Featured Articles

Image Recognition Technology that Helps Save Energy in Room Air Conditioners

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OVERVIEW: Room air conditioners need to be energy efficient, accounting as they do for a significant proportion of household power consumption. In addition to achieving industry-leading energy efficiency in the 4.0-kW, 5.6-kW, and 8.0-kW classes, room air conditioner launched in FY2014 also features the three-way front flap function that uses image recognition both to save power and improve comfort. Multi-monitoring system uses a near-infrared camera together with visible-light and thermal imaging cameras not only to identify the location of people and measure the surrounding temperature, but also to determine the location and shape of furniture and the room layout. The air conditioner provides comfortable heating and cooling throughout the year through fine-tuned control of air flow, including avoiding furniture and directing the flow of warm air toward people's feet when used for heating, and circulating cool air to lower the temperature of the entire room when used for cooling.*

INTRODUCTION

HOME appliances have evolved over time to satisfy demands for entertainment, convenience, and comfort, and to adapt to changes in society and the environments in which people live. Recent years have seen strong demand for more sophisticated functions, user interfaces that make appliances easier to use, and energy efficiency. The way in which home appliances have evolved can be broadly divided into the following two trends.

(1) Entertainment

The trend toward providing information, entertainment, and the enjoyment of life, starting with radio, television, and audio equipment

(2) Convenience

The trend toward washing machines, refrigerators, and other home appliances intended to make life more convenient by, for example, cutting the amount of time spent on housework

Furthermore, along with the higher living standards made possible by home appliances, comfort is now emerging as a third major trend thanks to the arrival of home appliances that operate entirely on electric power and advances in air conditioners that provide more comfortable living spaces[1]. Comfort means the optimal control of conditions like temperature and humidity, and providing a near-natural environment. The purpose of integrated air conditioners is to create comfortable air-conditioned living spaces like this. To design air conditioners that can provide comfort by satisfying various criteria, such as coping with seasonal temperature variations, differences in climate from Hokkaido to Okinawa, and highly airtight houses, air conditioner manufacturers have been developing energy-efficient technologies.

SENSING TECHNOLOGIES FOR ROOM AIR CONDITIONERS

As progress has been made on the development of energy-efficient technologies, air conditioner manufacturers have released models that offer more sophisticated functions and that achieve energy-efficient operation by controlling the direction and volume of air flow using technologies such as thermal detection sensors (thermopiles) and infrared sensors (pyroelectric sensors) to detect people entering or leaving the room and to collect information on aspects like the number of people in the room, where

* As of April 1, 2015. The power consumption during a period of operation is 1,036 kWh for the RAS-X40E2, 1,630 kWh for the RAS-X56E2, and 2,802 kWh for the RAS-X80E2, measured under Japanese Industrial Standards (JIS) conditions.

they are, and their level of activity. Along with more sophisticated functions, these air conditioners now also require technologies for detecting the location of walls, linear features, doors, furniture, and other aspects of the room layout, and for performing detailed control of air flow direction and volume.

The following three main methods can be used to detect furniture and other aspects of the room layout.
(1) Using multiple cameras
(2) Using ultrasonic sensors
(3) Using lasers

The method involving multiple cameras uses the differences between images from different cameras to determine the locations of objects. Problems with this approach include the high cost of using a number of cameras and the restrictions it imposes on where cameras are located and the size of the camera housings. Although the use of an ultrasonic sensor overcomes the cost problem, this method suffers from poor accuracy and poor detection range due to the limited amount of information the sensor is able to obtain. The problems with using a laser, meanwhile, include cost and safety[2].

Accordingly, to satisfy both cost and accuracy requirements, Hitachi embarked on researching and developing a technique for detecting room layout and furniture using a single camera[3), (4)]. The resulting technique uses a structural model of the room provided in advance to detect room layout and furniture from architectural information obtained from a single image, such as when doors are open or closed and the location of objects. In anticipation of the technique being used in home appliances, Hitachi also developed methods that could be implemented with a low computational load.

