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Human-swarm interaction via e-ink displays

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***Abstract*—This paper proposes the use of e-ink displays to enhance human-swarm interaction research, and presents example hardware for the e-puck robot. We outline potential applications, including the display of a robot's internal status, as well as the use of e-ink displays to create dynamic fiducial markers.**

***Index Terms*—Human-swarm interaction, e-ink, e-puck**

I. Introduction

Human-swarm interaction (HSI) research often concerns the control of swarm behaviour via gesture recognition, voice commands, or through a graphical user interface [1]. Without some form of external infrastructure, it is difficult to ascertain the internal state of individual robots, as the human operator relies upon visual feedback from the robots in the form of coloured LEDs, or sounds played through an on-board speaker. LCD, OLED, or TFT displays can be integrated into swarm robots to provide further feedback to the user, but electronic ink (e-ink) displays offer a number of advantages.

E-ink displays attempt to replicate the appearance of ink on paper, and have been used successfully to create e-book readers and smartwatches. The display technology is able to retain static text and imagery indefinitely without consuming power, offers wider viewing angles than traditional light-emitting flat panel displays, and is more readable in sunlight.

II. E-ink on the e-puck robot

The Pi-puck extension board [2] allows a Raspberry Pi single-board computer to be interfaced with the widely-used e-puck robot to enhance its computation, communication, and sensing abilities. The latest revision of the Pi-puck hardware was developed as a collaboration between the York Robotics Laboratory at the University of York and GCtronic, to support both the e-puck and e-puck2, and is available to purchase from GCtronic and its distributors.

By providing a common interface to 'pHATs' (add-on boards for the Raspberry Pi Zero), the Pi-puck's capabilities can be further extended by leveraging the Raspberry Pi ecosystem. This allows off-the-shelf products to be integrated with the robot, such as the Inky pHAT e-ink display from Pimoroni, as shown in Figure 1. This 2.13" display offers a resolution of 212x104 pixels, and three colours – black, white, and red (or yellow) for £24. The equivalent 2" Pi Supply PaPiRus Zero e-ink display (£30) could alternatively be used.

Text and images can easily be drawn to these displays from a Raspberry Pi via simple Python APIs that abstract the process of sending raw data to the display over SPI. The Inky pHAT takes approximately 5.5 to 8 seconds to refresh the display, depending on whether just black and white or three colours are used.

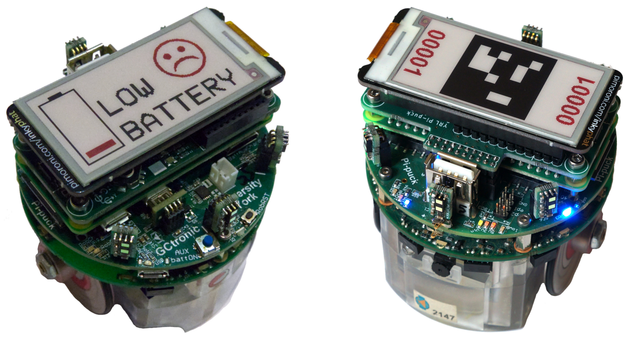

Fig. 1: Pi-puck robots with e-ink displays and example graphics. *Left:* robot status message. *Right:* ArUco tag and ID.

III. Potential applications

E-ink displays could be used to provide feedback on a swarm's internal state to a human operator at a glance. For example, the user could ask all of the robots to display their remaining battery level, and any reporting a low battery (as shown in Figure 1) could be selected for maintenance, or instructed to recharge. Block colours or simple iconography could also be used to display discrete internal states to a human experimenter, such as the current behaviour each robot is executing. Furthermore, these displays could be used to report infrequently changing information, such as the robot's ID or IP address. As an e-ink display does not consume power except when refreshing, it will continue to render the last drawn image if a robot's battery dies, or its control software crashes. This is useful for debugging a robot's behaviour if does not have the ability to log data externally, as status messages can remain on the screen to be read by a human operator.

This technology also has great potential for aiding HSI research through the display of dynamic fiducial markers. Static markers (i.e. those printed on paper/card and affixed to a robot) are widely used for tracking the pose of individual robots over time, but their use involves the manual allocation of tags to robots that does not scale well with increasing swarm size. The use of dynamic fiducial markers has recently been

