HomeTalk: A Smart Home Platform

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Abstract. This paper utilizes an IoT platform called IoTtalk to shape "consideration" into a house to make it a smart home. The developed project is called HomeTalk that serves as a platform to accommodate various smart applications in a house. We describe the following HomeTalk applications. The PlantTalk application takes care of house plants. The FishTalk application provides fish comfortable life in the fish tank at home. The BreathTalk application detects the number of people in a room, which also purify the air. The TheaterTalk application uses home and special appliances to create the effects for a 4D experience theater at home. The FrameTalk application allows a painting frame to interact with people in a house. The GardenTalk application provides smart gardening. Then we show how these applications share the sensors and actuators in the house. In the future, we will integrate them through an award winning project called Orchid House.

Keywords: Internet of Things · Smart home applications · Sensor integration

1 Introduction

Victor Marie Hugo said: "Architecture is the great book of humanity". Indeed, the architecture design determines the personality of the house. For example, we may say "consideration is what makes a house a home". This paper utilizes an Internet of Things (IoT) platform called IoTtalk [1] to shape "consideration" into a house. The developed project is called HomeTalk that serves as a platform to accommodate various smart applications in a house. We will describe the following HomeTalk applications: PlantTalk takes care of house plants. FishTalk provides fish comfortable life in the fish tank. BreathTalk detects the number of people in a room and produces fresh air if needed. TheaterTalk uses home appliances to create the effects for a 4D experience theater at home. FrameTalk allows a painting frame to interact with people in a house. GardenTalk provides smart gardening.

In [2], the authors described how to integrate the functionalities of Philips Hue light bulb and Nest Thermostat, as well as other sensors and actuators. The applications are a subset of HomeTalk. In [3] the authors identified the various home automation applications that are also a subset of HomeTalk. Furthermore, the authors emphasized on energy

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conservation, but did not give any details. The Orchid House of HomeTalk will show how energy conservation can be achieved. In [4], the authors described how to build smart home applications using the FLIP solution [5] based on Arduino Nano [6]. Similarly, the control for HomeTalk is developed through ArduTalk [7] that accommodates Arduino, MediaTek LinkIt Smart 7688 duo, ROHM IoT kit and ESP8266 ESP-12F. Security is an important issue for IoT, which is out of the scope of this paper. In [8], the authors addressed the security issues for smart home. The IoT security management system (SMS) is used to handle a large number of devices [9]. The SMS can also be used in HomeTalk.

This paper is an overview on several IoTtalk-based smart home applications we published recently. The paper is organized as follows. Sections 2–7 describe 6 smart home projects that were already published in journals. All of them are sustainable applications in daily operation. Section 8 outlines how these smart home applications will be integrated in the Orchid House built by National Chiao Tung University (NCTU).

2 The PlantTalk Application

Houseplants give a heartfelt look, which change the atmosphere and feel of the home. They also remove chemical vapors to assist cleaning the air to possibly enhance the living quality. However, to take care of houseplants may be tedious for the home owner. With the IoT technology, plant sensors and actuators can simplify the caring tasks of houseplants. An example is the hydroponic plant box in PlantTalk illustrated in Fig. 1 [10]. In PlantTalk, the actuators are automatically controlled by the sensors. Six sensors and nine actuators are deployed for the plant box.

Fig. 1. The hydroponic plant box

Figure 2 shows the PlantTalk functional block diagram, where the sensors values (Fig. 2 (1), (4), (6), (8), (11), (12), (17), (18)) are read from the input pins of the control board (based on Arduino, ESP8266 ESP-12F, and so on) to the HomeTalk server (Fig. 2 (2)) through WiFi or NB-IoT, and the server gives instructions to the actuators through the output pins of the control board (Fig. 2 (3), (5), (7), (9), (10), (13), (14),(15), (16)).

The pH sensor (pH-sensor in Fig. 2 (1)) indicates the quality of the water. In [10], the optimum pH of the water for misting is 5.5 to 7. When the tap water quality is out of the "sweet spot" pH range, the HomeTalk server (Fig. 2 (2)) activates the Reverse Osmosis (RO) actuator (Fig. 2 (3)) to improve the water quality.

The temperature sensor (Fig. 2 (4)) monitors the room temperature. Most plants prefer a temperature between 60 °F–80 °F. When the temperature is higher than 80 °F, the Fan actuator (Fig. 2 (5)) is activated to cool down the water.

Most plants grow better with a little bit more humidity. The humidity sensor (Fig. 2 (6)) monitors if the air in the room is too dry. If so, the sprayer (Fig. 2 (7)) is activated to mist the plant leaves to increase humidity so that dryness of leaves can be mitigated.

Old water loses oxygen and should be replaced by fresh water. The Dissolved Oxygen (DO) sensor (Fig. 2 (8)) is used to determine if the old water should be drained out by the drain pump (Fig. 2 (9)) and the fresh water should be sucked in by the suction pump (Fig. 2 (10)).