To provide a technique for achieving both energy efficiency and greater comfort, Hitachi was the first to use a visible-light camera as a sensor in an air conditioner, developing the multi-monitoring system function, which detects the movement of people in the living space to control comfort and energy use based on the actual circumstances. The function was included in the air conditioners it released in FY2012.

In FY2013, Hitachi succeeded in making the energy efficiency feature more accurate and comfortable by developing the enhanced multi-monitoring system function for sensing the room layout using a thermal imaging camera (thermopile) in addition to the visible-light camera. This function automatically controls the direction and volume of air by using the images captured by the cameras fitted in the room air conditioner to detect furniture and determine the room shape, when doors are open or closed, and so on. In a home that has an additional room adjoining the living room, for example, it can automatically perform air conditioning for the living room only when the connecting door is closed and for both rooms when the door is open. It can also automatically control the variable-direction (“swing”) of blowing air based on the room size.

For the FY2014 product range, Hitachi developed new multi-monitoring system. This is a further enhancement of the FY2013 models’ function that is designed not only for energy efficiency but also for a level of comfort that will obtain a sympathetic response from users. The FY2014 models not only determine the location of people and the surrounding temperature but also detect the location and shape of furniture and other aspects of the room layout to identify how air flows through a room. The following sections 3 and 4 provide detailed explanations of two image recognition technologies developed for use in air conditioners. The first technology is used for detecting the room layout, and the second technology is used for detecting furniture.

ROOM LAYOUT DETECTION TECHNOLOGY

Because past room air conditioners have been unable to detect things like the size and shape of the room and whether doors are open or closed, they have not been able to adjust air flow to accommodate the room layout, such as by boosting output to the most distant parts of the room[5].

To overcome this problem, Hitachi developed a technology for determining room layout. The technology works by identifying the movement and location of the structural elements of the room, including walls, floor, linear features, and doors. Its ability to detect the location of doors and whether they are open or closed means that a single air conditioner can, for example, direct a strong flow of air to the farthest corners of a room, even in cases where there are two adjoining rooms.

How Room Layout Detection Works

This research included the development of a technology for determining room layout from camera images of a room’s doors, corners, and other features in order to achieve a uniform air temperature throughout the room. By using the technology to identify doors and corners, it is possible to direct a strong flow of air to

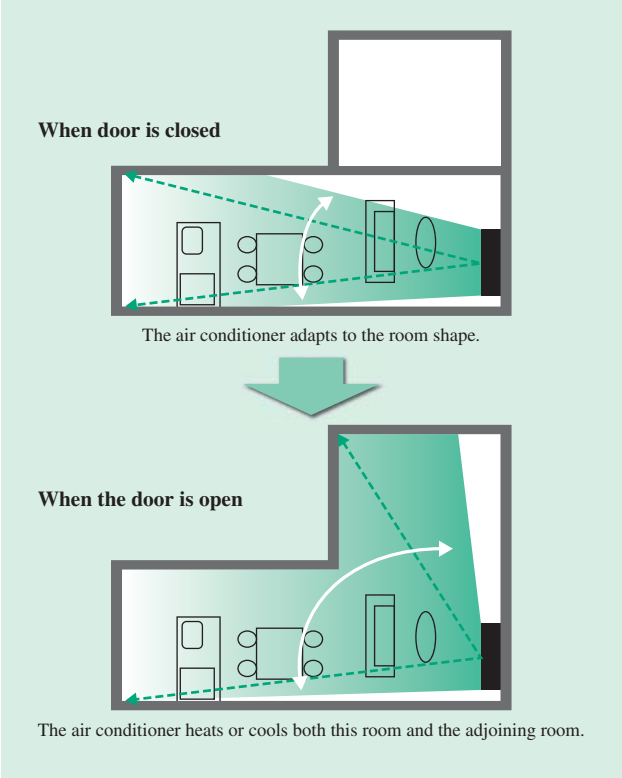

Fig. 1—Room Layout Detection Example.
Swinging (varying the direction in which air is blown from side to side) provides tight control over the volume of air reaching the back of a room while also preventing air flow from being blocked by walls and maintaining a uniform temperature throughout the room.

