

# Demo: Immersive Remote Monitoring and Control for Internet of Things

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## ABSTRACT

The Internet of Things (IoT) interconnects a vast number of physical devices with each other and enables remote monitoring and control of the physical system. This, together with the recent progress of virtual reality (VR) technology, provides an immersive experience for the user to perform remote monitoring and control as if she observes and controls the physical system in person. In this demo, we develop an immersive remote monitoring and control system consisting of 3D virtual monitoring and control panel and the physical water pump system. Users can remotely control and monitor the water level of the physical water pump system through the 3D virtual panel in real-time. We use Fourier transform to filter out the noise when the water level remains static and the exponential running average method to make the collected data more smooth when the water level dynamically changes. The experimental evaluations demonstrate that the difference between the physical and virtual water levels is small in both static and dynamic water levels.

## CCS CONCEPTS

• **Software and its engineering** → **Internet of Things**;

## KEYWORDS

Virtual Reality, Internet of Things

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## 1 INTRODUCTION

The Internet of Things (IoT) enables the remote monitoring and control of physical systems [3], which not only makes our life more convenient but also greatly improves work efficiency. On the other hand, virtual reality (VR) creates a new environment and

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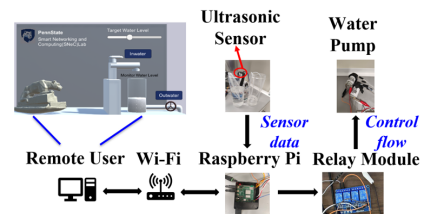
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provides an immersive and interactive experience for users [2]. It has received significant attention in recent years due to its wide applications in education, training, 3D design, and entertainment. The integration of VR and IoT naturally spurs immersive monitoring and control as if the user observes and controls the physical system in person. This has two significant advantages: i) it enables remote working without sacrificing work productivity; ii) it can leverage expertise worldwide.

In this demo, we prototype an immersive remote monitoring and control system consisting of a 3D virtual remote control and monitoring panel and a physical water pump system. In addition to providing the same functionality as the traditional IoT system (e.g., controlling and monitoring the water level), our system allows the user to interact with the virtual control and monitoring panel as if she is in front of the physical water pump. In order to provide an immersive and interactive experience for the user, we need to minimize the discrepancy between the physical water level and its virtual counterpart at any time instant. This is challenging due to the noisy sensory data. In the case of static water level, we use Fourier transform to denoise the sensory data, resulting water level measurement error of less than 1 mm. In contrast, in the case of dynamic water level, the sensory data changes significantly and has rich frequency components, yielding it hard to filter out the noise. As such, we directly apply the exponential running average to the noisy sensory data and use it to adjust the virtual water level accordingly, which significantly mitigates the discrepancy between the physical and virtual water levels.

## 2 SYSTEM ARCHITECTURE



**Figure 1: System Architecture.**

Fig. 1 illustrates the architecture of our developed immersive remote monitoring and control system. In our system, a user can remotely control and monitor the water level of a physical water pump system by interacting with a 3D virtual panel as if the user is in front of the physical system. In particular, if a user would like to increase the physical water level, she turns on the virtual tap by using her VR headset and controller. This results in an increase in the virtual water level. The virtual water level value is then sent to the physical water pump system via a network, which sets the physical water level the same as the virtual water level. Moreover,

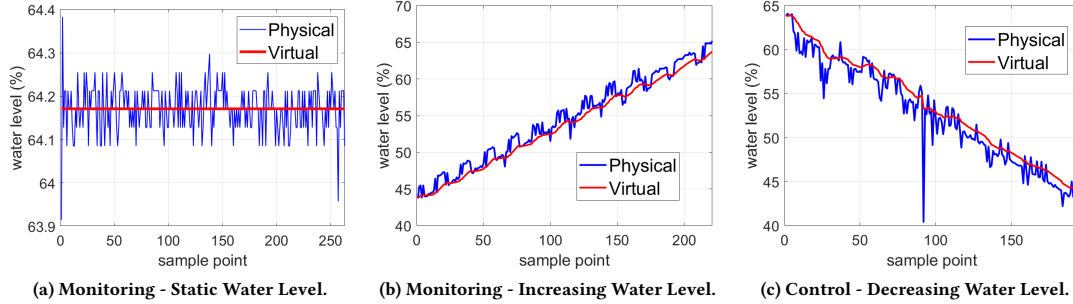


Figure 2: Performance Evaluation.

the physical pump water system constantly monitors the water level by using an ultrasonic sensor and sends its value to the server via a network. Then, the 3D virtual panel sets the virtual water level the same as the physical water level. The detailed designs are further discussed below.

