UKRI Trustworthy Autonomous Systems Hub

End of Award Report

This report is intended to capture key highlights of the project, including the research plan and key findings, outcomes and impacts, activities and progress around TAS Hub priorities and themes, and emergent themes and opportunities to develop beyond the project.
A clear and succinct style is encouraged. Tables, diagrams and images may be included, but be cognoscente of file size (10Mb max).

Project Details

Project ID: (e.g., TAS-PP-000xx)
Project Title: Trustworthy light-based robotic devices for autonomous wound healing
Start Date: 01.04.2021
End date: 31.03.2022

Main Contact: Sabine Hauert

Research Team

Name	Institution	Role
Sabine Hauert	University of Bristol	PI
Ana Rubio Denniss	University of Bristol	Co-I
Silke Henkes	University of Bristol	Co-I
Eugenia Piddini	University of Bristol	Co-I
Thomas Gorochowski	University of Bristol	Co-I
Jonathan Ives	University of Bristol	Co-I
Neshika Wijewardhane	University of Bristol	Researcher/Aligned PhD Student
Jordan Parsons	University of Bristol	Researcher
Namid Stillman	University College London	Collaborator
Open Cell	Open Cell	Industrial Partner

Executive Summary

Each year approximately 2.2 million UK adults are inflicted with a wound.
Robotic technologies have the potential to guide wound healing at the cellular level. Machine learning allows us to tailor the control to individual cellular dynamics on the go, enabling personalised solutions. This raises questions about how to ensure these systems are trustworthy and safe.
In this project we aimed to 1) demonstrate wound healing in the laboratory, and 2) define an envelope of operation that balances risks and benefits of machine learning and autonomous control.

Figure 1: EPI-DOME in an incubator setting to run wound healing experiments.

Research Plan & Key Findings

WP1 Adaptation of our open Dynamic Optical MicroEnvironment (DOME) to allow for cellular imaging and control of wound healing.

Key findings: This work package has been successful with the adaptation of the DOME which can now operate in an incubator environment, allowing for the imaging and closed-loop illumination of cells during a wound healing process in real-time. This required us to change the DOME hardware to be heat and humidity resistant, change the optics to improve imaging of tissue cells, and change the light source to illuminate at the right wavelength.

