# Mixed Reality Cyber-physical Systems Control and Workflow Composition

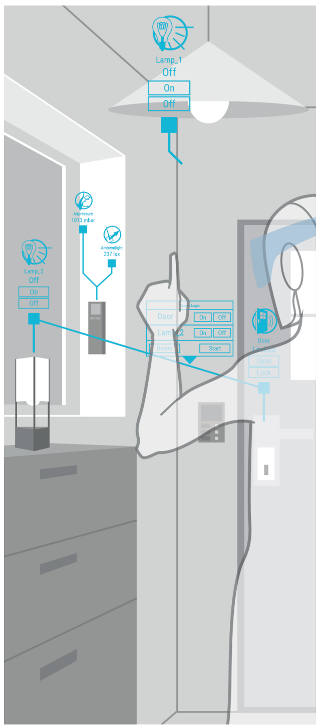

Figure 1: HoloFlows: sensor and actuator visualizations and control and workflow composition.

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## Abstract
With the emergence of Cyber-physical Systems (CPS) more and more smart devices become parts of our daily lives–letting us sense and control our physical surroundings via software. However, with the number of smart devices raises the complexity of understanding and managing all devices and processes within one’s vicinity. In this demo we present the *HoloFlows* mixed reality app, which allows users to directly explore, monitor and control physical devices within their surroundings. Simple workflows can be created between sensors and actuators to automate repetitive tasks in an end-user friendly way. We use gestural embodied interactions combined with real world metaphors to provide an intuitive and easy to learn interactive application for controlling complex CPS.

## Author Keywords
Mixed Reality; Cyber-physical Systems; Workflows; Natural Interaction

## ACM Classification Keywords
H.5.m [Information interfaces and presentation (e.g., HCI)]: Miscellaneous

## Introduction
With the current developments in the Internet of Things (IoT) many new sensors, actuators and processing units

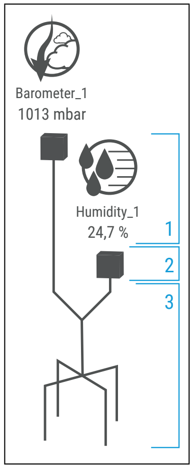


**Figure 2:** Sensors: 1) Info Panel; 2) Connector Box; 3) Anchor Box.

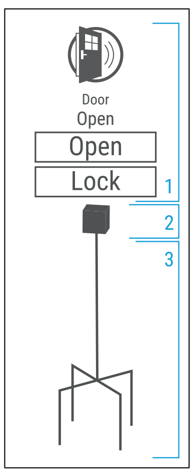


**Figure 3:** Actuators: 1) Info Panel; 2) Connector Box; 3) Anchor Box

are embedded into everyday devices leading to our surroundings becoming smarter and smarter. This trend facilitates the emergence of so-called *Cyber-physical Systems* (CPS)–systems consisting of mutually influencing virtual and real world components [12]. A smart home is a typical example of a CPS, which may have numerous sensors, actuators, things and virtual software components interacting with each other. Visualization, management and control of all devices and processes in a CPS becomes increasingly complex with the number of devices and entities [1, 13].

“Traditional” applications for managing CPS are based on control center and dashboard approaches [9], which usually present an abstract overview of all devices and processes and let users explore these entities individually [16, 8, 2]. However, these approaches require a conceptional understanding of the physical structures, context and functionalities of the CPS and individual devices, which rely on rather complex, abstract information [11]. Especially in smart homes users need an intuitive, end-user friendly way to ubiquitously explore and manage their environment including the visualization and control of devices and the definition of interactions (workflows) among these devices [12].

In this demo we present *HoloFlows*[1] as a mixed reality CPS control and workflow composition app using the Microsoft HoloLens smart glasses in a smart home setting. By applying holographic technology we place information about and options for interacting with the CPS devices at the respective physical location of the device. We provide means for an intuitive hands-free immersive exploration of the smart space and a natural control of devices using gestural interactions and everyday metaphors [4]. In addition users are able to compose and execute workflows among the devices to automate processes and create new interactions.

[1] https://github.com/IoTUDresden/HoloFlows

## Cyber-physical Systems Control

The main building blocks of CPS are sensors and actuators that interact with the physical world as well as complex combinations of sensors, actuators and processing units embedded into physical objects and devices. Compared to purely virtual software applications the physical context and the interactions of physical and virtual components play an important role in CPS. We exploit the physical location of CPS devices–*Sensors* and *Actuators*–to facilitate the exploration and understanding of the states, available functionality and processes within complex CPS settings. The current states of sensors and actuators as well as control functionality for actuators are presented within HoloFlows as a holographic box and information panel above the devices’ physical location (cf. Figure 1). The underlying data and the linkage of the control options to the actual control software are provided by a central IoT middleware that all devices are connected to and unified by [17, 3].

We use semi-transparent holograms of boxes as virtual anchor points that can be attached to the physical devices. The boxes are placed at the physical location of the respective device using the spatial perception feature of the Microsoft HoloLens. An information panel is connected with the anchor box via a line and shown above the box. This info panel presents a device specific icon and the device’s name. Multiple branches with info panels can be connected to one anchor box in case the physical device hosts multiple sensors and/or actuators (cf. Figure 2). The info panels are always directed towards the user’s gaze.