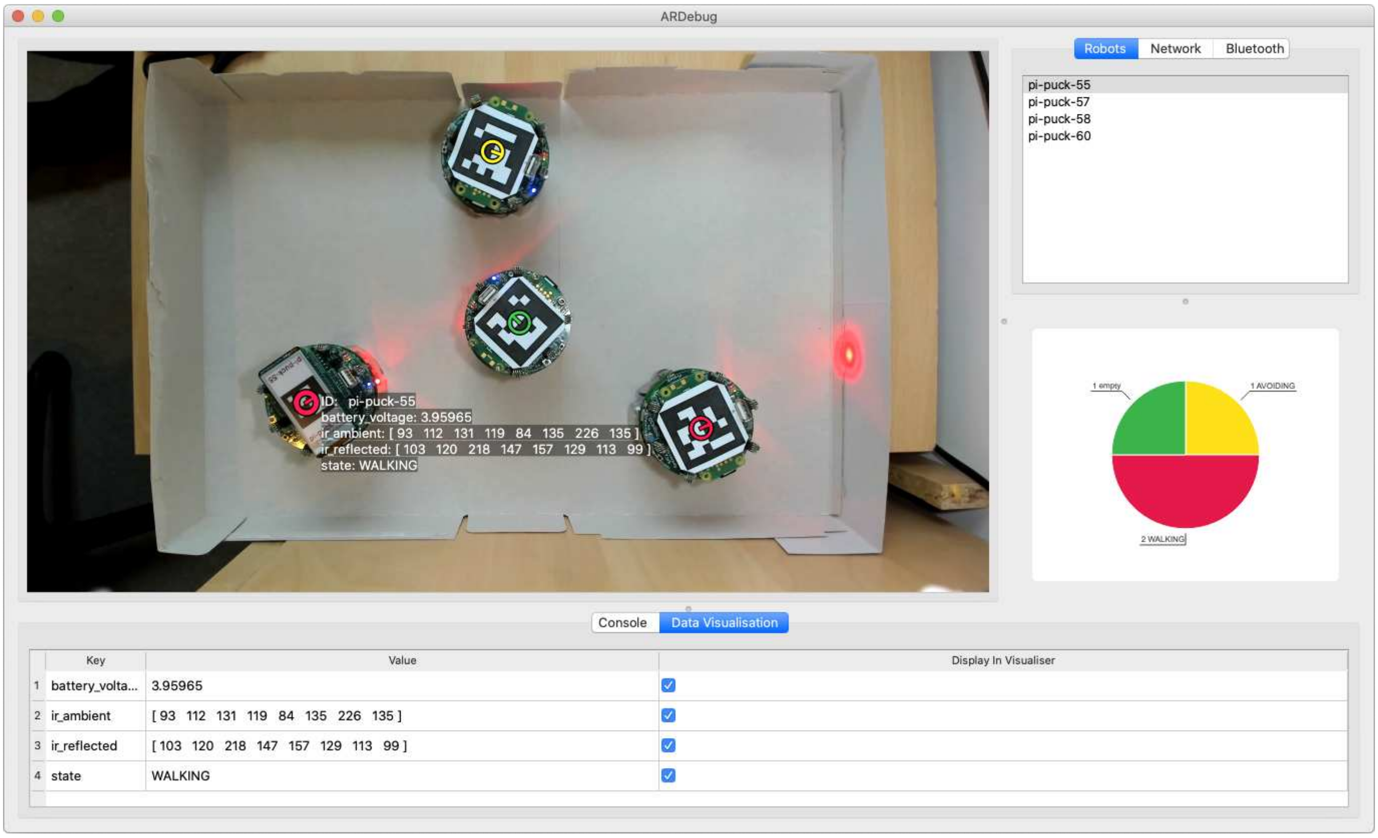

Fig. 2: Four Pi-puck robots integrated with ARDebug – three with static paper markers, and one with a dynamic e-ink marker.

proposed to aid UAV landing [3], and for indirect inter-robot communication in robot swarms [4], but may also be useful for integration with tracking systems.

We have used an e-ink display to integrate the Pi-puck with ARDebug [5] – an open-source, cross-platform, modular tool that allows the user to visualise the internal state of a robot swarm using augmented reality. The robot's e-ink display renders an ArUco tag (alongside a human-readable ID) that can be decoded by an overhead camera as shown in Figure 2, which is much easier for the camera to focus on and identify than a backlit display. These dynamic tags allow a human operator to reassign the IDs of each robot in a swarm, to more easily allocate them to sub-swarms that can then be given separate tasks. Dynamic markers also enable simpler debugging by allowing the user (or the swarm itself) to retire a faulty robot and substitute it for a working robot without having to physically exchange paper tags.

IV. Conclusions and Future Work

E-ink displays have great potential to enhance HSI research, as outlined in this paper. However, they are not without their limitations – their refresh rate is slow in comparison to other display technologies, so cannot be used to display fast real-time information. However, on certain models of display the responsiveness can be improved by updating only a small portion of the screen at once, or trading-off contrast and image ghosting for refresh rate. Being restricted to 2 or 3 colours also limits what can be displayed, and the cost of the hardware is high in comparison to traditional displays. Despite these drawbacks, e-ink is an attractive option for swarm robotics research due to its low power consumption and inherent compatibility with visual camera systems.

In future, we plan to integrate larger e-ink displays with various robot platforms, so that the information displayed on them can be interpreted from a greater distance, and experiment with iconography that can be easily interpreted by both human operators as well as machine vision systems.

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