Controlling droplet evaporation from surfaces for 3-D printing applications

Supervisor: Colm Connaughton (Complexity and Mathematics)

Co-supervisor(s): Emre Esenturk (Mathematics)

External stakeholder(s): IAMP Consortium: J. D. Shephard (Heriot-Watt University), C. Connaughton (University of Warwick), R. W. Kay (Loughborough University), P. J. Smith (University of Sheffield), Renishaw plc, SPI Lasers Ltd, Xaar plc, and M-Solv Ltd.

Scientific background

3-D printing is a fast emerging technology which has the potential to revolutionise the way we manufacture parts and products. There are multiple technological approaches to the problem of creating a 3-D object from a virtual template. Some of them involve assembling the object layer-by-layer. For example a layer of matrix material is laid down, a device similar to an inkjet printer is used to arrange the first layer of the object on the substrate using a special ink containing the printing material in suspension. When the ink evaporates, part of the final object is left behind on the surface. Another layer of matrix material is then laid down around the printed layer and the process repeated. After all layers have been printed, the matrix is dissolved using an appropriate solvent and the final object remains when the matrix has been removed. One difficulty with this approach (of many) is that droplets do not evaporate uniformly. As a result, the deposit of printed material which is left behind after evaporation does not have a uniform thickness. This is a familiar phenomenon in everyday life known as the 'coffee-stain effect' - after a coffee spill evaporates, the coffee is deposited in rings near the edge of the spill [1, 2]. This project is about modelling this effect mathematically with a view to learning how to control it.

Research challenge

The challenge is to develop a model of the dynamics of a droplet spreading on a surface in the presence of evaporation. This is primarily a mathematical study motivated by the engineering application described above. There is a fairly extensive literature on so-called gravity currents which are liquid volumes spreading on a surface primarily under the influence of gravity [3]. They can be described mathematically by self-similar solutions of a nonlinear partial differential equation obtained from the basic equations of fluid dynamics after various approximations have been made. This research will involve adding evaporation to these equations and studying how the self-similar solutions change in addition to adding the solute to the model to try to predict how it is transported.

Pre-requisites

This project is being offered as a MathSys or Erasmus Mundus M1 project. You should have a strong background in mathematical modelling and a scientific interest in dynamical systems, nonlinear partial differential equations and numerical methods.

Additional considerations

This project is tied into a larger EPSRC collaborative project between Heriot-Watt, Loughborough, Sheffield and Warwick called IAMP (Integration of Advanced Manufacturing Processes). IAMP aims to develop a new protocol for 3-D printing with multiple materials by combining a number of existing technologies. You will be expected to participate in this project by attending project meetings with the other partners, interacting with the post-docs and students from the other institutions and generally being a part of the team. You might care about the research themes falling under the umbrella of Warwick's Innovative Manufacturing GRP (http://www2.warwick.ac.uk/research/priorities/innovativemanufacturing/) since this is the research area you will be best qualified to work in after you graduate if you take your research in a more applied direction. There is a possibility of a follow-on PhD project subject to finding suitable funding arrangements.

References

[1] Robert D Deegan, Olgica Bakajin, Todd F Dupont, Greb Huber, Sidney R Nagel, and Thomas A Witten. Capillary flow as the cause of ring stains from dried liquid drops. *Nature*, 389(6653):827–829, 1997.

[2] Rajneesh Bhardwaj, Xiaohua Fang, and Daniel Attinger. Pattern formation during the evaporation of a colloidal nanoliter drop: a numerical and experimental study. *New Journal of Physics*, 11(7):075020, 2009.

[3] OE Jensen. The spreading of insoluble surfactant at the free surface of a deep fluid layer. *Journal of Fluid Mechanics*, 293:349–378, 1995.