In hydroponic planting, most of the roots should be submerged below water. Therefore we use water level sensor (Fig. 2 (11)) to determine how much water should be added. When the water level is too low, the suction pump is activated.

A software timer (Fig. 2 (12)) is used to trigger the actuators for routine jobs such as nutrition and the photosynthesis process. PlantTalk exercises the Nutrient Film Technique (NFT) where the suction motor (Fig. 2 (13)) pumps the nutrient solution into a grow tray to be absorbed by the plants when the nutrient solution passes through their roots.

For the photosynthesis process, plants need to be exposed to sunlight for at least six hours a day. If the hydroponic plant box cannot access to direct sunlight, light fixtures is required. The software timer periodically activates the white LED (Fig. 2 (14)) for this purpose.

The beauty of PlantTalk is that the plants enhance the air quality of the house through the photosynthesis process. The CO2 and O2 sensors (Fig. 2 (17) and (18)) monitors the air quality. When CO2 is too high, the photosynthesis process is activated by turning off LED-W (white light; see Fig. 2 (14)) and turning on the red light LED-R (Fig. 2 (15)) and the blue light LED-B (Fig. 2 (16)) to speed up the photosynthesis process that transforms CO2 and water into carbohydrates and O2. More details can be found in [10].

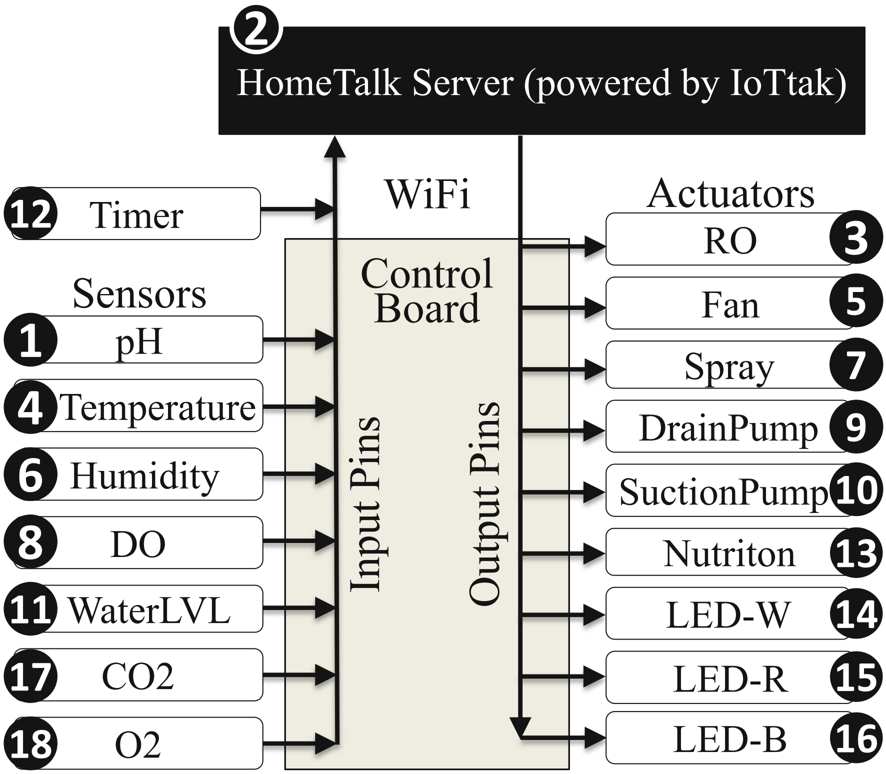

Fig. 2. PlantTalk functional block diagram.

3 The FishTalk Application

A fish tank is a pretty and lively decoration for a house. Watching fish has the calm effects to reduce stress. The IoT technology can further amplifies these effects. For example, a remote food feeder allows the home owner to watch fish feeding at any time in any place. As an example, Fig. 3 illustrates the smartphone display for FishTalk [11], where a camera provides video streaming in the display (Fig. 3 (1)). The camera can be zoomed in and out (Fig. 3 (2)) and moved left and right (Fig. 3 (3)). The dashboard shows all sensor values such as temperature (Fig. 3 (4)) and pH (Fig. 3 (5)). There is also a control panel that allows the user to control the actuators such as the heater (Fig. 3 (6)) and the fan (Fig. 3 (7)).

Figure 4 shows the FishTalk functional block diagram. The temperature sensor (Fig. 4 (1)) monitors the water temperature. For most fishes, the optimal temperature ranges from 77 °F to 80.6 °F. When it is hot, the fan (Fig. 4 (2)) is activated to blow across the surface of the tank water to increase evaporation and therefore cool down the water. When it is too cold, the heater is activated (Fig. 4 (3)) to warm up the water.

