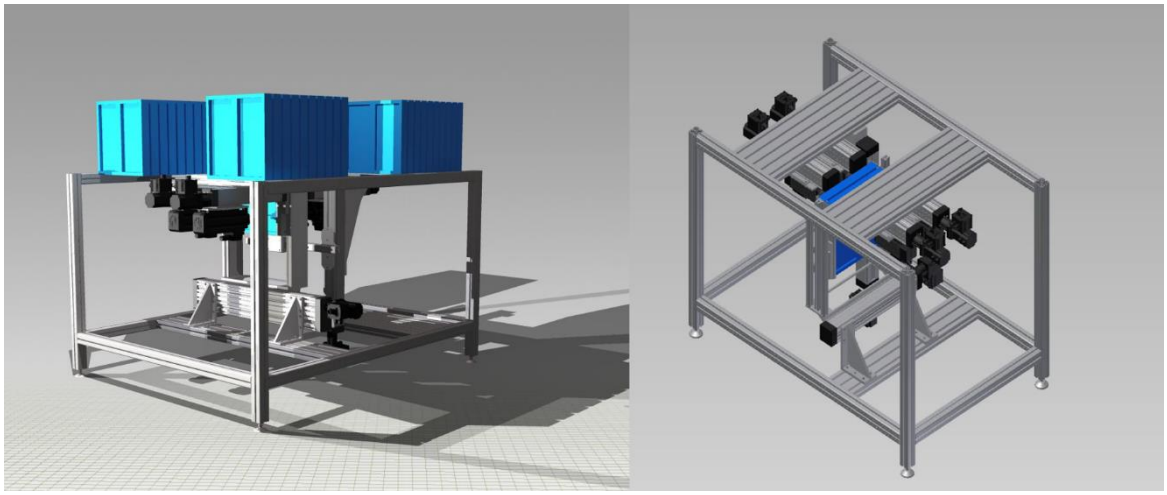

Fig. 5 Main mechanical components of the machine. Shows the vertically positioned working space with X and Y axes and two pairs of coaxially coupled independent Z axes.

The system achieved a production time of 5-8 minutes per pair of insoles (processed upper and bottom sides of the insoles with contours and tabs for insole support in the surrounding material), significantly reducing time and other requirements compared to traditional methods.

The system's ability to handle various materials and ensure precise customization allowed the production of high-quality and accommodative custom made insoles for users. The IPASIOU system utilizes a specially developed 3D scanning technology that enables quick and precise definition of the plantar surfaces of both feet. The combination of digital scanning based on structured light pattern projection ensures high resolution and accuracy of the scanned surface results in the form of a 3D point cloud. The scanning data is used for the automated generation of three-dimensional models, which serve as the basis for the CAD design of the insole.

The insoles are then produced using a developed CNC machine specialized for working with different materials. The application of this machine, with four independent Z axes, allows simultaneous processing of four different surfaces (a pair of top and a pair of bottom surfaces of the insoles) (Figure 6). The machine is equipped with advanced features for handling and clamping workpieces in the working space, allowing for quick and precise surface processing, resulting in highly customized insoles with almost no additional work needed for their adaptation to the shoe they are applied to (Figure 7). After machining, the material block with the finished insoles exits the working space. The insoles are separated from the surrounding material with very little force and are ready for application in shoes, as their bottom side is complementary to the inner sole. This approach improves the comfort and functionality of the insoles and reduces the time needed for their production and fitting. Although the achieved system is primarily intended for the production of custom made shoe insoles, whose design is primarily based on the given geometry of the scanned plantar foot surfaces, the system can also be used as a production unit for foot orthoses, functionally adapted to patient needs by applying corrective elements. The developed CNC machine can also receive input from multiple remote units and serve as the main production unit of a central laboratory.