*Sensor Visualization*

Sensors are able to measure physical properties, e. g., illumination, temperature or humidity. They can be standalone sensors or built in to other more complex devices. Besides a type specific icon and the sensor’s name, the info panel

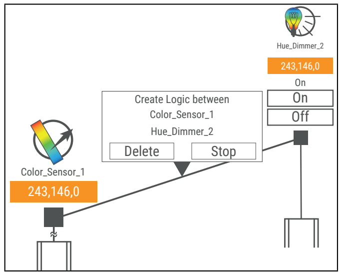


**Figure 4:** Direct Sensor–actuator workflow.

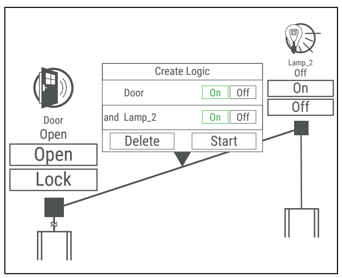


**Figure 5:** Actuator–actuator workflow.

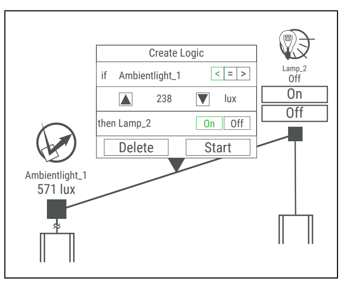


**Figure 6:** Conditional Sensor–actuator workflow.

presents the current value of the particular sensor as provided by the IoT middleware (cf. Figure 2).

*Actuator Control*
Actuators are able to influence the physical world by executing commands. The info panels also present a type specific actuator icon, its name and its current state. In addition virtual buttons representing the actuator’s individual commands (e. g., *On/Off* for a light switch or *Open/Close* for a door lock) are shown (cf. Figure 3). With the Microsoft HoloLens users apply gaze and head movement to control the focus pointer. Once focused the individual button is highlighted; and activated via a simple air tap gesture, which leads to the triggering of the actuator command via the middleware.

## Mixed Reality Workflow Composition

Besides direct monitoring and control of CPS devices, interactions and workflows among these entities become increasingly important for the automation of processes in CPS [14]. Connecting two or more devices to create workflows usually requires a graphical workflow editor or even programming skills as the devices are not designed to interact with others [15, 7]. Our mixed reality app HoloFlows supports the creation of simple workflows and rules between devices in CPS. To establish such a connection a small box below the info panel of the respective device can be selected via air tap. The user selects the first device’s connector box and then the second device’s connector box, which creates a virtual connection between both devices–in analogy with running a physical cable between the devices (cf. Figure 1). To avoid unintentional behaviour the user can activate, deactivate and delete a connection once it has been created. We also perform a simple form of constraint checking to prevent certain types of connections (e. g., between two sensors or between an actuator as first and a sensor as second device) as they are not supported yet. Depending on the types of the first and second device we distinguish between three types of workflows:

*1) Direct Sensor–Actuator Workflow*
Direct Sensor–Actuator Workflows can be created between devices whose states can be directly mapped to each other (cf. Figure 4). The first device is a sensor (e. g., a potentiometer or color sensor) and the connected device is an actuator (e. g., a light dimmer or hue lamp). Changes within the sensor values will be mapped to the state of the actuator by calling the corresponding operations to increase, decrease or set its current state.

*2) Actuator–Actuator Workflow*
Actuator–Actuator Workflows are created between two actuators. After connecting the first and the second actuator, a configuration panel is shown to configure the connection. Here, the user selects the operations of the first and the second actuator to be executed as part of the workflow (cf. Figure 5). Once the workflow is activated these operations are executed in sequence in the order of first device operation and then second device operation.

*3) Conditional Sensor–Actuator Workflow*
The HoloFlows application also supports the creation of conditional Sensor–Actuator Workflows in the form of simple *Event-Condition-Action* (ECA) rules. Connecting a sensor as data source with an actuator as target opens up a new configuration panel to set the corresponding event, condition and action (cf. Figure 6). The event corresponds to the current value of the particular sensor. The condition can be set with respect to that value by selecting a comparison operator (smaller, bigger, equals) and by increasing/decreasing the threshold of the sensor value for this condition to become true. The last step consists of selecting the actuator operation that should be executed once the

condition is true. Once the workflow is activated the sensor value is constantly monitored and checked with respect to the pattern defined in the condition. If the condition becomes true the operation is executed once and the connection becomes inactive.

*Complex Workflow Execution*
Although the three types of workflows described in the previous sections are relatively simple as they only connect two devices with each other, more complex workflows can be created using our application by event-driven chaining of multiple connections. An example of this chaining of an actuator–actuator workflow and a conditional sensor–actuator workflow could be the scenario *Coming Home*: the actuator–actuator connection defines that first the door should be opened and then the light should be switched on; the conditional sensor–actuator connection defines that when the light levels increase and reach a certain threshold due to the switching on of the light, the coffee maker should start brewing coffee.

