# Artificial flagella: bio-inspired responsive polymers for micro-object manipulation

Technische Universiteit Eindhoven University of Technology

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# Artificial flagella: Bio-inspired responsive polymers for micro-object manipulation

Danqing Liu[1], Dick Broer[3], Kees Bastiaansen[3], Jaap den Toonder[1,2]

*[1]TU/e MaTe, [2]Philips Applied Technologies, [3]TU/e SKT*

## Introduction

In lab-on-a-chip devices in, it is important that one is able to accurately move and position micro-objects to be analyzed (cells, organelles) within the micro-fluidic features of the device. Nature has solved this problem by means of active hair-like structures, known as flagella, which are able to propel the cells to which they are attached, see figure 1.

Figure 1: Micro-organisms propelled by means of flagella

## Objective

Inspired by nature, we aim to develop polymer based artificial flagella, that can be actuated by a magnetic field. Also, we intend to attach these to an object to create an artificial swimmer and control which the swimming direction by another trigger such as temperature, PH or light.

## Materials and Methods

### Magnetite embedded polymer

The first version of our artificial flagella consists of a micro-flap with a photo-curable polymeric material as the principle component, in which magnetic nanoparticles are dispersed to achieve a magnetic structure.

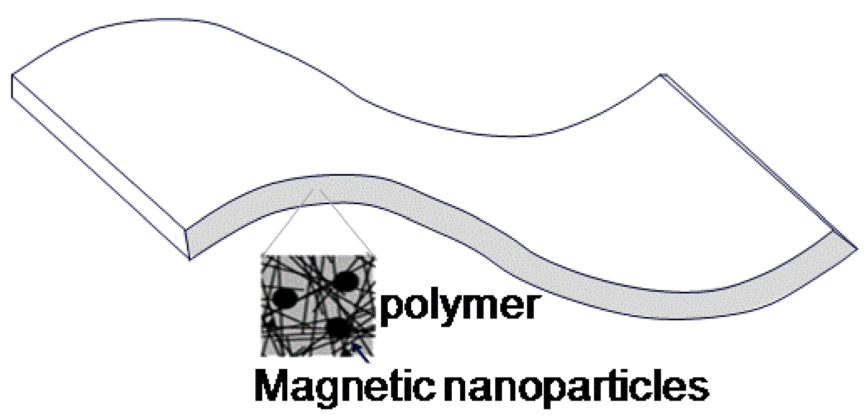


Figure 2: Sketch of our first magnetically-actuated artificial flagellum

Using the compounds listed listed, and after polymerization, we observed that the magnetical nanoparticles are dispersed quite evenly in the polymer. See figure 3.

- Toluene based ferrofluid (magnetite) 28.6wt%
- 2-Ethylhexylacrylate (base material) 61.0wt%