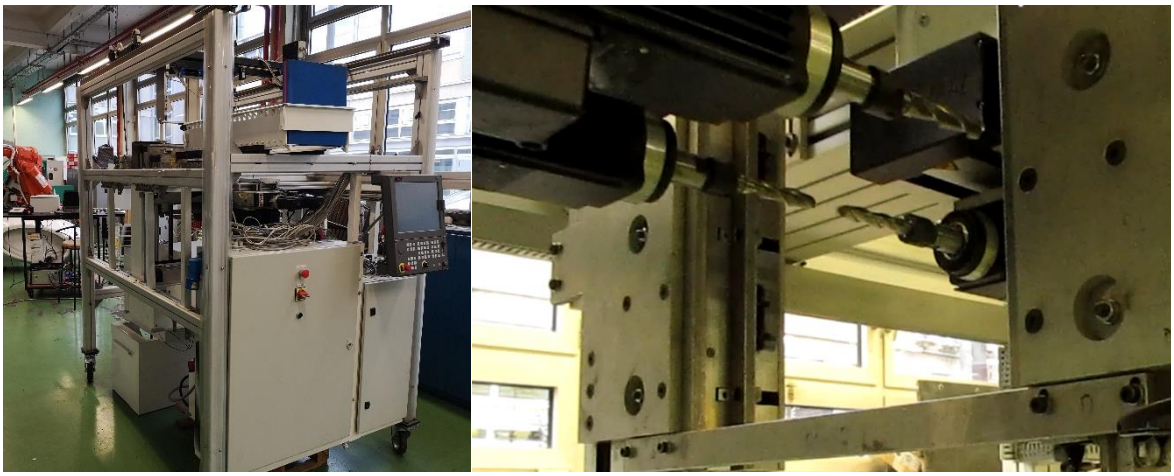

Fig. 6 Left - realized IPASIOU machine; Right - machine's working space.

Fig. 7 Processing of EVA material block for making orthopaedic insoles. Left: processing the lower sides of the insoles; Right: processing the upper surfaces of the insoles.

4 Results

The results of the IPASIOU system showed significant improvements in several areas:

1. Precision: The use of advanced scanning technologies allowed for a high level of precision in insole manufacturing. This resulted in better-fitting insoles that provide greater comfort and effectiveness for users (Figure 8).

2. Production Speed: Automation of the process significantly reduced the time needed to produce insoles. The average production time for a pair of insoles was reduced to 5-8 minutes, representing a significant improvement over traditional methods.

3. Intuitive Interface: The system enabled easy selection shoe size, insoles type, level of arch support and the choice of materials with different properties (e.g., material hardness), resulting in better product adaptation to individual requirements.

4. Cost Efficiency: Long-term savings were primarily achieved by reducing production time and the need for manual labour (insoles made by the IPASIOU system do not require additional processing for application in shoes). This resulted in a reduction in overall production costs.

5. User Satisfaction: Feedback from users showed a high level of satisfaction with the comfort and functionality of the insoles. The customized approach to insole design allowed for quicker and better adaptation.

Fig. 8 Insoles made using the IPASIOU system. Left - pair of newly made insoles; Right - pair of insoles after 5 years of use.

Conclusion

The development and implementation of the IPASIOU system represent a step forward in applying digital technologies in orthopedic insole production.

The integration of advanced technologies, such as 3D scanning and CAD/CAM systems, allowed for a high level of precision and individual customization in insole production, resulting in significant improvements in comfort and functionality for users. The automation of the production process reduced the time needed to produce insoles, simplified the entire procedure, and enabled the production of quality products, ease of application, reduced need for human labour, and improved overall efficiency of the process necessary to achieve such orthopaedic aids.

The IPASIOU system also demonstrated cost efficiency, despite initial implementation costs, due to increased productivity and reduced need for manual labour. User feedback confirms a high level of satisfaction, further emphasizing the value of this system in general and O&P applications.

Future development of the IPASIOU system is focused on expanding capabilities and exploring new applications in orthopaedic and prosthetic technologies. This system holds potential for improving orthopaedic care by providing high-quality custom made insoles to both the general population and patients who require such products.

The IPASIOU system is an example of how modern technologies can be successfully integrated into the production of individual medical products, bringing numerous benefits to both patients and healthcare professionals. Continued research and development on this system promise further improvements and innovations.

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