The execution of the workflows is currently done directly on the end-user device (Microsoft HoloLens) as the underlying execution logic is relatively simple. We are currently working on exporting the workflow definitions to a more formal process notation to be able to also execute the processes on a standalone workflow management system. In accordance with the process meta-model presented in [15], the actuator–actuator workflows can be mapped to a sequence of REST service calls as the IoT middleware exposes the device functionality via a REST API. The conditional sensor–actuator workflows can be mapped to a *TriggeredEvent* process step that contains the pattern of the condition as an *EPL* statement [15]. With these mappings we are able to also execute the processes using the *PROtEUS* process execution system [14].

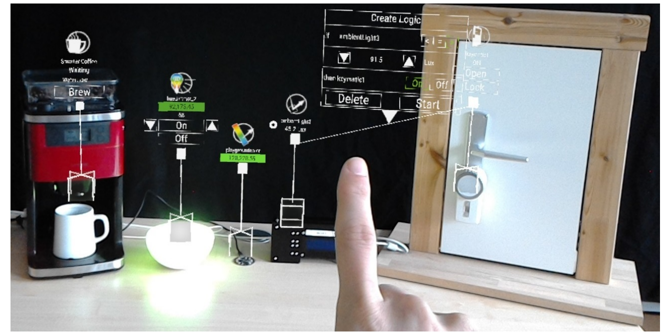


**Figure 7:** Live demo interactions with HoloFlows.

## Demo
Users can interact with our IoT infrastructure consisting of various sensors and actuators via the HoloFlows mixed reality app for direct CPS control and workflow composition using the Microsoft HoloLens smart glasses as described in previous sections (cf. Figure 7).

*Hardware*
We have the following set of sensors available for interaction: humidity, temperature, air pressure, illumination, color sensor, potentiometer, NFC reader, Myo gesture control armband. We have the following set of actuators available for interaction: dimmer switches for lights and fans, hue lamps, a light and sound gong, a coffee maker, a door lock mounted on a miniature door. Known sensors and actuators can be connected/disconnected from the IoT middleware, which also makes them appear/disappear in the holographic scene. The IoT middleware *OpenHAB* is running on a dedicated computer, which is connected to all devices via LAN or WiFi. It also provides a Web interface to interact with the sensors and actuators in a traditional way. The Microsoft HoloLens is connected to the middleware via WiFi.

*Configuration Mode*
The HoloFlows app can be used in two modes. The *Configuration Mode* lets the user position the anchor boxes with respect to the physical locations of the corresponding devices. For a more convenient demo we are relying on the spatial perception feature of the Microsoft HoloLens, which enables a static positioning of holograms. Optical live tracking of CPS devices is currently not supported by our application as it is still very unreliable and expensive with respect to computations–especially when dealing with multiple devices that need to be tracked within the scene.

*Normal Mode*
In *Normal Mode* the user interacts with the app as described in the previous sections. Anchor boxes are positioned statically in relation to the physical devices. In case one of the devices is moved in the physical world, a manual repositioning has to be performed in *Configuration Mode*.

## Discussion & Conclusion

Our HoloFlows prototype combines mixed reality technology with gestural, embodied interaction to provide users with an intuitive, easy to use and easy to learn way of exploring and controlling the cyber-physical environment. The physical location of devices plays a key role when interacting with CPS as they are able to directly influence their surrounding physical world. In comparison with classical control center approaches, augmented reality facilitates the user's ability to correlate the physical effects with the control actions. The smart glasses enable a hands free, mobile exploration and monitoring of available devices and provided functionality in a user friendly way [6]. In order to control these devices, we apply everyday metaphors (e. g., virtual buttons to switch devices on or off; or the running of virtual cables between two devices to connect them). This leads to an easier understanding and mastering of the application.

The focus of our demo is smart homes as examples of CPS. Here end-users need to be presented with intuitive and easy to understand user interfaces, which we provide with our demo application. The semantics of the connections between the CPS devices (i. e., Do they make sense?) are up to the user. The definition of conditional sensor–actuator workflows requires more knowledge about basic end-user programming though. The suitability of our concepts for other more complex CPS domains (e. g., automotive or production) needs to be further evaluated [10]. Information and control options become increasingly complex in these domains, which is why the information panels may become highly complex very quickly. Abstractions and simplifications have to be introduced in order to remedy this information overload. However, this may reduce important information and functionality to a point where the CPS cannot be explored or controlled anymore. The usability requirements in these domains differ as they are targeted towards domain experts and not smart home residents [10].

With this demo we contribute an intuitive mixed reality application, which facilitates the mobile and ubiquitous exploration and control of CPS and their elements based on their physical locations. The application's workflow composition feature provides an easy to use way for end-user programming of automated processes without relying on complex and abstract editors or development environments. Future work will include an extension of supported workflow elements, sensor and actuator combinations, as well as the application of HoloFlows in smart factories and facilities [5].

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