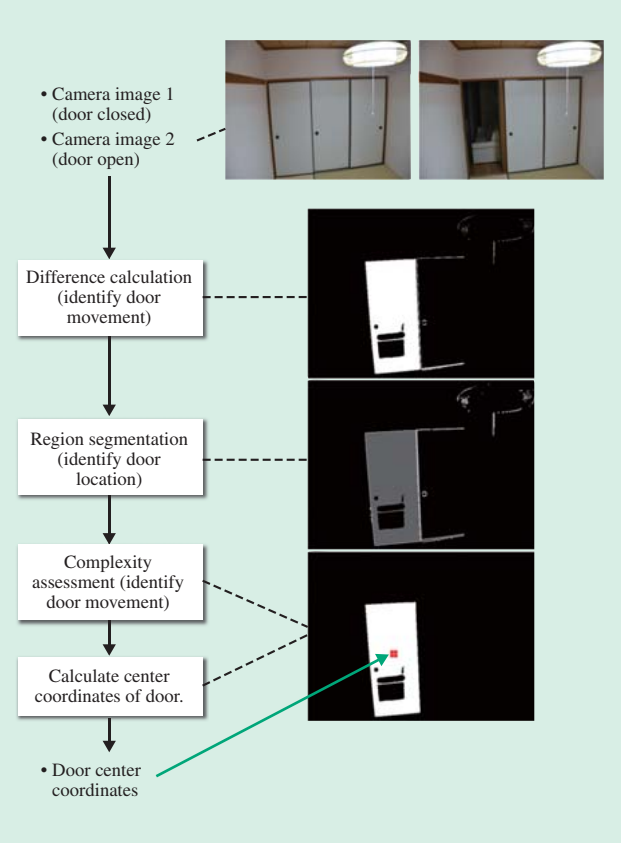

Fig. 2—Sequence of Steps for Door Detection.
The technology identifies a number of possible doors in camera images and then narrows these down to determine which ones are in fact doors.

the farthest corners of a room, or to an adjoining room, by directing the air flow toward the corners only.

Fig. 1 shows an example of how this room layout detection technique is used. Swinging the direction in which air is blown from side to side provides tight control over the volume of air reaching the back of the room while also preventing air flow from being blocked by walls and maintaining a uniform temperature throughout the room.

To determine room layout, it is necessary to identify the location of doors. This is done by identifying a number of possible doors in the camera images and then narrowing these down to those that are in fact doors. This procedure is able to identify doors rapidly. Fig. 2 shows the sequence of steps for detecting a door. The first step is to calculate the differences between an image in which the door is open and one in which it is closed so as to identify the movement of an opening or closing door. Next, a region segmentation process is applied to the calculated differences to identify possible doors. These candidates are then assessed for characteristics like size and squareness of shape until there is only one candidate left. A complexity value (indicating the complexity of the color pattern across the entire surface of the door) is then calculated for the identified door and this is used to determine whether the door is open or closed. Finally, the centerpoint coordinates of the door are calculated from its area.

To detect the architectural structure of the room, it is necessary to identify the linear features of the building accurately. The new technology uses information about the structure of the room provided in the form of a model to identify which of the numerous possible linear features in the room are in fact structural and determine the building structure based on where these intersect. The structural information about the room (model) consists of the angles and positions at which lines intersect and how clearly the lines are visible. This is used to narrow-down possible linear features and identify the corners of the room.