$CH_2{=}CH{-}C({=}O){-}O{-}CH_2{-}CH2{-}CH_2{-}CH_2{-}CH_2{-}CH_2{-}O{-}C({=}O){-}CH{-}CH_2$

- 1,6-Hexanediol diacrylate (crosslinker) 9.7wt%

$CH_2{=}CH{-}C({=}O){-}O{-}CH_2{-}CH(C_2H_5){-}CH_2{-}CH_2{-}CH_2CH_3$

- Irgacure 2959 (photo initiator) 0.7wt%

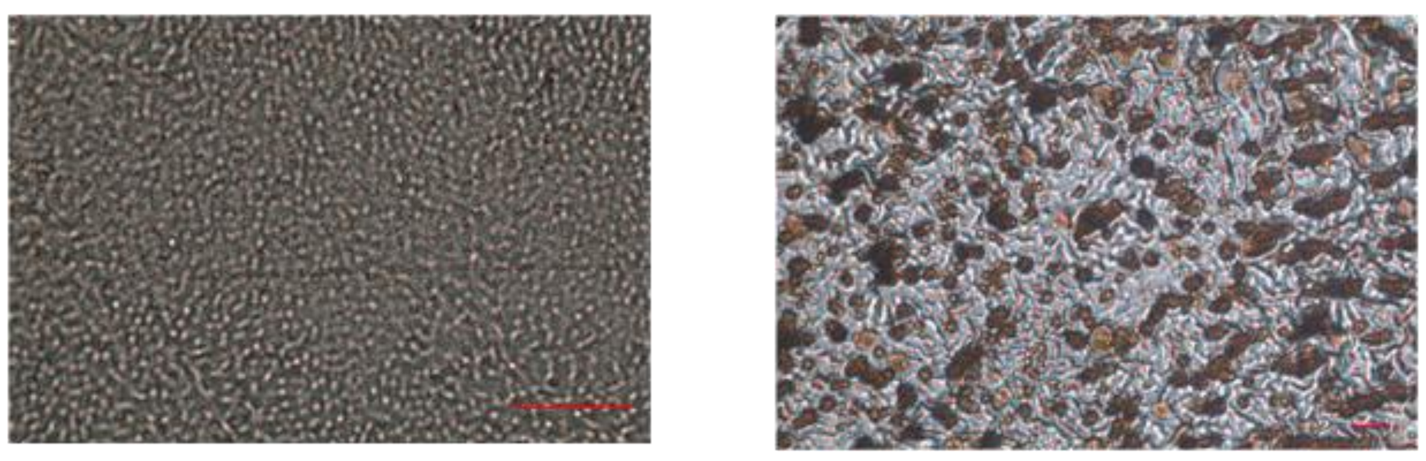

Figure 3: Optical microscopy image of magnetite dispersed in the polymer. The scale bar indicates 50μm (left) and 5μm (right)

### Fabrication

Inkjet printing of the uncured mixture including the magnetic particles is used to structure the flagella. Compared with the conventional lithographic approach, inkjet printing reduces the processing steps and the material used by depositing material on demand and in a direct way.

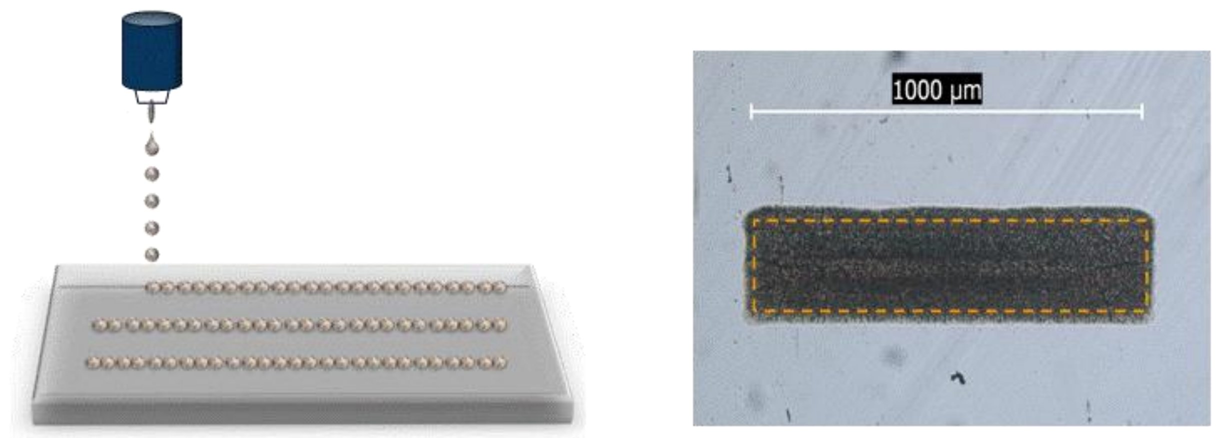


Figure 4: Schematic of the inkjet printing process (left) and the optical microscopy image of the printing result (right). The original design is a 1mmx0.2mm rectangle, represented as the dashed contour.

After inkjet printing, the material is polymerized by UV light under nitrogen flow. Figure 4 shows that the printing result is close to the design. Finally, the flagella are released from the substrate using the dissolution of a polyvinyl alcohol layer from underneath the flap.

## Magnetic Actuation

Figure 5 shows the magnetic set-up used. Each coil is addressed with a sinusoidal current that has a phase lag of 90˚ w.r.t. the adjacent coil. This creates a rotating magnetic field between the coils, with a strength 40 mT.

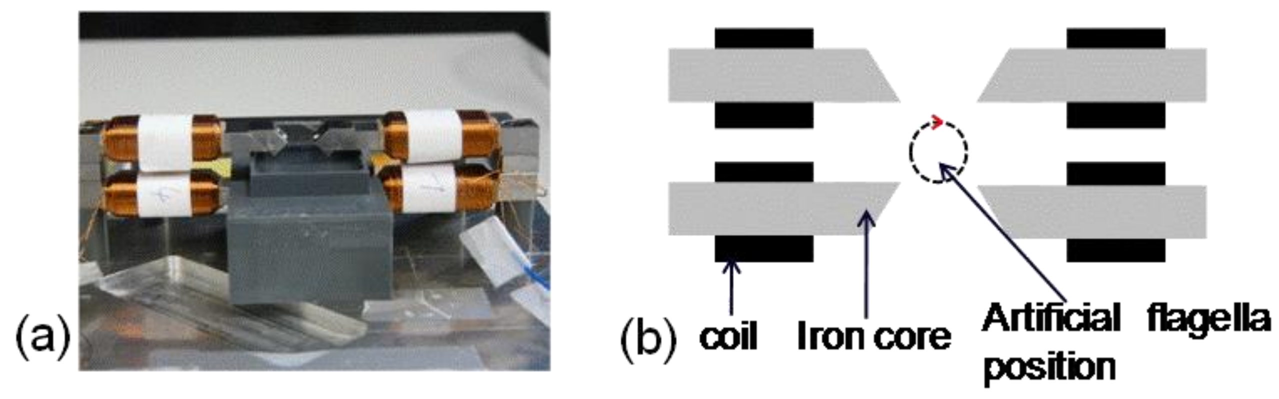


Figure 5: (a) Photo of the quadrupole used, (b) sketch of cross sectional view of the quadrupole; the red arrow indicates the rotation direction of the magnetic field.

