The implementation of two-photon polymerization (TPP) in the microrobotics community has permitted the fabrication of complex 3D structures at the microscale, creating novel platforms with potential biomedical applications for minimizing procedure invasiveness and diagnosis accuracy. Although advanced functionalities for manipulation and drug delivery tasks have been explored, one remaining challenge is achieving improved visualization, identification, and accurate closed-loop control of micrrobebots. To enable this, distinguishable identifying and trackable features must be included on the microrobot. Toward this end, the construction of micro- and nanoscale patterns using TPP is demonstrated for the first time on microrobot surfaces with the intent of mimicking color-expressing nanostructures present on beetles or butterflies. The patterns provide identification and tracking targets due to their vivid color expression under visible light. Helical and rectangular microrobots are designed with the topical patterns and further functionalized with magnetic materials to be externally actuated by magnetic fields. Vision-based tracking of a 20 μm × 30 μm colored feature on a 100 μm-long helical microrobot using a fixed angular position light source during microrobotic motion is shown. This versatile structural color patterning approach shows great potential for the visual differentiation of various microrobots and tracking for improved closed-loop control.

1. Introduction

Two-photon polymerization (TPP) is a 3D-printing technique that allows for submicron resolution by cross-linking the monomers present in a photoresist through exposure to femtosecond laser excitation, resulting in a well-defined solid structure at the microscale.[1] Among the different 3D-printing methods used for the fabrication of soft matter at the meso-, micro-, and nanoscale,[2] TPP has been of special interest in the microrobotics field due to the complex and accurate designs that one can achieve in a single run. The resolution of TPP is typically about 300 nm for commercial TPP devices and is related to the minimum volume element or voxel, which is dependent on the photoresist used, laser power, and exposure time, among other machine settings.[3] A 3D model is first created by conventional rendering software, allowing for the creation of structures with appendages, containers, and other curved structures, which are useful as building blocks or chassis for microrobotic systems.

Microrobots are microscale devices that are able to perform various tasks, from micromanipulation to operation as advanced sensing systems.[4] Due to their size, one of the major challenges in designing such miniaturized robots is the integration of actuation and wireless control in one single device. They are generally actuated using external energy sources, such as a fuel in the case of chemically propelled microrobots, or an external physical source (i.e., light, magnetic fields, electric fields, ultrasonic acoustic waves). Microrobots are divided into three main groups depending on their nature: biological, hybrid, and synthetic.[5] Such microrobotic platforms are implemented in many fields, ranging from automated manufacturing processes to biomedical or environmental applications. In the biomedical field, actuation of microrobots with external magnetic fields has proven to be the most robust for implementing various control methods[6–8] and exploring microrobot mobility on complex terrains in both dry and wet conditions.[9,10] At low Reynolds numbers, helical microswimmers can be actuated under rotational magnetic fields.[11] Those fabricated using TPP represent one of the most attractive structures in terms of efficient motion and fine guidance. This geometry has been extensively studied and optimized for efficient motion,[12–14] which was later applied as microtransporters for drug delivery purposes in in vitro conditions in a fully synthetic form[15,16] and in hybrid platforms based on a helical 3D-printed body and a sperm for assisted fertilization applications.[17] The latter configuration was also applied as a drug delivery platform through an advanced sperm-head design that opens up when a mechanical stress is applied,[18] envisioning and expanding the use of the spermbot in microrobot applications.[19] Another interesting geometry and mechanism explored for microrobots has been the creation of asymmetric tubes where chemical reactions are confined[20] also known as catalytic micromotors. Complex tubular structures, as well as single and double conical structures
of varying roughness and geometry, fabricated using 3D-printing processes proved the versatility of the present method, and further demonstrated 3D chemical patterning of very specific areas of 3D-printed structures for encoded functionality. Advanced biodegradable micromswimmers for environmental applications, as well as target cell labeling and drug delivery tasks, have recently been reported, exploring biocompatible microrobotics with theranostic capabilities.

One of the main challenges in the field is the imaging of microrobotic systems in vitro and in vivo conditions, seeking for efficient methods to clearly visualize, identify, and ultimately track microrobots. Feedback systems are a necessary aspect of robot control to properly automate their motion and obtain successful manipulation operations. Tracking robots are currently limited to vision-based imaging systems, as other conventional sensors (i.e., electrochemical, light, temperature) cannot be easily integrated on the microrobot structure due to size constraints. A specific template characteristic of a robot body can be used to develop a speeded-up robust feature (SURF) algorithm to track a microrobot’s real-time position and orientation. By applying the SURF algorithm to a microscale magnetic robot with a compliant and stiffness calibrated end-effector, automated force-guided micromanipulation tasks with real-time micro-Newton (μN)-level force control was achieved, including the controlled application of manipulation forces.