Fig. 3 shows the sequence of steps for detecting corners. First, the edges present in camera images are detected to identify potential linear features. Next, a line detection technique is applied to the images

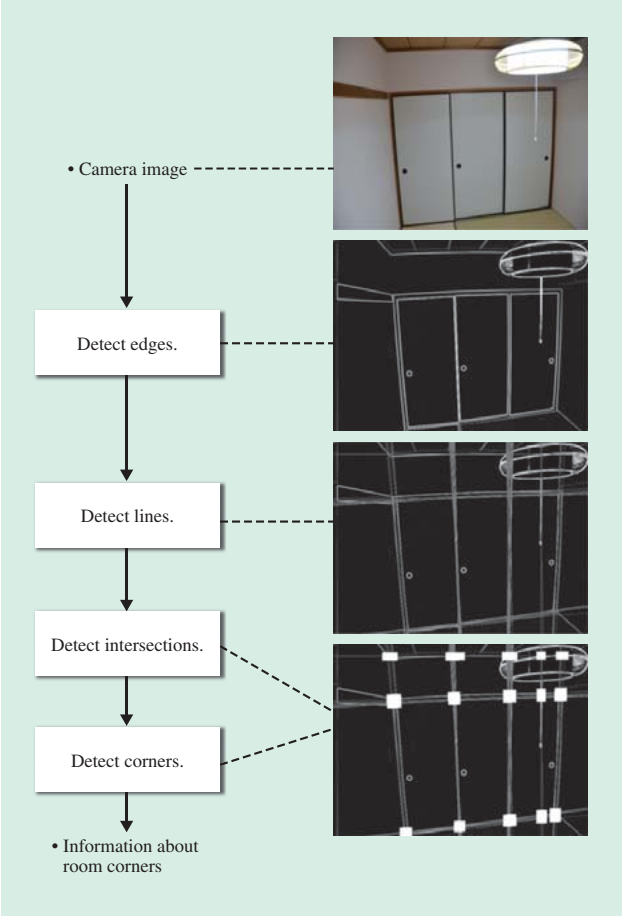

Fig. 3—Sequence of Steps for Corner Detection.
Structural linear features are identified from a large number of candidates and the room's structure determined from the intersections between these.

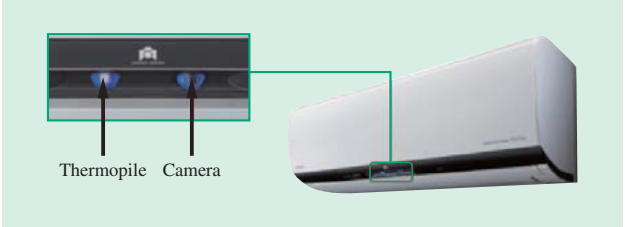

Fig. 4—Camera Mounted on Air Conditioner.
The thermopile and camera are located on the front of the air conditioner, as shown.

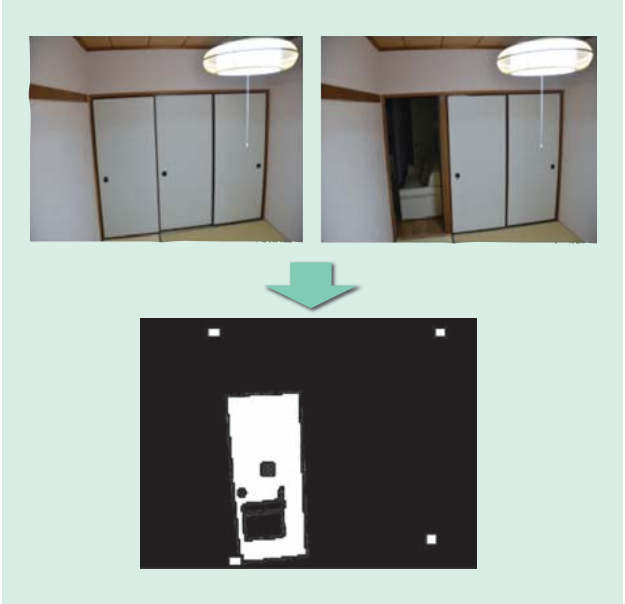

Fig. 5—Operation of Room Layout Detection.
This shows the operation of room layout detection in practice using a data set of images from a camera mounted on an air conditioner.

containing detected edges to narrow-down the number of potential linear features. Finally, the predefined structural model of the room is used to determine which of the many potential linear features are in fact structural, and the intersections between these are used to determine the room's structure.