**Physical Prototype:** The physical water pump system consists of a Raspberry Pi serving as a controller, two plastic jars, two water pumps, a relay module, an ultrasonic module, and two silicone tubes. The ultrasonic module is placed on top of one plastic jar and constantly monitors the physical water level. In the remote monitoring mode, an onsite user can directly adjust the water level via the user interface in the Raspberry Pi, which communicates with a remote user with the VR headset. In the remote control mode, the Raspberry Pi receives the desired water level from a remote user and adjusts the physical water level accordingly. In both working modes, the ultrasonic sensor needs to constantly measure the physical water level and inevitably introduces measurement errors. We drop measurements with obvious mistakes, e.g., negative water levels or water levels larger than the height of the plastic jar.

**Virtual Panel:** In order to provide an immersive experience for remote users as if they are onsite, we develop a 3D virtual water control system in Unity, including a table, a tap, a valve, and a jar. Then, we deploy this 3D virtual system in Oculus such that the user can interact with those virtual models through the Oculus controller. In the remote control mode, the virtual system has the same functionality as its physical counterpart. In particular, a remote user can turn on the virtual tap to increase the water level or the virtual valve to reduce the water level. Moreover, the user can directly control the water level via a virtual slider. The desired water level is then sent to the Raspberry Pi which sets the physical water level accordingly. In the remote monitoring mode, the virtual system receives the physical water level measures from the Raspberry Pi and sets the virtual water level accordingly.

### 3 DEMONSTRATION

We have implemented our system design. Particularly, the 3D virtual control and monitoring panel is deployed on an Oculus Quest 2 that connects to a Dell Precision 7920 workstation through a wired cable; the Dell workstation communicates with the Raspberry Pi 3S via WiFi that controls and monitors the physical water pump system. The Dell workstation is equipped with an Intel Xeon Gold 6242R CPU @ 3.10GHz, NVIDIA Quadro RTX 5000 Graphics Card ×2, 128 GB RAM, and Windows 10 Enterprise. A TPLink Archer AX50 is responsible for wireless communication. The physical water pump system includes two jars, two Gikfun 12V DC Dosing pumps, a

JBtek 4-channel DC 5V relay module, and an HC-SR04 ultrasonic sensor. Each jar has a capacity of 40 oz, and its height is 23.5 cm. A demo video is available at [1].

We evaluate the performance of our system in both remote control and monitoring modes, as shown in Fig. 2. In all experiments, the ultrasonic sensor samples the water level every second. In the remote monitoring mode, there are two cases: i) static water level: the Raspberry Pi constantly monitors the water level that does not change over time; ii) increasing water level: the Raspberry Pi increases the water level and sends the update to the Dell workstation. In the case of the static water level, we use Fourier Transform (FT) to filter out the noise and obtain the denoised water level, as shown in Fig. 2a, which is very close to the manual physical water level measurement with an error less than 1 mm. In the case of increasing water levels, the water level measurements change significantly and have rich frequency components, rendering it hard to filter out the noise. As such, we apply the exponential running average with a parameter of 0.1 to the water level measurements, obtain the denoised water level and adjust the virtual water level accordingly. We can observe from Fig. 2b that the virtual water levels match the physical water levels quite well. However, it is hard to manually measure the physical water level, and thus is hard to quantify the discrepancy between the physical and virtual water levels. In the remote control mode, remote users set the desired water level through the virtual panel, and the Raspberry Pi adjusts the water level accordingly. We use the same denoising technique to the decreasing water level. As shown in Fig. 2c, the measured water level has more noise than that in the remote monitoring mode, but the physical and virtual water levels are also well matched.

### 4 CONCLUSION

In this paper, we developed an immersive remote control and monitoring water pump system. In our system, a user can remotely control and monitor the physical water level by directly manipulating the 3D virtual panel in her VR headset. Our experimental evaluation demonstrated that the discrepancy between the physical and virtual water levels is small.

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