It was later demonstrated that integrating colored features in the body of such microforce sensing mobile microrobots (μFSMM) allowed the application of a less computationally expensive color-based tracking algorithm, which could provide real-time sub-μN-level force information to the user teleoperating the μFSMMs. The μFSMM colored features consisted of colored dyed dots of about 80 μm in diameter integrated into the silicon body during the microfabrication process. For 3D-printed microrobots with smaller dimensions, alternative fabrication approaches are needed to integrate distinctive tracking features, including marking the microrobot surfaces with fluorescent materials such as quantum dots (QDs) or using fluorophores selectively attached to specific functional groups. Despite their success in tracking, these materials lose their fluorescence over time, limiting their duration of usefulness.

Structural color presents a permanent alternative to fluorescence-based coloration methods. Structural color occurs when visible light interacts with patterned nanostructures causing constructive interference. The spacing, size, and shape of these nanostructures trap light resonantly, yielding the expression of a specific color. Morpho butterflies and beetles, among other insects, show vivid colors this way, and various studies have proven means of replicating this concept using synthetic approaches. Using additive manufacturing methods, structural color can be achieved by integrating fiber structures with an outer layer of microspheres which assemble into a color-expressing photonic crystal structure. However, there are other fabrication techniques that offer a wider range of expressed colors consisting of patterns made up of or lined with a metal or high-index dielectric material. Multiple studies use laser lithography to create repetitive extrusions out of polymer substrates or dielectrics such as silicone. Germanium, a high-index dielectric that can be applied via electron beam deposition, proved to be a suitable coating to express high-contrast colors. The integration of an aluminum oxide dielectric layer onto a network metamaterial (dealloyed Pt3Al) resulted in mechanically robust and saturated structural colors due to the resonant coupling of the light with surface plasmons. TPP has been used to mimic Morpho butterfly lamella to express a blue sheen. Such photonic structures expressed different noniridescent colors that were determined by the thickness of the polymer lamellas, their orientation, and the resultant air cavities. Also, localized color micropatterns were achieved on an ordered coassembly of polystyrene/silicon dioxide photonic crystals by degrading the polystyrene beads through a multiphoton effect. The increased resolution in 3D techniques for structural color printing led to the development of computationally designed structural color patterns, representing the first step toward the rational design of 3D-printed structural colorizations.

Some interesting advanced functional capabilities have been associated with 3D photonic crystals, ranging from advanced label-free sensors to multilevel security applications. By correlating the color shifts to a specific physical (e.g., temperature, strain, electric fields) or chemical stimuli (e.g., organic molecules, metabolites), low cost and simple colourimetric sensors with high sensitivity have been developed. They have been implemented in both point-of-care diagnostics and environmental applications, generally targeting label-free detection and involve the integration of stimuli-responsive materials. Interestingly, a living biohybrid inverse opal-structured hydrogel has been recently reported to characterize beating cardiomyocytes, demonstrating their ability to self-report by translating cellular forces into visual signals. In addition, a vapochromic response was demonstrated in a worm-like structural-color walker at the centimeter scale based on structural color polymers. Another relevant aspect of structural coloration is its associated wettability properties, which was first demonstrated in superhydrophobic and superhydrophilic structural color films and later implemented in security-related applications by creating complex wettability patterns that are visually revealed depending on the solvent polarity. There is an increasing interest on the implementation of structural color as security materials for anticounterfeiting applications, with examples in colloidal photonic crystals to quasi 2.5D holograms based on microscale honeycomb pyramids.

This study is the first to use TPP to fabricate 3D-printed microrobots—helical micromswimmers and rectangular platforms— with structural color expressing patterns for real-time tracking and identification purposes. The features included were inspired by the nanostructures obtained using photolithography techniques onto dielectric materials but 10 times bigger in size (150 nm for Nagasaki et al. vs 750 μm in our design) due to the size constraints inherent to the 3D-printing technique hereby used. However, structural coloration is obtained, demonstrating the embedding of different and distinct colored features in microrobotic systems for the first time using a flexible fabrication technique with potential for mass production. As 3D-printing allows for one-step fabrication of computer-aided (CAD) models, the size, shape, and location of structural color tracking points are subject only to printer resolution limitations, and thus provide expansive potential for microrobotic tracking and identification operations. In addition, considering the wide range
of properties associated with structural coloration, the present fabrication approach can be later explored for the rational design of localized structural color features with tunable hydrophobicity, in situ sensing, and advanced anticounterfeiting capabilities in the 3D-printed microrobotics field.