Results of Real-world Testing of Room Layout Detection

Testing was conducted to evaluate the performance of room layout detection in a room air conditioner. The testing used a data set of images from a camera mounted on an air conditioner (see Fig. 4). Fig. 5 shows an example of room layout detection being used.

FURNITURE DETECTION TECHNOLOGY

The most common layout for Japanese homes includes a living, dining, and kitchen area in which a single large room air conditioner is installed and used extensively. This area is characterized by being a place where family members congregate and is the scene of various different activities at different times of the day. The living area differs from other rooms in that it contains furniture such as a sofa or dining table, and feedback from customers indicates that this furniture can block air flow and prevent warm air from reaching their feet, or that temperature variations occur such that only parts of the room are cooled. In response to these issues, Hitachi developed a furniture detection technique that determines the location and shape of furniture and identifies the pathways through which air flows across the room.

Sequence of Steps for Furniture Detection

A camera is fitted on the front of the indoor unit of the air conditioner. It is able to operate as a near-infrared camera by using a shutter mechanism to place a filter

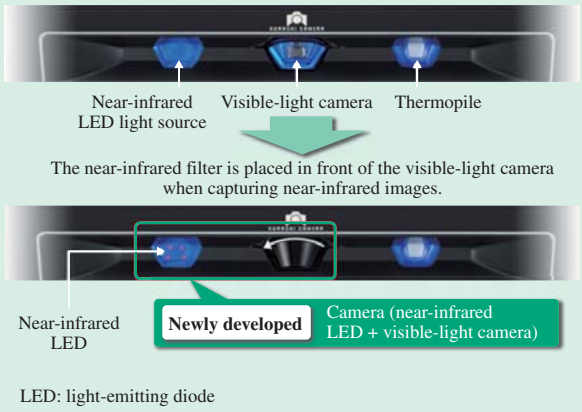

Fig. 6—Multi-monitoring System Components.
A filter transparent to near-infrared light is placed in front of the visible-light camera (middle) when needed to obtain near-infrared images.

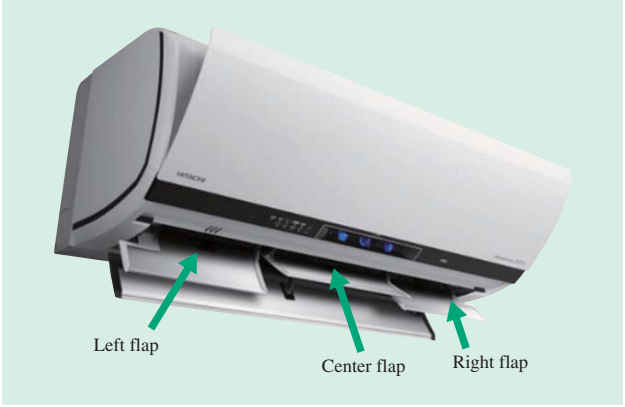

Fig. 8—Three-way Segmented Front Flap.
Each of the three flap segments can be positioned independently to provide fine-tuned control of air flow direction.

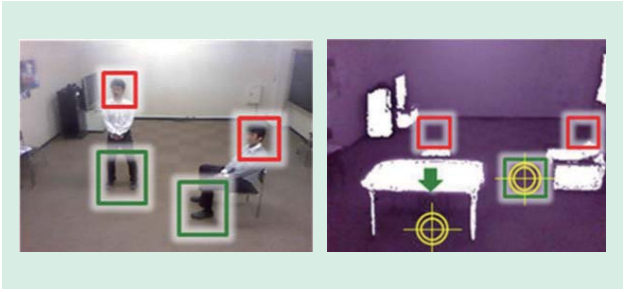

Fig. 9—Detection of People's Feet (Left) and Detection of Air Flow Paths when Heating (Right).
This uses the visible-light camera to detect people's feet and the near-infrared camera to determine how air flows through the room.

in front of the central visible-light camera that allows near-infrared light to pass when needed. In this case, a near-infrared light-emitting diode (LED) is used to illuminate the scene so that an image can be acquired (see Fig. 6).