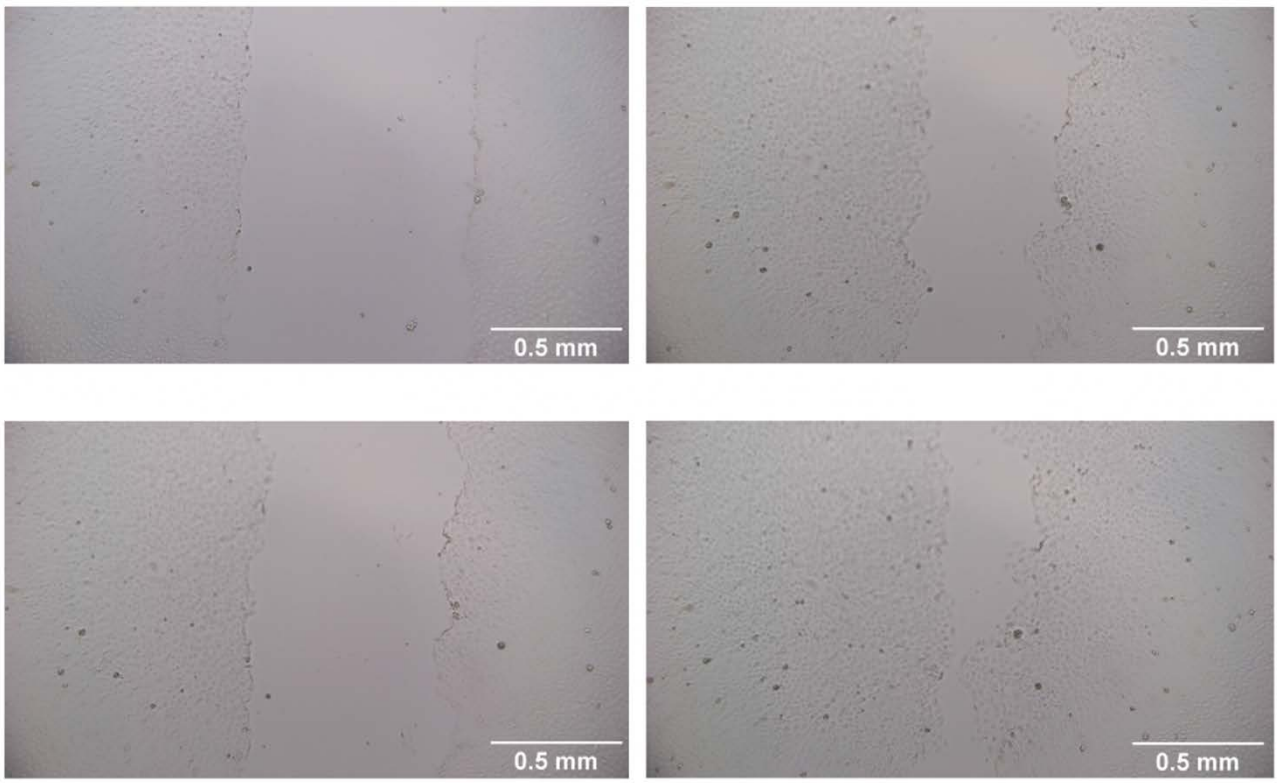


Figure 2: Real-time imaging of wound healing in the EPI-DOME.

This work has resulted in the following paper accepted for publication, attached to this report for your convenience:
Long-term imaging and spatio-temporal control of living cells using Light, Neshika Wijewardhane, Ana Rubio Denniss, Matthew Uppington, Helmut Hauser, Thomas E. Gorochowski, Eugenia Piddini, and Sabine Hauert, IEEE MARSS, in press

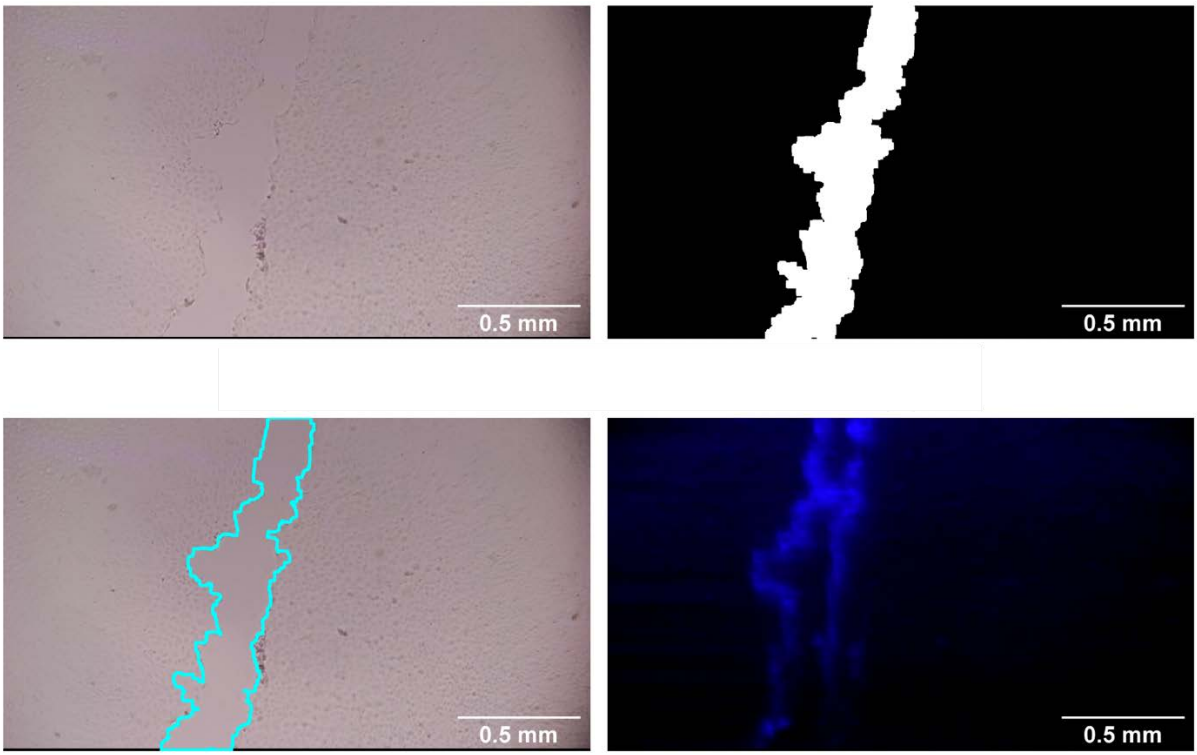


Figure 3 Closed-loop illumination of the wound-healing front in the EPI-DOME.

In addition, Silke Henkes and Nam Stillman have been working on automatically extracting models of wound healing from video data using machine learning to fit parameters of the cell replication and motility. This has now been achieved using high quality images of wound healing from the Piddini lab and is being tested with images of wound healing from the EPI-DOME. This would allow models fine-tuned to the patients using machine learning to inform the best treatment illumination strategy.