Using a microscope we took movies of our artificial flagellum placed between the poles. The flagellum perfectly responded to the applied field.

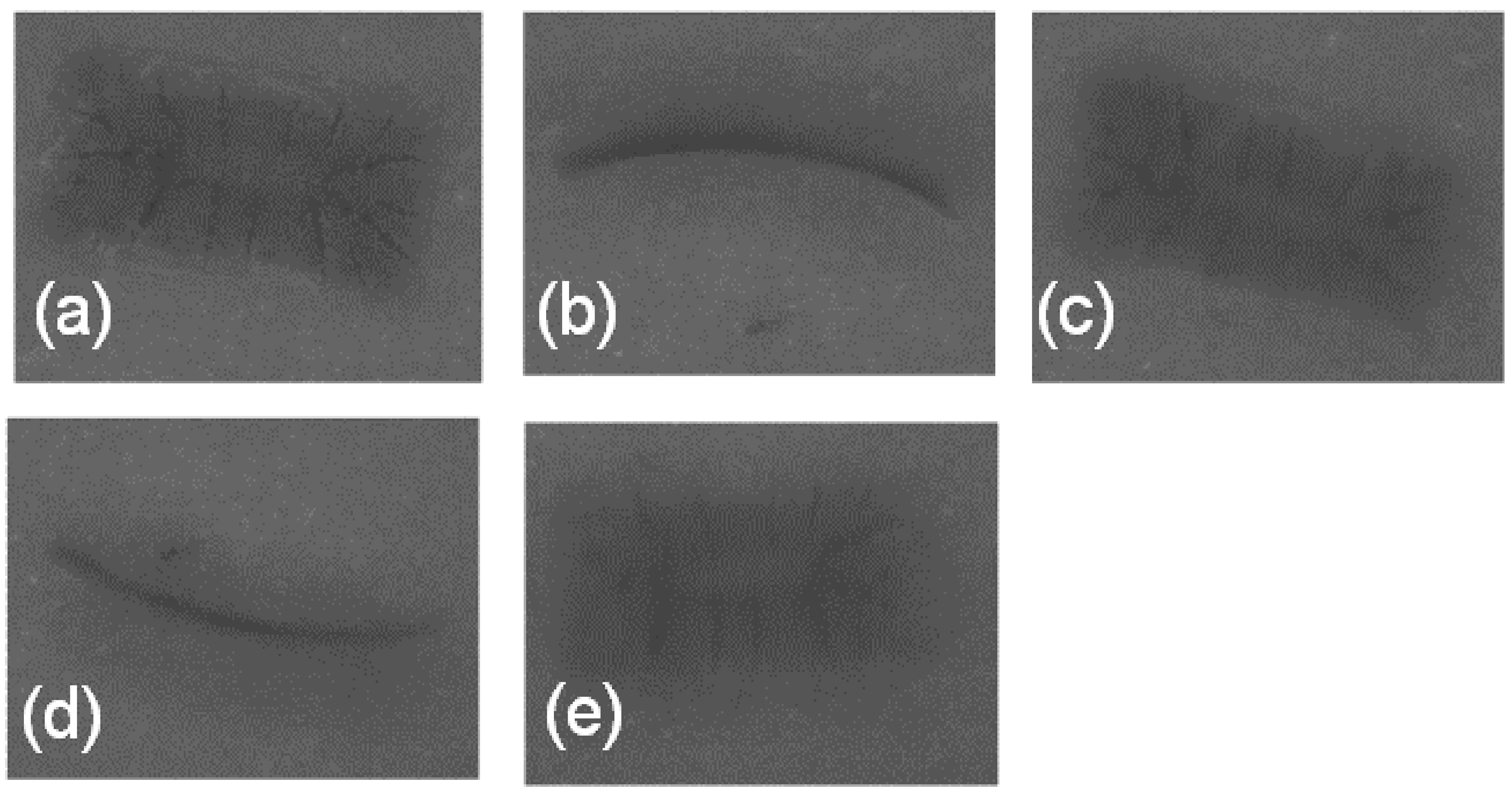


Figure 6: Artificial flagelum rotates along with the magnetic field. Without magnetic field (a) ; snapshots at different angles of field rotation (b) 90˚, (c)180˚, (d) 270˚, (e) 360˚

## Conclusions

We demonstrated that the magnetite embedded polymer can be structured via inkjet printing. After releasing from the substrate, our artificial flagellum can be actuated using an external magnetic field.