PhD proposal: Multi-material 3D printing for orthoses fabrication.

Brief

We are looking for a PhD student with a strong background in the fields of additive manufacturing, computer graphics and geometry to study multi-material 3D printing for the design of orthoses. Orthoses are plates with specific bending behaviors that are applied to the body to correct or prevent certain movements. For instance these include braces and insoles. They are often found in medical applications but may also be used in sport, or for personal comfort. Our goal is to study novel ways to fabricate orthoses, using inexpensive filament printers and multiple materials, including active materials that react to external stimuli.

The candidate should be proficient with C++, have a competent background in geometry and computer graphics, with ideally some experience in 3D printing. Candidates should demonstrate a high motivation for these topics, as well as an excellent academic track record.

- **Location:** LORIA / Inria, Nancy, France.
- **Advisors:**

  - Sylvain Lefebvre, LORIA-Inria (sylvain.lefebvre@inria.fr)
  - Dider Rouxel, Institut Jean Lamour (didier.rouxel@univ-lorraine.fr)

- **Collaborators:**
  - Samuel Kenzari, Institut Jean Lamour
- **Context:** This PhD topic is done within the context of a LUE exploratory project, funded by Lorraine University, between IJL (Jean Lamour Institute), LORIA (Lorraine Research Laboratory in Computer Science and its Applications), LRGP (Reaction and Process Engineering Laboratory), ERPI (Research Laboratory on Innovation Process), IRR Nancy (Regional Institute for Physical and Rehabilitation Medicine) and Nancy CHU (University Hospital). The project considers the creation of flexible plates with controlled elasticity for use in medical applications (orthoses, insoles). The student will join a team of researchers and engineers collaborating together with health care professionals to create novel types of ortheses (braces, insoles and other plate-like medical devices).
- **Keywords:** orthoses, 3d printing, additive manufacturing, multi-material, fused filament fabrication.

Figure 1: Illustration of a shoe insole with varying elasticity, modeled using a porous pattern that can be manufactured on filament printers [5].

Topic

We investigate novel ways to produce orthoses for applications in health care, sports and personal comfort. Technically, orthoses are plate-like devices with a controlled elasticity, controlled bending behavior, and varying responses to impact and flexion.

An active line of research investigates the possibility to control these properties through the creation of inner structures within the parts, e.g. [8, 10]. Intuitively, creating holes of varying sizes and shapes will modify the elastic response of the object, making it more or less flexible. This is a line of research we pursue as well in the context of this project [4, 6]. However, there are several drawbacks to this approach. First, the structures are assumed small with respect to the object they fill. This is required to estimate the average behavior of the equivalent homogenous material, using numerical homogenization [1]. Unfortunately, as the structures have to comply with additive manufacturing processes, they still have a relatively large size, which may produce cases where simulation ends up too far from the final physical behavior. Second, the inner structures often have a complex shape and can only by manufactured on high end printers. This results in high costs, and the products have to be manufactured in remote, specialized facilities. Third, the porosity introduces potential drawbacks for medical applications: they may capture humidity and complicate cleansing, while their shape could also lead to local mechanical fatigue in areas that deform often. Another approach is to rely on multiple materials [7, 14, 13] using high end printers. Such processes are however expensive, and materials can be subject to fatigue and changes of properties over time.

Instead, in this thesis we will consider novel deposition algorithms aimed at 3D printing orthoses using inexpensive, widely available multi-material filament printers. These printers are equipped with multiple extruders, that can jointly extrude several materials. Unfortunately, the techniques used for printing with multiple-materials are currently limited to juxtapositions [2] or dithering [9, 3]. We seek to produce improved mixing, allowing for precise gradients of properties using different filaments, and also investigating ways to prevent fatigue and fragilities in the final parts.

We will combine three different methodologies. The first is a technique for micro-layering that we initially developed for color printing [11]. The second is to develop novel toolpath planing algorithms that take into account deformations when producing the deposition paths, such as to reduce material fatigue. Third, we plan to investigate how to improve surface finish by 3d printing slightly out of plane, building on our prior work [12]. In addition, we will investigate with our partner, Institut Jean Lamour, the possibility of embedding active materials with the printed parts: these materials react to their environment and dynamically shrink or expand – a principle referred to as 4D printing.

References

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