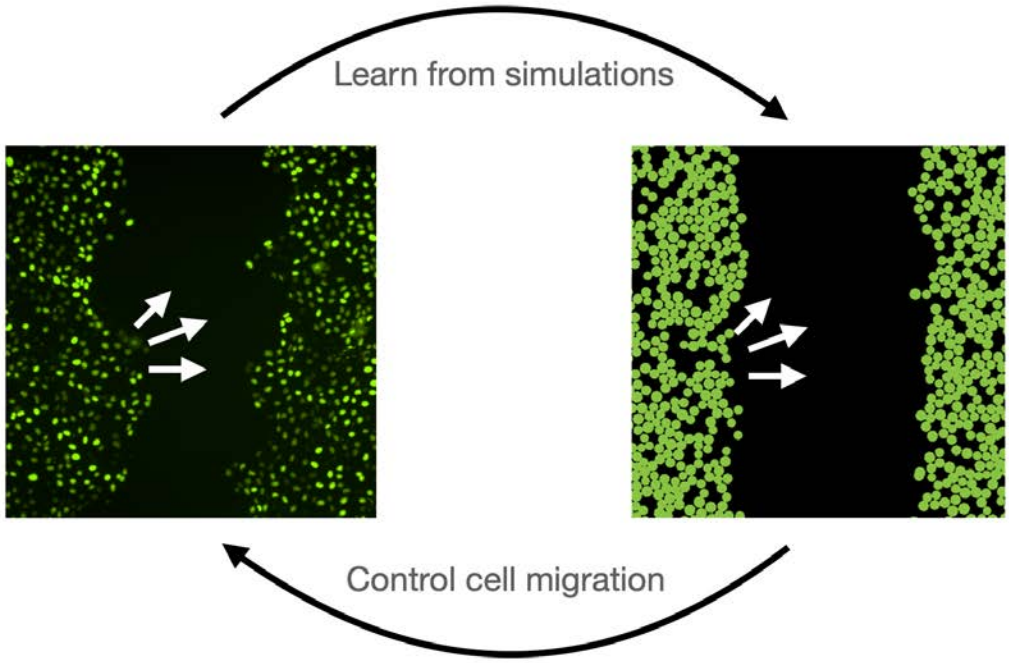


Figure 4 Wound healing modelling using machine learning for personalisation.

WP2 Conceptualisation of the wearable EPI-DOME.

Based on feedback from two doctors and our public outreach events, we designed the following two prototypes for a future EPI-DOME which could either be wearable (Fig.4 – left) or set on a table (Fig. 4 – right). LEDs were integrated to show users in future focus groups what it would feel like to wear/use the technology in their home. The wearable has the advantage of allowing users to walk freely while ensuring alignment with the location of the wound, and the disadvantage of needing to be specifically adapted to the location of the wound. On the other side, the desktop device could be useable for different locations of wounds, and has the advantage of being settled, which may help with calibration, although the body can more freely move in the device.