2. Results and Discussion

2.1. Fabrication of 3D-Printed Colored Microrobots

To properly evaluate the integration of structural color features in fully 3D-printed robots at the microscale, nanopatterns with distinctive unit cells were printed in a well-defined section within the microrobot body. It should be noted that such nanostructures are printed with the rest of the microrobot body, demonstrating the simplicity and high flexibility of the current manufacturing approach. The microrobot designs explored were 1) helical microswimmers, consisting of a half-cylindrical head and helical tail, and 2) rectangular control platforms. Both microrobots are printed horizontal to the glass slide. The color structures were designed onto the flat surface of the half-cylinder end of the helices (Figure 1A,B) and the top surface of the control platforms (Figure 1C). The helix is designed as 100 μm long, with a circular cross section measuring 9 μm in diameter. The outer diameter of the microswimmer is 30 μm and the head is 20 μm thick. The design was sized such that the head of the helix could be easily observed with a 4.5× optical lens. The rectangular control platforms, measuring 100 μm × 30 μm, were printed to evaluate the consistency of 3D-printed structural colors across large planar surfaces and observing their response to rotating in and out of the plane of the workspace. The main body of the platform is 6 μm tall with 3 μm struts underneath to allow for clean release. Microrobots were fabricated with a Nanoscribe GT Professional machine (Nanoscribe GmbH, Germany) and later coated with layers of nickel (Ni) and germanium (Ge). The Ni layer allows for magnetic control of the microstructures using external magnetic fields, whereas the dielectric properties of Ge were intended to enhance color expression in the regions where the nanostructures were integrated.

2.2. Structural Color Design and Characterization

For the microrobots in this study, artificially manufactured structural color is based on a color-expressing pattern consisting of arrays of prisms extruding upward from a flat surface. This allows us to easily design them onto various parts of a microrobot. Furthermore, the pattern is advantageous in terms of manipulating the color expressed because it is based on the prism dimensions. The structures designed by Nagasaki et al. [40] fabricated with laser lithography techniques, featured distinguishable patterns exhibiting red, green, and blue colors. The “red” pattern consists of blocks with a 160 nm × 170 nm footprint, whereas the “green” pattern is based on blocks with a footprint of 120 nm × 90 nm. Originally, the features were spaced 300 nm apart and were 300 nm tall. For this study, “red” and “green” features were scaled by factors of 5× and 10× to account for the resolution provided by the available 3D-printer technology (Table 1). The arrays designed onto both of the helix and platform microrobots consist of all red (R), all green (G), or alternating red and green (RG) blocks (Figure 1B). Microrobots were also fabricated without any patterns for comparison purposes.

The resulting expressed colors can be changed based on the relative location of the light source. The high-index dielectric layer of Ge was added to increase color contrast, but the difference between the samples with and without Ge was minimal. The schematics in Figure 2 show the color expression of the helical microrobots for different angles relative to the light source and different patterns. The light source was fixed above at a set position/angle (Figure S4, Supporting Information) with constant intensity, and then the samples were rotated manually, and pictures were taken when a significant color change from the previous image occurred. The RG pattern was shown to express a wider spectrum of colors in comparison to just R and the G patterns alone (Figure 2). The R and G patterns expressed bright colors of blue and red only, whereas RG additionally expressed bright green. To illustrate the superior spread of the RG pattern, the various colors expressed by each type of pattern was graphed on a CIE1931 (International Commission on Illumination, from French Commission Internationale de l’éclairage) plot (Figure 2A). By contrast, microrobots without patterns did not express any colors.

The same rotation angle experiments were performed with platforms to observe a larger area of structural color. These larger colored areas proved to have more color variation and showed minimal differences with or without the top Ge layer (Figure 3). Color changes due to the variation of the angle in the vertical plane were also observed. Samples were tilted using wedges of 30°, 45°, and 60° (Figure 4A), in addition to tilting due to magnetic influence on platforms fixed on one edge (Figure 4B). Note that the microrobot samples shown in Figure 1–4 were in a dry air medium, whereas the sample shown in Figure 4B was in a silicone oil medium. Under the same lamp conditions of previous experiments, a clear change in color expression was observed when the angle with respect to the xy plane was slightly altered, demonstrating that the color structures can qualitatively reveal its orientation. Fine tuning of color expression depending on the applied angle can potentially provide real-time information of a microrobot’s position in both x–y and z directions by identifying the change in color while it is moving in the 3D workspace (Figure 4).

