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Multi-material 3D Food Printing Towards Simulation Driven Powder Depositor Design

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Introduction
3D food printing is a new and rapidly developing technology capable of creating entirely new food structures. One of the challenges in 3D food printing is the creation of a multi-material object from a powder bed. A key challenge is the deposition of a variety of powders in order to create a multi-material powder bed. Simulating powder flow of the deposition process is done with a 2D Discrete Element Method (DEM) model capable of simulating arbitrarily shaped powder particles.

Multi-material Powder Deposition
The ability to dose distinct powder in a voxel pattern is imperative for creating a multi-material powder. This can be done by using a vibrating nozzle[1]. After deposition, a flattening and densification step is required to create a smooth and densely packed powder bed. A rendering of this process and the envisioned powder bed after densification is shown in Figures 1 and 2.

A proof of principal experimental design of the powder depositor was made where the vibration in the nozzle was optimized through the placement of the piezo[2]. This leads to fast and reliable breaking of the powder bridge in the nozzle which induces flow.

For determining optimal hopper designs and settings for multiple powders a discrete element method model is developed.

Discrete Element Method
A discrete element method can simulate powder flow by modeling every particle and calculating the position of the particles by solving the equations of motion,

\[ a_i = \frac{F_i}{m_i} = \frac{\alpha_i}{t_i} \]

for the lateral and rotational motion of each particle. The force upon the particle is the summation of all forces experienced by the particle,

\[ F_i = \sum F_{ij} + \sum F_{ij}^{slide} + F_{ij}^{damp} + F_{ij}^{roll} \]

where the forces are contact and non-contact forces between the particles and damping and gravitational forces. The torques are calculated with summation,

\[ M_i = \sum (M_{ij}^{slide} + M_{ij}^{roll}) + M_{ij}^{damp} \]

where the torques are caused by sliding and rolling friction and additional damping. The contact force between two particles \( F_{ij} \) is calculated with a linear hysteretic force model based on the intersection area when two particles overlap.

Calibration of shape and material properties are necessary for a correct discrete element method simulation of powder flow.

Calibration of Discrete Element Method
Particle shape has a big influence not only on flowability of the powder but also on the computational time required for resolving intersection areas. For the DEM model particles are defined as polygons. These polygons are fitted based on microscope images with a limited number of vertices that still capture the overall particle shape but reduces computational time as much as possible.

With calibration values based on microscopic properties, a DEM simulation can be done to verify whether it correctly captures macroscopic behavior of powders.

Results
The model can simulate the angle of repose of sugar, but needs further validation before being applicable to many 3D food printing processes.

Conclusions and Future Outlook
• The DEM model captures macroscopic properties but needs further validation before it can simulate powder flow in the designed hopper
• It has been shown that the hopper design can deposit multiple materials with accurate enough precision for building 3D food objects.
• Creation of a multi-material object with multiple layers showcases that scaling to complete 3D printed food objects is possible
• All separate processes have been shown to function. Further research is now focused on the validation of the DEM model to couple all processes.

References
[1] Yang, et. al. , A multi-component powder dispensing ... Powder Tech., 2004