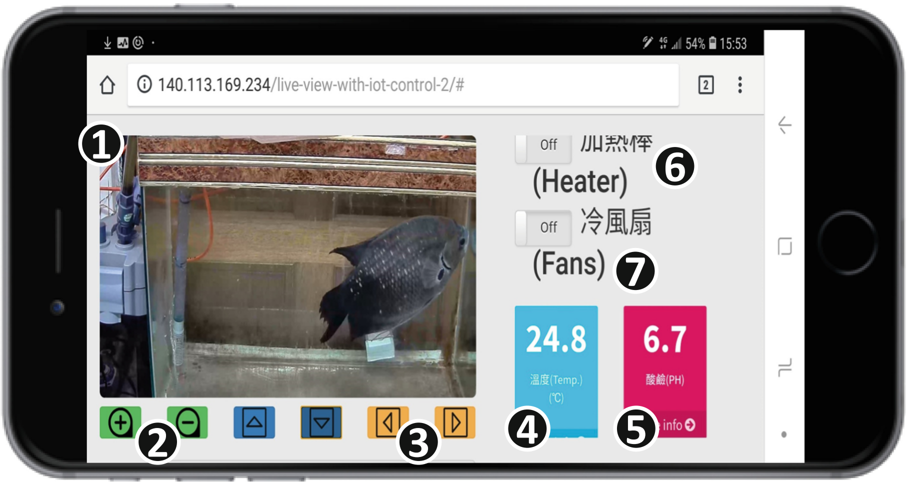

Fig. 3. Viewing the aquarium through the FishTalk display.

Decreased O2 concentration combined with elevated CO2 concentration in the water results in fish suffocation. The Dissolved Oxygen (DO) sensor (Fig. 4 (4)) monitors the dissolved O2 concentration. When it is below a threshold, the air pump (Fig. 4 (5)) is activated to increase the dissolved oxygen in the water.

The comfortable pH level in the aquarium ranges from 6 to 9. The pH value is affected by water hardness, and is also affected by CO2 that acidifies the water. When the pH sensor (Fig. 4. (6)) detects that the pH level is out of the comfortable range, the Reverse Osmosis (RO; see Fig. 4 (7)) is activated to purify the water for the pH level adjustment.

Appropriate Electrical Conductivity (EC) level is essential for fish health. Comfortable EC value ranges from 100 to 300 µS/cm for community freshwater tanks. The EC value is increased due to pollutants. The EC sensor (Fig. 4 (8)) monitors the water quality, FishTalk makes decision on when to activate the drain and the suction pumps (Fig. 4 (9) and (10)) to change the water for reducing pollutants.

The Total Dissolved Solids (TDS) sensor detects (Fig. 4 (11)) anions and cations (such as magnesium, calcium, silicate, sodium, phosphate and nitrate) in the water. When the RO membranes become blocked, the TDS value turns high. When the TDS value is higher than e.g., 40 ppm, it is an early warning for water deterioration, and we should clean or replace the RO membranes.

The water level sensor (Fig. 4 (12)) monitors the water volume in the tank. When it is below a threshold, the suction pump is activated to add water. Like PlantTalk, a timer (Fig. 4 (13)) is used for routine tasks. For example, the timer periodically turns on the food feeder to feed the fish (Fig. 4 (14)). FishTalk also provides lighting for viewing fish (Fig. 4 (15)).

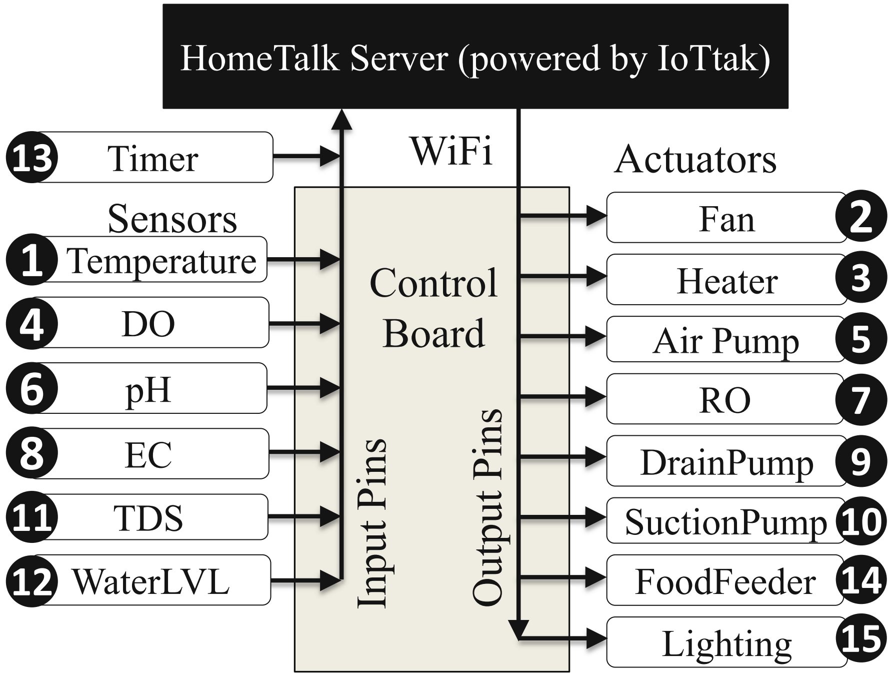

Fig. 4. FishTalk functional block diagram.