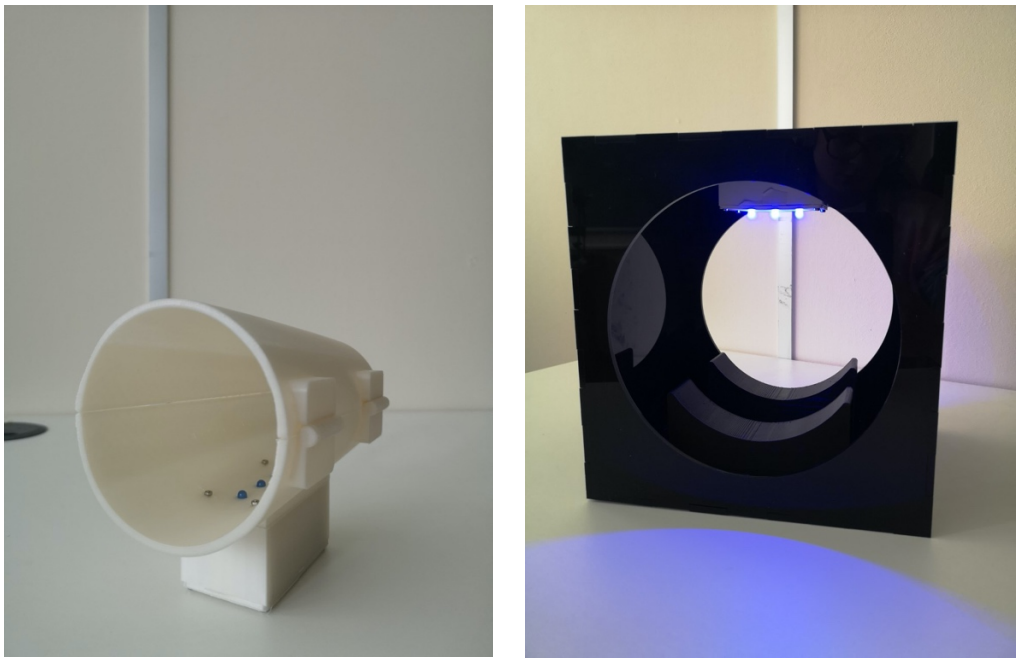


Figure 4 Prototype developed of a wearable and table-top device based on clinician and public feedback.

WP3 Empirical bioethics to design Trustworthy Autonomous Systems for cellular control.

There is growing recognition that the development of autonomous devices that are intended to interact with humans has the potential to raise serious ethical concerns. As such, early engagement with pertinent ethical considerations is important to the research and development process around such technologies.

To explore this, we engaged with two clinicians over several meetings and held a public engagement event online with 10 participants. A final in-person event is planned for after the end of the project at We The Curious (Science Museum) in conjunction with a large event organised by the Trustworthy Autonomous Systems Node in Evolving Functionality as a way to improve participant uptake (We The Curious recently suffered a fire which caused us to move the date back).

The feedback from attendees has helped us think about key ethical issues related to the EPI-DOME from the perspective of the potential user. This information has been explored alongside the ethical literature and considerations from the perspectives of other stakeholders in a publication that is fully drafted and will be submitted over the summer. The paper focusses on the most pertinent issues of safety, trust, opportunity cost, and justice. An initial draft is provided in appendix.

In addition to exploring ethical questions around the device. Our engagement with clinicians and the public was encouraging due to their general excitement about the technology, and many scenarios raised where this might be useful (chronic wounds, diabetes patients, elderly patients, scar reduction). Combining these areas of potential, with the careful ethical considerations outlined above, will be important to deploying such technology.

WP4 Exploration of the translation of the EPI-DOME through collaboration with Open Cell and engagement with the NHS.

We have been keeping OpenCell up to date about the progress of the project. In our most recent meeting with Javiera Pérez from OpenCell, she outlined help they could offer going forward with this project. We discussed the potential that in the future the space at OpenCell could be helpful. They are currently acquiring some more units, this time a floor in a disused retail centre which they are looking to equip with tissue culture and imaging facilities, she also said that if there was demand for more design-based tech such as 3D printers they would be open to that.
In the shorter term and throughout the project, she has been helpful disseminating our social media updates and public engagement events through their media team. She also offered to help us produce videos for publicity if needed. In addition, we've been exploring IP opportunities for the device with Caroyln Jenkins at University of Bristol. It was agreed that once closer to a prototype, we would be able to file internally for potential IP protection.

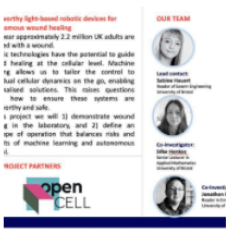
WP5 Engagement with the public through outreach activities.

The EPI-DOME was the subject of two podcasts (TAS organised) and a blog post (sent with this report). We also produced the website https://theopendome.org/ which hosts the open-source material needed to produce a DOME. You can find some useful youtube videos here: https://youtu.be/MaPmAVyvZIs

The work was also presented at the following conferences through keynotes and invited talks by Sabine Hauert:
TAS Pump Priming Launch
TAS-RUSI
Edinburgh CDT keynote
SIAM 2021
METNANO 2021
ICRA 2021 Workshop on micro-nano systems
IMA
KAUST
SWARM 2021
Reddit Showcase
Gatsby/SWC symposium
LS2 Systems Biology Meeting
NASA/JPL
AIRS in the AIR

In addition, Ana Rubio Denniss and Neshika Wijewardhane have given several talks in Bristol about their work on the project.

In addition, we have been active on social media. Project PIs and CO-Is have a combined 10k+ following on twitter for example.



