Phygital Field: an Integrated Field with a Swarm of Physical Robots and Digital Images

Takefumi Hiraki*, Shogo Fukushima, and Takeshi Naemura

The University of Tokyo

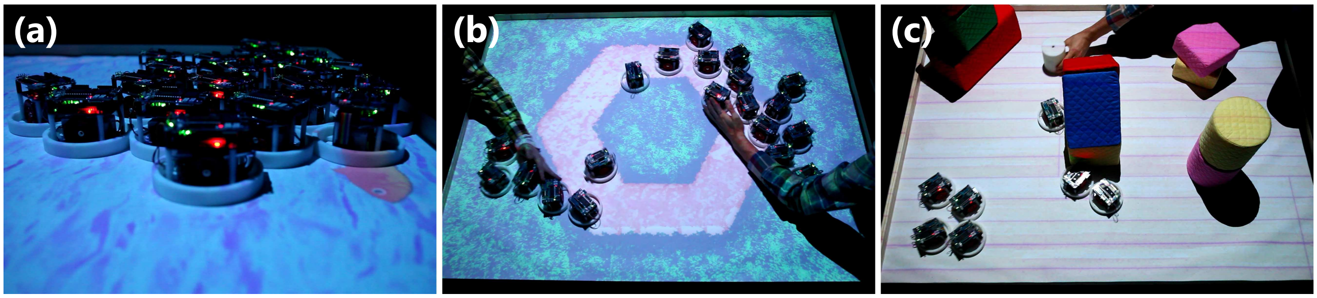

Figure 1: *(a) Appearance when a swarm of robots was controlled by coded light. (b) Appearance of the interaction between moving robots and users' hands. (c) Appearance when a user was manipulating a physical object and navigating robots in the field with real blocks.*

Abstract

Collaboration between computer graphics and multiple robots has attracted increasing attention in several areas. To preserve the seamless connection between them, the system needs to be able to accurately determine the position and state of the robots and be able to control them easily and instantly. However, realizing a responsive control system for a large number of mobile robots without complex settings and at the same time avoiding the system load problem is not trivial. Our system, called "Phygital Field", can project two types of information: visible images for humans and data patterns for mobile robots in the same location by utilizing pixel-level visual light communication (PVLC) technology. Phygital Field offers two technical innovations: an initialization-free and marker-free localization and control method, and a system noted for its simplicity and scalability. Phygital Field enables the robots to always recognize their own positions and states immediately, the measurement devices are not required because localization and control of the robots are realized through projection. These features are very important to improve the reconfigurability of the system. The idea of controlling robots by using information embedded in projected images allows users to easily design an integrated environment for the physical robots and digital images to preserve the seamless connection between them.

Keywords: Robot swarm, pixel-level visible light communication, digital micromirror device, high-speed projector, mixed reality

Concepts: •**Computing methodologies** → **Mixed / augmented reality;**

*e-mail: hiraki@nae-lab.org

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1 Introduction

Collaboration between computer graphics and multiple robots has attracted increasing attention in the area of human-computer interaction. The robots are utilized as a physical media, and they cooperatively work with computer-generated visual images by changing their states, such as position and rotation, caused either by human intervention or by themselves. Because robots can be physically manipulated, they are more intuitive than a conventional flat display. A requirement of the proposed system is that can determine the position and state of the robots accurately and can control them easily and instantly on various physical surfaces.

Two problems remain to be addressed to ensure seamless collaboration between computer graphics and multiple mobile robots. First, many of these robots utilize computer vision from the center system for localization by recognizing invisible marker patterns. However, it is necessary to fix the position of the cameras, calibrate them, and calculate the spatial location of robots in the camera images. The system named Augmented Coliseum [Kojima et al. 2006] approaches this problem by using display-based computing technology. This technology obviates the need for any position measurement devices, and it can support a large number of robots on the display; however, it requires prior initialization of tracking robots by marker-pattern images; thus, adding or removing robots is not allowed. Second, since independent control signals via wireless or wired communication are often required in conventional methods, the system load increases in proportion to the number of robots, which presents a scalability problem for controlling robots. Thus, realizing a responsive control system for a large number of mobile robots without camera calibration and at the same time avoiding the system load problem is not trivial.