4 The BreathTalk Application

Heating, ventilation, and air conditioning (HVAC) [12] are considered items for typical building maintenance. Such maintenance often depends on the number of human occupancy information. In [13] we build the BreathTalk application that utilizes the CO2 sensors to detect the number of people in a room. The BreathTalk functional block diagram is illustrated in Fig. 5.

In this application, the indoor CO2 sensor (Fig. 5 (1)) is used to detect the number of people in real time. An outdoor CO2 sensor (Fig. 5 (2)) is also used as a reference point. The counting prediction is achieved by a machine learning module that includes kNN, decision tree and random forests. In [13] we subtly implemented the machine learning module as a cyber sensor and a cyber actuator. The cyber actuator is called Features (Fig. 5 (3)) that receives the indoor and the outdoors CO2 values as the features of the machine learning algorithms. The cyber sensor (Fig. 5 (4)) sends out the prediction results to the Display (Fig. 5 (5)). Figure 6 shows the time series for the indoor and the outdoor CO2 reported in [13]. The figure also shows the predicted numbers of people as well as the ground truth. We note that if we use the indoor CO2 sensor as the only feature to the AI model, the accuracy of prediction is less than 90%. By adding the outdoor CO2 sensor as the reference feature, the accuracy of prediction is 96.5%, which is better than the previous known results.

Besides counting people, when the CO2 concentration is high, BreathTalk automatically winds up the curtain (Fig. 5 (6) and Fig. 7 (1)) and opens the window (Fig. 5 (7) and Fig. 7 (2)).

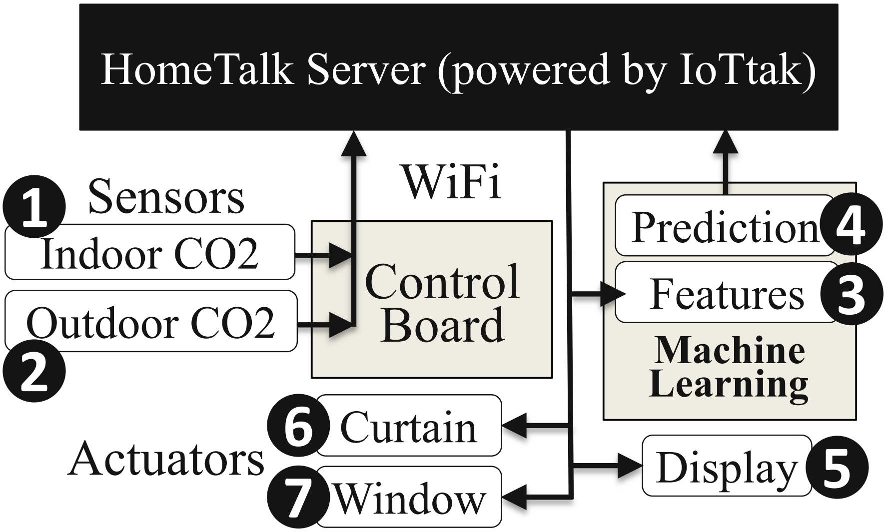

Fig. 5. BreathTalk functional block diagram.

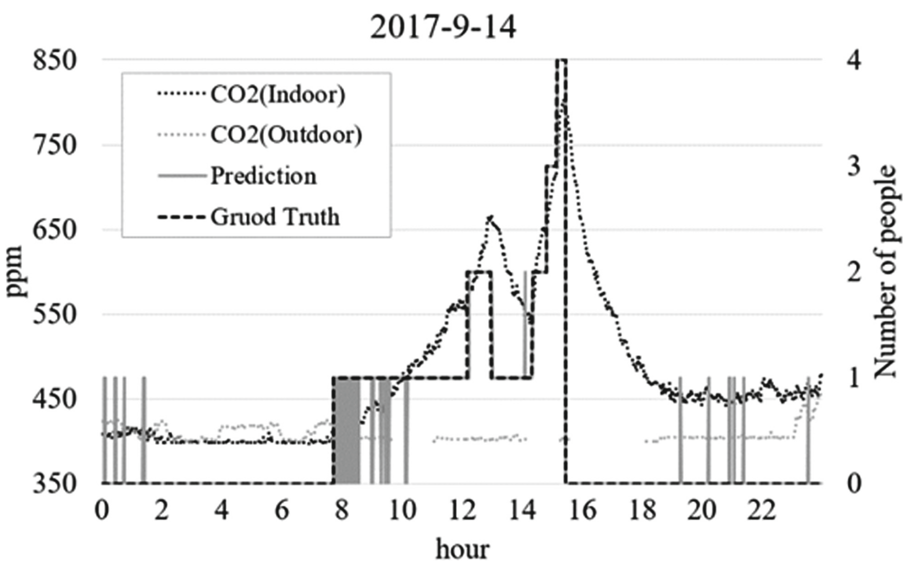

Fig. 6. The relationship between CO2 concentration and people count (reproduced from [13]).

Fig. 7. BreathTalk control of the curtains and the windows.