The expressed red, green, and blue (RGB) values were extracted from the images of the microrobot, to be later used by the tracking systems during processing. While helical microswimmers were actuated with rotating magnetic fields using the Magnebotix coil system (Figure 2), the control platform microrobots were actuated with gradient fields using the Helmholtz coils. (The Helmholtz coils provided larger field gradients that were needed to induce a motion response from the control platforms.) The color was visible on the control platforms as they rotated in the plane of the workspace (Video S1, Supporting Information) and on the helical robots operating at low frequencies (Video S2, Supporting Information). The light source is fixed during microrobotic movement, thereby introducing variation to the relative angle between the nanostructures and incoming light which makes the expressed color susceptible.
Figure 1. Fabrication and characterization of 3D-printed microrobots with structural colored features. A) Fabrication process of the 3D-printed microrobots: (i)–(iii) IP-DIP photoresist is deposited on a glass slide and the microrobots are printed using a TPP fabrication system (Nanoscribe Photonic Professional GT); (iv) removal of nonpolymerized photoresist; (v)–(vi) Ni and Ge are sequentially deposited (100 and 35 nm, respectively) onto the structures at 2 Å s⁻¹; (vii) microrobots are moved to an aqueous solution and later released using a micropipette. B) (i) CAD design of helical microrobots with a structural colored area located on the top surface of the helix head. Different unit cell designs include R, G, and RG, based on dimensions from Nagasaki et al.[41]. (ii) Scanning electron microscope (SEM) image of a single helical microrobot with 10 × RG pattern and (iii) optical image of the same structure under white light expressing color. C) (i) CAD image of control platform microrobot design with a structural color pattern. (ii) SEM image of the control platform with 5 × RG pattern and (iii) optical image of the same structure under white light expressing color. (Note: saturation value during the optical image acquisition: 4, according to Basler’s Pylon Viewer software).
to change. However, successful tracking was achieved for helical robots with consistent color expression.

2.3. Motion Studies and Automation of 3D-Printed Colored Microrobots

Effective motion of the helical microrobots was obtained by applying rotating magnetic fields. Such external magnetic fields were generated by the MFG-100 system (MagnebotiX AG, Switzerland) (Figure 5A). Samples were tested at the center of the workspace, of approximately 10 mm in diameter, where rotating fields of frequencies up to 5 Hz at 20 mT were applied to induce corkscrew-like movement resulting in translational motion (Figure 5B). For cases exhibiting slower rotations, a frequency of 1 Hz at 20 mT were applied. In addition to the conventional MagnebotiX setup, a lamp with a high-intensity white light bulb (Thorlabs—OSL2B2 3400K Replacement bulb) was used to obtain bright colors when evaluating the microrobots.

Motion studies of the microrobots were performed using containers made up of an opaque material (planarized silicon wafer; Figure 6) or a transparent substrate (glass petri dish; Figure 6C). In the case of working with opaque substrates, we observed a brighter color expression from the microrobot. Therefore, the silicon wafer was chosen as the preferred substrate (background) when evaluating the colored helical microrobots. All studies where the microrobots were in motion were performed within a silicone oil medium approximately 0.5 cm in thickness. Apart from an inconsequential bright spot resulting from the lamp light reflecting on the surface of the liquid, there were no significant differences in color expression observed between the liquid and air mediums. By comparing helical microrobots with (labeled as colored microrobot) and without (labeled as control) structural colors designed onto the flat surface of the head (Figure 6A), it was observed that color was only expressed when nanopatterns were present on the head of the helical microrobots. Furthermore, we observed that color expression differs depending on the frequencies of the rotating magnetic field applied. At low frequencies, the rotation of the structure is clearly observed, showing an intense bright color only when the head’s face containing the structural color is facing the optical lens (Figure 6B(i)). However, at a fixed translational direction and higher rotating frequencies, a constant color combination of the color expressed by the colored and noncolored face is observed (Figure 6B(ii)), mainly dominated by the colored face (see Video S2, Supporting Information). Colored helical microrobots with different integrated nanopatterns were also evaluated on transparent substrates, showing distinct color expression (Figure 6C and Video S3, Supporting Information). It should be noted that on the transparent glass substrate, microrobotic motion was slightly restricted due to the influence of adhesion when compared with the planarized silicon substrate. The feasibility of using such colored marks as tracking features for vision-based control methods is demonstrated by using a color-based tracking algorithm. The feature detection