We solved these problems by utilizing pixel-level visual light communication (PVLC) technology [Kimura et al. 2008]. PVLC is a data communication method based on human-imperceptible high-speed flicker from a high-speed digital light processing (DLP) projector. Utilizing this, our system can project two types of information: visible images for humans and human-imperceptible data patterns for mobile robots in the same location. Robots localize their self-position by decoding the information received via the projected light, which can therefore be used to control the robots. Thus, the system does not require measurement devices such as cameras or

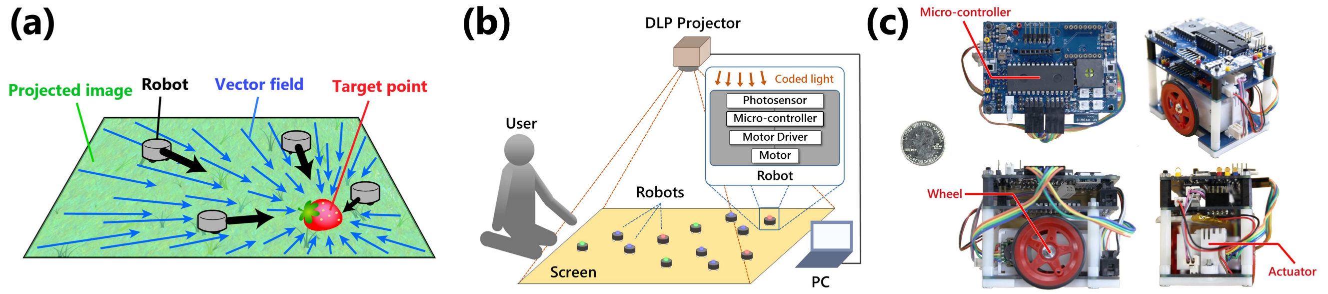

Figure 2: *(a) System concept of Phygital Field. Each pixel of the projected image contains the various information such as velocity vector field. (b) Overview of our system. (c) A prototype mobile robot (overall view is upper right, top view in upper left, side view in lower left, and front view in lower right).*

high load communication, since localization and control of robots are realized through projection. Furthermore, the robots can recover instantly from irregular users' manipulation since positional deviation between images and robots does not occur in principle.

2 Technical Innovations

Our proposed "Phygital Field," which is based on our basic concept [Hiraki et al. 2015], integrates physical movement with a digital display by enabling a swarm of mobile robots to interact with computer graphics. The robots are controlled by way of projection-based localization. Compared with previous work, Phygital Field offers two technical innovations: an initialization-free and marker-free localization and control method, and a system noted for its simplicity and scalability.

The first of these innovations, an initialization-free and marker-free method, enables the robots to always recognize their own positions and states immediately by interpreting data patterns in pixels. This feature allows the robots to recover instantly from irregular user manipulation such as brushing aside and obstructing. Furthermore, users can add and remove robots at will and control robots without the need for positional displacement.

The second innovation, i.e., the simplicity and scalability of the overall system, is implemented by designing the system such that measurement devices are not required, because localization and control of the robots are realized through projection. The fact that the robots require only photo detectors for sensing means that they can be built to a very small size. These features are very important to improve the reconfigurability of the system. In addition, the central system load does not increase if the number of robots increases, since PVLC can be regarded as highly parallel communication channels.

3 Implementation

Figure 2 (a) shows a concept of Phygital Field. Each pixel of the projected image contains various information such as the two-dimensional coordinates or velocity vector field. The localization and control of robots can only be performed by this projected information. In the proposed method, we specified various target points and designed the velocity vector field to serve as convergence pattern to these points. Figure 2 (b) shows an overview of our system. Our system comprises a PC, a full-color DLP projector (ViALUX STAR-07), a display screen, and robots. The PC generates binary frames, which include data frames for localization and for controlling the robots, after which the DLP projector projects these binary frames. We developed the robots that receive the light from the projector, and move in accordance with the embedded information in each pixel. An appearance of a robot is shown in Figure 2 (c).

4 Application

We created some applications involving a swarm of robots and visible projected images by designing two types of affection to robots. An appearance of a swarm of robots is shown in Figure 1 (a).

Figure 1 (b) shows an application in which robots are affected by the virtual environment. The brown and green areas displayed in the image are intended to imitate a circular road and forest, and two types of velocity vector fields were embedded in each zone. All of the robots moved rapidly towards the road following which they proceeded clockwise along the road. The robots followed these instructions even when we attempted to use our hands to obstruct their movement, thereby confirming that they are only controlled by information they receive via the projection.

Figure 1 (c) shows an application in which robots encounter a real environment, which has the spatially and temporally varying code embedded in visual images. By manipulating the physical target, the user is able to navigate the robot swarm while avoiding physical blocks. The orientation of a robot becomes disordered when it collides with a block; however, the characteristics of the system allow it to continue along its intended path.

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