5 The TheaterTalk Application

Sensory friendly shows create art performance particularly delightful for children. Specifically, the shows generate sensitivity to sensory inputs that expose children to different situations and allow them to enjoy these interesting experiences. As an example, TheaterTalk [14] creates the multi-sensory experiences (such as scents, wind, rain and so on) by using home or special appliances for a video playing at home. Therefore, the viewer can enjoy 4D movies at home without special 4D movie effect systems. We note that this application can create the multi-sensorial effects for any video film, e.g., a video recorded from a smartphone or a video in YouTube. Figure 8 illustrates the TheaterTalk functional block diagram. The video source (Fig. 8 (1)) streams to the display (Fig. 8 (2)). The Sensory Event System (SES; Fig. 8 (3)) marks the time of the video for a specific sensory event. The SES was originally designed for inserting advertisements into a streaming video, and is reused in TheaterTalk for inserting multi-sensory events. The TheaterTalk is a cyber sensor device that includes 6 cyber sensors driven by the SES. The thunder flash sensor (Fig. 8 (4)) activates the lighting (Fig. 8 (5)) and the wind sensor (Fig. 8 (6)) activates the fan (Fig. 8 (7)). The weather sensor (Fig. 8 (8)) activates the heater (Fig. 8 (9)) or the air conditioner (Fig. 8 (10)) and the perfume sensor (Fig. 8 (11)) activates the smell generator (Fig. 8 (12)). The rain gauge (Fig. 8 (13)) activates the sprinkler (Fig. 8 (14)) and the earthquake sensor (Fig. 8 (15)) activates the massage chair (Fig. 8 (16)).

Figure 9 shows the multi-sensory video streaming. In the surfing scene, the SES sends the wind event to the wind sensor, and the fan is activated to blow so that the viewer feels the wind effect. The signaling path is ((3)->(6)->HomeTalk server->(7) in Fig. 8).

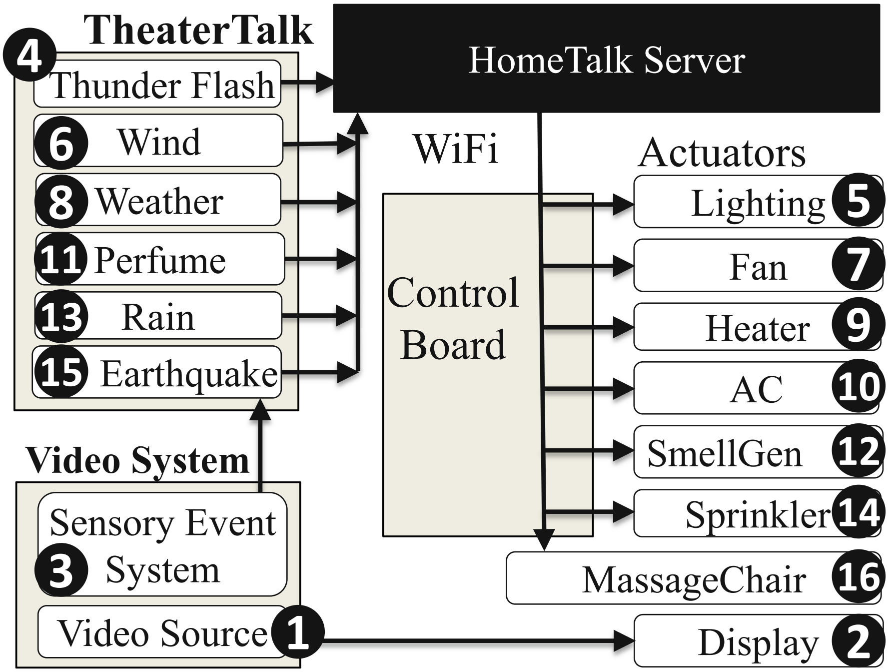

Fig. 8. TheaterTalk functional block diagram.

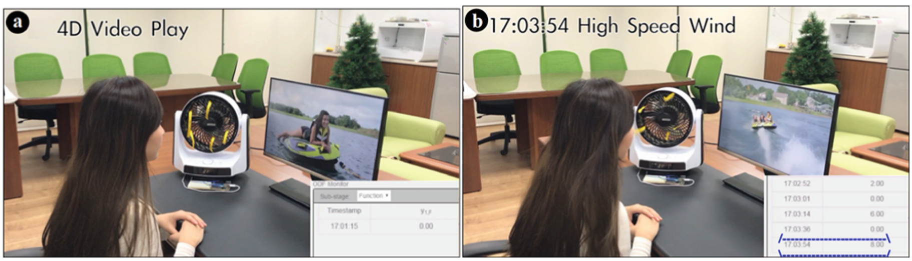

Fig. 9. Video streaming with multi-sensory effect.

6 The FrameTalk Application

As another sensory friendly show, the FrameTalk application [15] allows a smart frame to interact with the environment conditions at home. In Fig. 10, when it is a sunny weather, the frame shows Vincent van Gogh's art work "Sunny Day". When the camera detects that a person approaches, the frame interacts with the person through her/his smartphone. For example, by using the gyroscope of the smartphone, the person waves to change the pictures in the frame.