The resulting near-infrared image is then subjected to a variety of processing, including noise cancellation, edge detection, and region segmentation to identify potential items of furniture. Next, the features of the furniture (such as shape and size) are used to narrow down the number of candidates. The length of the furniture legs and the area of openings through which air can flow are then calculated to determine whether or not each item of furniture will block air flow (see Fig. 7).

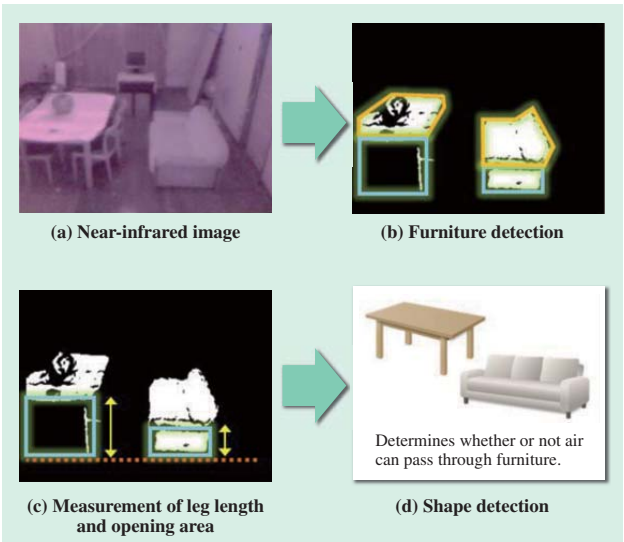

Fig. 7—Furniture Detection Using Near-infrared Images and Image Processing.
Furniture features (shapes) are identified using edge processing and pattern recognition. This also differentiates between furniture through which air can and cannot pass.

To control the flow of air from the indoor unit to the air flow paths identified by this process, Hitachi developed a three-way segmented front flap (see Fig. 8). Whereas previous models had two continuous flaps to direct air flow, the upper flap on this new design is split into three segments. This provides finer control over the direction of air flow and allows air to be directed toward these paths, ensuring comfortable air conditioning by directing warm air toward people's feet when heating and circulating the air when cooling in a way that minimizes the buildup of pockets of cool air.

Furthermore, Hitachi also developed a foot detection technique that uses the visible-light camera to enable the detection of people's feet, regardless of their temperature or what they are wearing (slippers or thick socks, for example) (see the left side of Fig. 9).

Results of Real-world Testing of Air Flow Path Detection

The right-hand image in Fig. 9 shows how the above information is used to identify where air needs to be blown in order to reach people's feet when heating.

CONCLUSIONS

This article has described room layout detection and furniture detection technologies for room air conditioners that use image recognition and were developed with the aim of providing both energy efficiency and comfort.

Room layout detection detects the size and shape of the room and determines whether doors are open or closed from images captured by a camera fitted onto the air conditioner. Using this information it automatically controls the volume and direction of air based on conditions in the room. Furniture detection, meanwhile, determines the position and shape of furniture and other aspects of the room layout, and identifies how air flows through the room, enabling fine-tuned control of air flow direction to blow warm air toward people's feet (when heating) or circulate cool air to lower the temperature of the entire room (when cooling). This fine-tuned control of air flow direction improves energy efficiency while maintaining comfort by preventing pockets of higher temperature from forming.

These technologies were developed with a view to their use in home appliances, using images from a single camera, and capable of being implemented with a low computational load. In the future, Hitachi intends to investigate other applications, including spatial detection and obstacle identification when operating mobile robots, or detection of abnormal situations in buildings or structures (such as offices, stores, or tunnels).

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