Sabine Hauert @sabinehauert

TAS Pump Priming kick-off meeting is today. Excited to be one of 12 new research projects funded by the **@UKRI_News @tas_hub** Programme. We'll explore trustworthy light-based robotic devices for wound healing with **@arubiodenniss**, S. Henkes, **@epiddin**, **@chofski** & @jonathanives4 pic.twitter.com/erzAQy13PS

Impressions 5,176
times people saw this Tweet on Twitter

Total engagements 170
times people interacted with this Tweet

Outputs, Outcomes & Impacts

Outputs

Type	Description and Impact
Publication (accepted)	Accepted full paper at IEEE MARSS on "Long-term imaging and spatio-temporal control of living cells using Light" by members of the consortium: Neshika Wijewardhane, Ana Rubio Denniss, Matthew Uppington, Helmut Hauser, Thomas E. Gorochowski, Eugenia Piddini, and Sabine Hauert. This provides the proof of concept that we can run wound-healing experiments in laboratory settings, which was not possible at the start of the project.
Publication (fully drafted)	A paper on "Ethics and the EPI-DOME" describes ethical questions that will need to be explored in the development of the EPI-DOME by Jordan A. Parsons, Jonathan Ives, Ana Rubio Denniss, & Sabine Hauert
Publication (in preparation)	A paper on "Machine learning for automatic model fitting of epithelial cell models" describing the use of machine learning to model and control wound healing. This is in preparation as still waiting final results based on images from the EPI-DOME.
Research tools/method	New experimental setup that allows us to test closed-loop wound healing methods in the laboratory.
Ethics insight	New insight into questions that need to be explored to build trustworthy wearables for autonomous wound healing without clinical supervision.

Outcomes

Type	Description and Impact

ICRA 2021 workshop on swarming micro-nano systems	https://hauertlab.com/icra2021-workshop-on-micro-nano-swarm-robotics/ with 200 participants. This will result in a special issue of a journal on swarming micro-nano systems. https://www.springer.com/journal/11721/updates/20100598
The Open Dome Project	http://theopendome.org/ Open resources to produce a DOME and use it for scientific research.
13 Presentations (keynotes and invited talks) where EPI-DOME was mentioned	This has raised awareness about the project and enabled a broader engagement with the research community.

Submissions to Researchfish

We confirm that summary details of publication and other outcomes from the project have been submitted and/or will be submitted ahead of the submission deadline.
Yes – this was submitted and the new papers will be in the next submission.

Acknowledgments of TAS

We confirm that we have referenced funding (e.g., publications) in standard format: "This work was supported by the UKRI Trustworthy Autonomous Systems Hub (EP/V00784X/1)", or contracting to "TAS (EP/V00784X/1)" or (EP/V00784X/1) due to constraint of word limits
Yes

TAS Priorities & Themes

This project has contributed **"**to ensuring TAS improves rather than harms our physical wellbeing" by both designing new technology for future wound healing, and exploring ethical considerations so autonomous treatment without clinical supervision is deployed in a responsible manner.

Trust & Trustworthiness

- This project engaged with clinicians and the public through public engagement events, and with the bioethics literature, to produce a publication looking at bioethical considerations with the design of the EPI-DOME.

EDI

- We considered EDI in the bioethics work.
- 5/8 researchers on the project team were women.
- Action: Added EDI as a standing item on a regular meeting.

RRI

Ethics approval was granted to run the public engagement events. The work on bioethics also allowed us to explore RRI questions related to the design and future use of the EPI-DOME.

Advocacy & Engagement

- We've engaged with the TAS Node in Evolving Functionality by presenting at their weekly feedback and gathering feedback. Two Co-Is on this pump priming are also Co-Is on the TAS Node. We also presented the project at the TAS pump-priming kickoff meeting and RUSI meeting co-organised by TAS.

- We've engaged with clinicians and the public through our bioethics work.
- We've engaged with the wider research community through a workshop, 13+ presentations at conferences and events, and through publications.
- We've engaged with industry partner OpenCell and explored IP protection with University of Bristol to determine future translation opportunities.

Forward Look

Opportunities and plans to develop beyond the PP project.

- We are currently planning several larger grants to continue this work including an EPSRC Healthcare Technology Award, an NIH award, and EPSRC postdoctoral fellowships for Rubio Denniss.
- Rubio Denniss is also exploring translation opportunities with IAA awards, and OpenCell.

Reflection

I really appreciated that the scale of this project allowed for proper pump-priming of both the socio- and technical aspects needed to design autonomous wound healing devices. This would not have been possible without the resources to hire staff to work specifically on these questions.

Report Date: 05/06/2022

Appendix: Financial Statement Summary (Pump Priming Projects only)

Total Budget (80%fEC)		
Invoiced Costs		
Directly Incurred	Researcher(s)	46,139.87
	Researcher Co-Investigator(s)	6,587.61
	Travel and Subsistence	
	Other Costs	2,322.10
	Sub-total	55049.58
Directly Allocated	Investigator(s)	
	Estates	11,851.94
	Other Directly Allocated	713.22
	Sub-total	12565.16
Indirect Costs	Indirect Costs	67,825.34
TOTAL		135,440.09