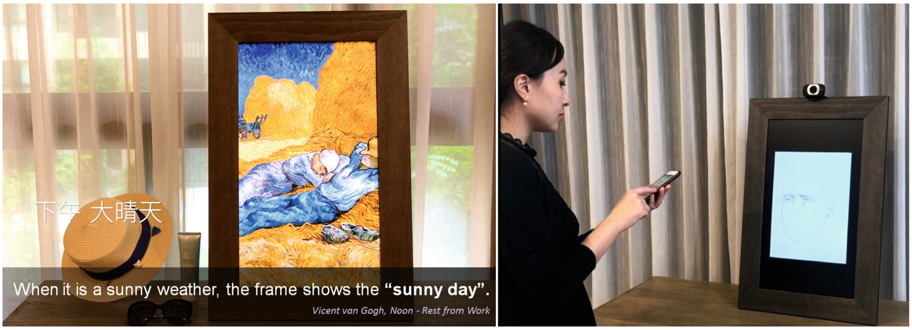

Fig. 10. Interaction with a picture frame.

Figure 11 shows the FrameTalk functional block diagram. The sensors in the house such as temperature (Fig. 11 (1)) and humidity (Fig. 11 (2)) collect the room conditions and the HomeTalk server passes them to the display of the frame (Fig. 11 (3)). The camera (Fig. 11 (4)) detects the presence of persons, and the gyroscope (Fig. 11 (5)) interacts with the frame content.

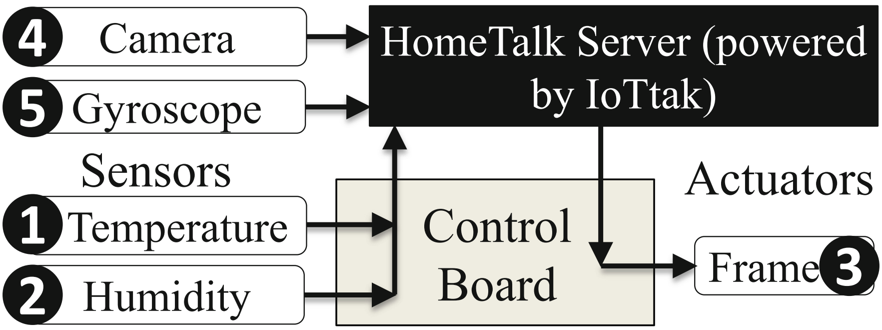

Fig. 11. FrameTalk functional block diagram.

7 The GardenTalk Application

Gardening adds gorgeousness to the yard at home. Besides enjoying of homegrown harvest, a garden provides healthy environment around the house. The IoT technology assists the gardener to handle plant growing. An example is GardenTalk that uses the technology developed in [16] to deploy sensors and actuators in a garden. A micro weather station (Fig. 12 (1)) is deployed with sensors (Fig. 13 (1)–(7)) for CO2, temperature, humidity, atmosphere pressure (AP), the rain gauge, the ultraviolet (UV) and the wind gauge. GardenTalk also deploys soil sensors include (Fig. 13 (8)–(11)) a 3-in-1 sensor for moisture, temperature, and electrical conductivity (EC; see Fig. 12 (2)), and a pH sensor (Fig. 12 (3)). The actuators (Fig. 13 (12)–(14)) include those for irrigation, fertilization and pesticide. The drippers are connected to the irrigation tank (Fig. 12 (4)) and the fertilizer tank (Fig. 12 (5)) to form a drip irrigation system controlled by the pump (Fig. 12 (6)).The pest sprayers connected to the biopesticide tank (Fig. 12 (7)). Like the irrigation system, the biopesticide liquid is sent to the sprayers by the pump.

Fig. 12. The garden with sensors and actuators.

The irrigation drippers are driven by soil moisture sensor, the rain gauge and a timer. When the humidity level is too low, the water is pumped in. We also use the timer (Fig. 13 (3)) to perform routine irrigation when the rainfall amounts lower than 2 mm measured by the rain gauge. The fertilizer drippers are controlled by the EC and the pH sensors (Fig. 13 (10) and (11)). Through these sensor values, GardenTalk calculates the Nitrogen, Phosphorus and Potassium ingredients in soil through the AI module (Fig. 12 (15)) and decides the amount of fertilization. The pest control (Fig. 13 (16)) is more complicate. We used a regression model with temperature (Fig. 13 (2)), humidity (Fig. 13 (3)) and wind speed (Fig. 13 (7)) to create the features for the AI model to determine if the pest sprayer (Fig. 13 (14)) should be activated. The sensors and actuators involve other complex agriculture functions and the reader is referred to [16] for the details.

8 Discussion and Conclusions

Most HomeTalk applications can share same kinds of sensors, although we have not done so for the current implementations described in Sects. 2–7. For example, FrameTalk may interact with all sensors listed in Table 1 with various animation art works displayed in the frame. If the water sources for the aquarium tank and the hydroponic plant box are the same, then most sensors and actuators can be shared by PlantTalk and FishTalk.