| Name            | Length [μm] | Width [μm] | Height [μm] | Spacing [μm] |
|-----------------|------------|-----------|-------------|--------------|
| Typical 3D-printer resolution | 0.15       | 0.15      | 0.80        | –            |
| Original “G”    | 0.12       | 0.09      | 0.15        | 0.30         |
| Original “R”    | 0.17       | 0.16      | 0.15        | 0.30         |
| 5 × G           | 0.60       | 0.45      | 0.75        | 1.50         |
| 5 × R           | 0.85       | 0.80      | 0.75        | 1.50         |
| 10 × G          | 1.20       | 0.90      | 1.50        | 3.00         |
| 10 × R          | 1.70       | 1.60      | 1.50        | 3.00         |

Figure 2. Structural color characterization. A) Expressed color from the helical microrobots plotted in the CIE1931 color space using RGB values obtained by ImageJ. Optical image of the expressed color versus angle by the helical-like microrobots: B) 5 × R, C) 5 × G, D) 5 × RG, and E) 10 × RG.
method used allows for easy recognition of the microrobot location by tuning the hue, saturation, and value (HSV) parameters for the RGB colors corresponding the colored head. The real optical image and the corresponding color tracking mask are shown in Figure 6D(i) and (ii), respectively. A compilation of different images from the microrobot tracking in Video S4, Supporting Information, is shown in Figure 6E.

3. Conclusion

The results presented in this article are noteworthy for several reasons. Previously, other 3D-printed microrobots have been colored after printing for tracking purposes. However, those methods require multiple functionalization steps and the resulting colors fade over time. In contrast, the 3D-printed structural color presented here provides a permanent solution for the integration of colored tracking and identifying features in microrobotic systems. This study demonstrates the first attempt of one-step TPP fabrication of microrobots that include structural color, as well as the first study to observe microrobots both translating and rotating with embedded structural color fabricated by TPP. Arrays of blocks with dimensions of approximately 1 μm or less are added to flat surfaces on a 3D-printed microrobot. Existing block dimension ratios from this or previous studies can be scaled and applied for microrobots of different sizes. Following printing, a metallic or dielectric material is coated on the patterned surface for distinct color response under visible light.

The fabricated microrobots respond to magnetic fields and visibly expressed color under white light. The expressed colors provide a permanent, robust qualitative method for visually locating and identifying robots. Although color was visible in both types of microrobots studied here, as well as trackable in the case of the helical robots rotating at low frequencies, the color varied with angular orientation with respect to the light source. Therefore, rotational changes in the horizontal and vertical planes can be detected from observing the expressed colors. This can be useful to quantitatively identify angular changes that can prove to be cumbersome in color tracking applications. Further studies will work toward making the colors expressed constant regardless of orientation of the microrobot or light angle of incidence. The Ge coating used in previous studies to increase color contrast was shown here to provide minimal

![platform color expression](image1)

**Figure 3.** Platform color expression. Different patterns according to the unit cell designs defined in Table 1 were printed on the control platforms, which were later sputtered with 100 nm of Ni for magnetic control. The corresponding color expression was evaluated in the absence and addition of a Ge layer (35 nm).

![structural color with respect to vertical tilt](image2)

**Figure 4.** Structural color with respect to vertical tilt. A) Released control platforms on a planarized silicon wafer tilted at 30°, 45°, and 60° out of the horizontal plane. (Note: the image background has been removed for clarity.) B) Control platforms with one edge fixed to a transparent substrate and the other tilted out of plane at different amounts using magnetic fields resulting in different color expressions. For both parts (A) and (B), the lamp was held in the same position while the platforms were tilted.
effect to the color expression when the robots also have layer of Ni on them. This may be due to reflections caused by the Ni layer under the Ge layer for the certain wavelengths of light that are able to pass through high-index dielectrics subsequently encounter an iridescent metallic surface.

