A soft pneumatic actuator with integrated deformation sensing elements produced exclusively with extrusion based additive manufacturing

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In recent years, soft pneumatic actuators have come in the spotlight because of their simple control and the wide range of complex motions. For the monitoring of soft robotic systems, elastomer-based deformation sensors are being used. However, combination using of conventional mold casting processes for embedding deformation sensors in soft actuators are time consuming and difficult to upscale on an industrial production level. In this study, it is shown how such soft bending pneumatic actuator with integrated sensing elements can be produced using extrusion-based additive manufacturing. The advantage of fused deposition modeling (FDM) against direct printing or robocasting is the significantly higher resolution and the ability to print large objectives. The newly commercial launched pellet-based FDM printers are compatible with thermoplastic elastomers of low shore hardness that are required for the soft robotic applications. In this study, soft pneumatic actuator with the in-situ integrated piezoresistive sensor elements was successfully fabricated using a commercial styrene-based thermoplastic elastomer (TPS) and a TPS/ carbon black (CB) combination, developed at Empa. It has been demonstrated that the integrated sensing elements could monitor the motion of the soft robot with high resolution, linear response and low drift. The findings of this study contribute in extending the applicability of additive manufacturing for integrated soft sensors in large soft robotic systems.