In Table 1, the pH sensor in the water can be shared by PlantTalk and FishTalk. GardenTalk needs a separate pH sensor inserted in the soil. The indoor temperature sensor can be shared by PlantTalk and FrameTalk (to display the room temperature). FishTalk may share the same temperature sensor or have a separate one inserted in the water. An outdoor temperature sensor is used by GardenTalk.

The indoor humidity sensor is used in PlantTalk and the outdoor sensor is used in GardenTalk. BreathTalk may use both indoor and outdoor humidity sensors for HVAC. The indoor O2 sensor can be shared by PlantTalk and BreathTalk. FishTalk used DO, the O2 sensor in the water. The water level sensor can be shared by PlantTalk and FishTalk.

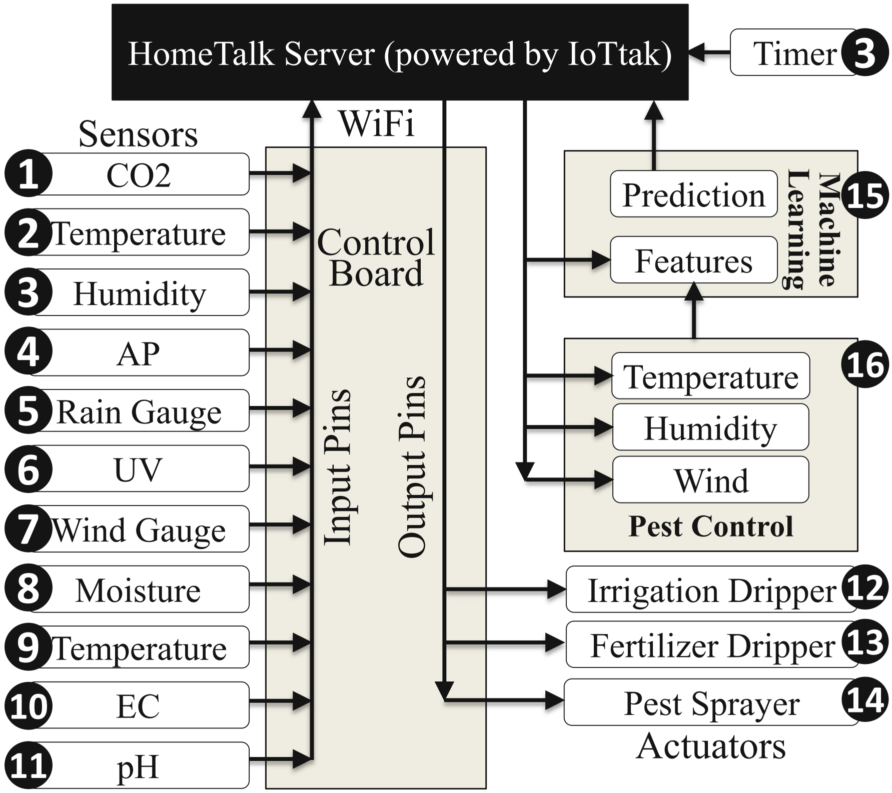

Fig. 13. The GardenTalk functional block diagram.

The indoor CO2 sensor is shared by PlantTalk and BreathTalk. The outdoor CO2 sensor is used by GardenTalk and BreathTalk. The software timer with multiple targets is shared by all applications that execute routine tasks. The EC and the TDS sensors can be shared by PlantTalk and FishTalk to detect water quality.

In the current implementations, both BreathTalk and GardenTalk use the AI module. In the future, all applications can utilize AI to do something smart. In HomeTalk, all applications can use smartphones to provide the control panel, the sensor dashed board, and video streaming. The FishTalk smartphone example is shown in Fig. 3, which applies to all HomeTalk applications. Similarly, all HomeTalk applications in a room can share one camera. The zooming and rotating features of the camera in Fig. 3 (2) and (3) can be preset to point to several applications, and the camera automatically moves to the target object (e.g., the aquarium tank, the plant box, the curtains and so on) that the user wants to view.

The sensors in a micro weather station for rain, air pressure, UV, and wind are used in GardenTalk. These sensors can be calibrated with the near-by government weather station. Although the sensor values of the government station and the micro station are not exactly the same, they have some correlations (see Fig. 14) that can be used for calibration. Then the micro weather station's sensors may serve for sensor failure detection at home. For example, we use the rain gauge, the indoor and the outdoor humidity sensors to mutually test if any sensor is out of order. The details will be addressed in a separate paper.

Table 1. Sensors used in HomeTalk

Sensors	PlantTalk	FishTalk	BreathTalk	FrameTalk	GardenTalk
pH	x	x			x
Temperature	x	x		x	x
Humidity	x			x	x
O2	x		x		
Water level	x	x			
CO2	x		x		x
Timer	x	x			x
DO	x	x			
EC	x	x			x
TDS	x	x			
AI module[a]			x		x
Smartphone[a]	x	x	x	x	x
Camera	x	x	x	x	x
Rain gauge				x	x
Air pressure				x	x
UV				x	x
Wind gauge				x	x

[a]The device serves as both sensor and actuator.