The variation of structural color block dimensions was used to explore the ability to manipulate color expression. In this study, the alternating block geometries provided a wider range of colors than arrays with a single type of block geometry. With increasing accuracy of micro-3D-printing technologies and by exploring complex patterns, noniridescent colors can be obtained. This has been recently demonstrated for 3D-printed lamellar-like structures similar to the ones of the Morpho butterfly, though this type of pattern only expressed an artificial blue color and was not applied to structures while moving. By exploring new computationally designed structures and integrating them into 3D microrobotic systems, structural color can become a common element not only for tracking and identification but also for creating tunable surface properties. Conclusively, the design here demonstrated the feasibility of including identification features by locally incorporating structural color within the microscale robot body, allowing for real-time tracking using color-based algorithms. Although the current configuration is not extensible to in vivo application, it represents a step forward to achieving better control and later automation of microrobotic systems using the proposed integrated structural color designs.

4. Experimental Section

Colored Platforms and Helical Microrobots Fabrication: Robot microstructures were 3D-printed with a Nanoscribe Photonic Professional GT machine using IP-Dip photoresist. The system used a 100 femtosecond pulsed laser with a wavelength of 780 nm through a 63× oil objective. The laser was configured to a power and scanning speed of 50 mW and 10 mm s⁻¹, respectively. The samples were further developed with propylene glycol methyl ether acetate (PGMEA) for 9 min and isopropanol.
for 9 min, drying in air afterward. The structures were later coated with 100 nm of Ni and 35 nm of Ge at a deposition rate of 2 Å s⁻¹ using a CHA electron beam (CHA Industries, USA).

Experimental Setup: Rotating magnetic fields were generated using the MFG-100 system (MagnebotiX AG, Switzerland). The power unit of the field generator could supply up to 20 A currents through eight coils at a time and was able to generate either a specific field or gradients within the workspace. The associated software allowed the control of the applied field strength, gradient, and frequency of rotational magnetic fields, as well as control the yaw, roll, and pitch of the field’s rotational axis. Videos were acquired by real-time imaging (30 frames s⁻¹) using a CMOS (complementary metal-oxide semiconductor image sensors) camera (Basler puA1600-50uc, Basler AG, Ahrensburg, Germany, baslerweb.com) along with a 0.7× to 4.5× variable magnification microscope lens (Edmund VZM 450i, Edmund Optics, Barrington, NJ, USA).

Video Data Treatment: All videos for the vertical angle measurements were acquired with Basler’s Pylon Viewer software (Version 5.0.12.11830, Basler AG) using the default settings for Windows 64-bit systems. Under “Image Quality Control” in the image acquisition options, “Light Source Presets” and “Balance White Auto” were both turned off. The “Saturation” was increased to “4.0” to make color differences more apparent.

Evaluation of Color Expressed by 3D-Printed Nanostructures: To obtain the CIE color map shown in Figure 3, color measurements and conversions were performed. First, the average RGB value of each helix head was measured using the RGB Measure Image] plugin for each light angle and corresponding color expressed. Then, using a simple Matlab script with a conversion matrix, the RGB values were converted to XYZ and subsequently normalized to x, y, and z, which was plotted to create the CIE color map. The normalization was done using the following equations

\[
x = \frac{X}{X+Y+Z} \tag{1}
\]

\[
y = \frac{Y}{X+Y+Z} \tag{2}
\]

\[
z = \frac{Z}{X+Y+Z} \tag{3}
\]

Finally, the x and y values were plotted and overlaid on the colored background, which represents the wavelengths and corresponding colors of each point on the color map. The color map was obtained through the cieplot function of the Computational Colour Science toolbox for MATLAB.

Microrobot Tracking: A simple color tracking script was written using Python along with OpenCV to show that this application was possible. The code applied a threshold of its location.

To handle that case, the script stored the location was not exceeded. As the rotational frequency was high compared with the color was not visible. To handle that case, the script stored the location.

The code applied a threshold Python along with OpenCV to show that this application was possible.

Supporting Information

Supporting Information is available from the Wiley Online Library or from the author.

Acknowledgements

C.A.K. and M.G. contributed equally to this work. This work was supported by NSF IIS Awards 1149827 and NRI 1637961, as well as Purdue University’s Summer Undergraduate Research Fellowship program and Honors College undergraduate research grant. The authors acknowledge the facility access at Birck Nanotechnology Center at Purdue University and the Nanotechnology Core Facility at the University of Illinois-Chicago, and Benjamin J. Johnson, Jae S. Hyun, and Song Zhang for their support and valuable discussions. They also thank Seyoung An and Jacek Lechowicz for help 3D-printing the microrobots.

Conflict of Interest

The authors declare no conflict of interest.

Keywords

mobile microrobots, structural color, vision-based tracking, 3D-printing

Received: November 21, 2019
Revised: February 16, 2020
Published online: March 29, 2020

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