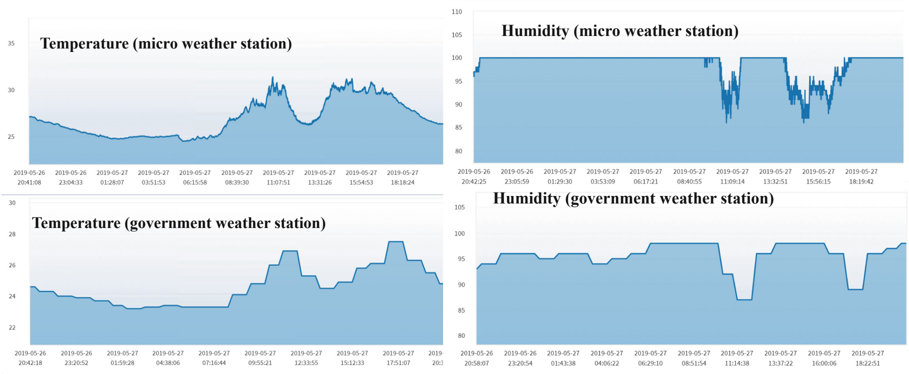

Fig. 14. Sensor Data from the micro weather station and the nearby government weather station.

Table 2 lists the actuators used in the HomeTalk applications. Sharing of actuators is subtle and should be carefully planned. For example, the RO actuator can be shared by PlantTalk and FishTalk to purify water. However, when to activate the RO should be carefully designed. For example, the optimum pH level for PlantTalk ranges from 4.5 to 7. On the other hand, the range is [6, 9] for FishTalk. Therefore, we may activate the RO if the pH level is not in the range [6, 7].

Similarly, the optimum water temperature range is [60 °F, 80 °F] for PlantTalk and is [77 °F, 80.6 °F] for FishTalk. Therefore the fan, the AC, and the heater can be shared to maintain the water temperature in the range [77 °F, 80 °F].

Indoor water spray can be shared by PlantTalk and TheaterTalk but is activated at different times for these two applications. Drain and Suction pumps are shared by both PlantTalk and FishTalk. In “aquaponics”, the nutrition of the plants may come from fish excrement. Furthermore, the waste water filtered by the RO outlet contains fruitful ingredients such as nitrates, phosphates, heavy metals, and pesticides that can be reused by the irrigation system of GardenTalk [11].

The curtain is controlled for PlantTalk to get more sunlight. Both the window and the curtain are controlled to get fresh air in BreathTalk, and the indoor blue and red lights are used in PlantTalk to generate fresh air for BreathTalk. The outdoor lighting is

Table 2. Actuators used in HomeTalk

Actuators	PlantTalk	FishTalk	BreathTalk	TheaterTalk	FrameTalk	GardenTalk
RO	x	x				
Fan	x	x		x		
Spray	x			x		x
Drain pump	x	x				
Suction pump	x	x				
Nutriton	x					x
Lighting	x	x		x		x
Heater		x		x		
Air pump		x				
Food feeder		x				
Display				x	x	
Curtain	x		x			
Window	x	x	x			
Air cond.	x	x		x		
Massage chair				x		
Perfume			x	x		
Dripper						x

used by GardenTalk at night. The water dripper used in GardenTalk can be extended to indoor orchid irrigation shown in Fig. 15 (4)).

In the future, we will integrate the smart home applications in NCTU Orchid House that took three big awards in Solar Decathlon Europe 2014 [17]. Figure 15 illustrates the Orchid House sponsored by Taiwan Semiconductor Manufacturing Company Limited. This building was constructed with recycled plastic material for heat storing wall (thermal mass; Fig. 15 (1)) that achieved 97% of plastic recycling. Over 90% of recycled glass was used as heat and sound proof materials (Fig. 15 (2)). The house collects rain water. The water is blown by several large silent fans to cool down the air (Fig. 15 (3)). The cool air is then drawn through the house by a water wall stationed at the opposite end of the house. POLLI-Brick™ made by the recycled plastic bottles is used to fill with water to absorb heat during the day. Radiant heat is released at night. Drip irrigation of GardenTalk is being used for watering the orchids in the wall (Fig. 15 (4)).

Fig. 15. The Orchid House.

Besides the sensors and the actuators in Tables 1 and 2, there are over 50 light sources in the Orchid House. We will study how to use HomeTalk to control the light colors and intensities to create various atmosphere scenarios at home.

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Author Contributions. Y.-B. Lin: Design of IoTtalk and smart home applications, Y.-W. Lin: Design and implementation of IoTtalk, S.-K. Tseng: Orchid house architecture, J.-K. Liao and T.-H. Hsu: Design and implementation of IoTtalk.

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Conflicts of Interest. The authors declare no conflict of interest.

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