Direction-based Wireless Remote Controller: A Smartphone Application

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Abstract

Recently, smartphones have been used as remote controllers for home appliances through connectivity of mobile telecom network or Wi-Fi. To control several home appliances in a room, a mechanism is required for a smartphone to correctly select the target appliance. Through the built-in electronic compass function in the smartphone, we propose a scheme called *Point-and-Control* (PnC) that allows a user to select a home appliance by pointing the smartphone to that home appliance. In this paper, we design the PnC and show the performance of this solution. Our study indicates that the PnC can effectively achieve the remote control function.

Keywords: electronic compass, positioning algorithm, remote controller, smartphone application.

1 Introduction

Nowadays, smartphones are widely used to offer many advanced applications in mobile telecom. One of the innovative applications is the remote control for home appliances [1], [2], [3], [4]. A typical architecture for the smartphone remote control application is illustrated in Figure 1. The application can control the home appliances by sending infrared ray (IR) signals [1], [2]. In this approach, the smartphone (Figure 1 (1)) needs to point to the IR receiver of the home appliance (Figure 1 (2)). Alternately, the smartphone can send Wi-Fi signals. Through a converter (Figure 1 (3)) with Wi-Fi receiver and IR transmitter functions, Wi-Fi signal is converted into IR signal that is directed to the IR receiver of the home appliance (Figure 1 (2)) [3]. These two alternatives require an IR path directly points to the home appliance to be controlled, and only one or few home appliances can be controlled (due to the limitation of direct-path setup of IR). In the third alternative, either the mobile telecom network (Figure 1 (4)) or the WLAN access point (AP; Figure 1 (5)) is connected to several home appliances. In mobile telecom, the connection for remote control applications can be provided through *Next Generation Network* (NGN)/*IP Multimedia Subsystem* (IMS). The reader is referred to [5] for the details.

In the existing approaches for the third alternative [3], [4], when the user executes the remote control application, the smartphone first enters the home appliance list. For example, Figure 2 (a) illustrates home appliances that can be controlled in the room. When the user selects the DVD player from the list, the control interface of this appliance is shown on the smartphone (Figure 2 (b)) and then the user can control this DVD player through the touch panel. Although the third alternative relaxes the limitation

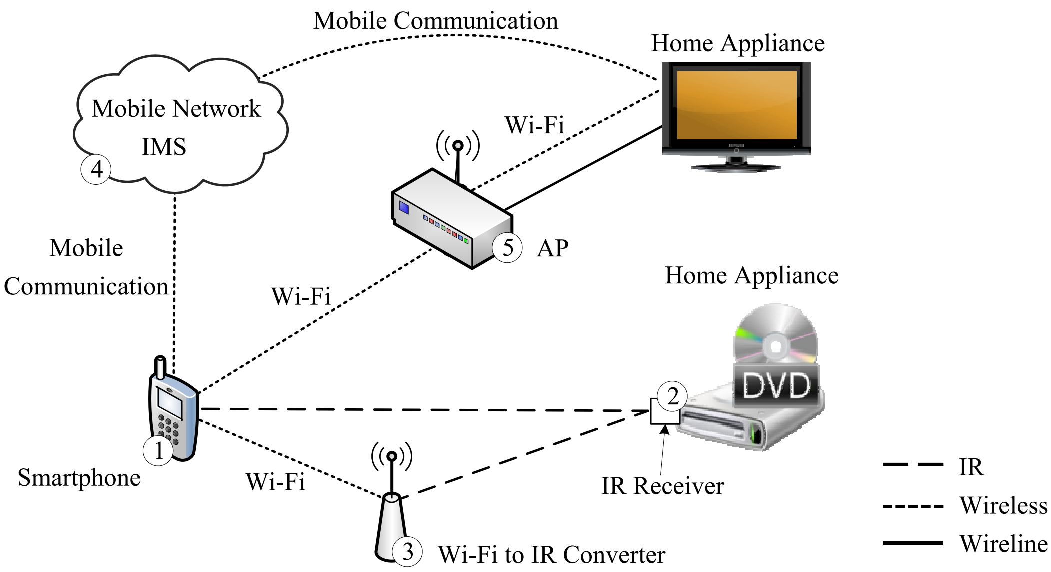


Figure 1: A typical architecture for the smartphone remote control application

of IR, it cannot take the advantage of the "direction" information of the first alternative. In Figure 2, if the user wants to control another home appliance, she has to go back to the home appliance list again to select another appliance manually from the list. Clearly, this solution does not utilize the "direction" information.

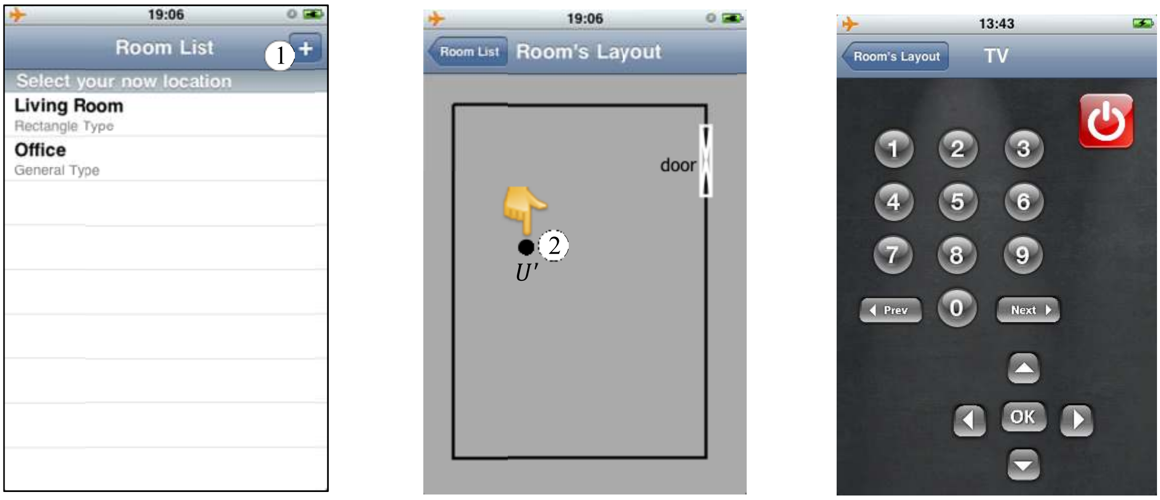
(a) Home appliance list (b) DVD control interface

Figure 2: Screenshots of RedEye application

To take the advantage of the "direction" information in the smartphone remote control application, we consider a scheme called *Point-and-Control* (PnC), which utilizes the electronic compass feature that has been built in many smartphones. In this scheme, when the user wants to control a particular appliance, she just points toward this appliance and its control interface will show on the screen immediately. The PnC uses an angle-based positioning algorithm to achieve this function, and it can be easily installed on a compass-enabled smartphone (e.g., iPhone 4). This paper is organized as follows. Section 2 proposes the concept of the PnC. Sections 3-4 investigate the performance of the PnC. Finally, the conclusion is given in section 5.

2 Concept of Point-and-Control

This section describes the concept of *Point-and-Control* (PnC). As mentioned before, the PnC uses an angle-based positioning algorithm to calculate the position of each home appliance. When a user wants to control a home appliance, she points the smartphone to that home appliance. Then the PnC will display the remote control interface of the home appliance located along the pointed direction.



(a) Room List page (b) Room's Layout page (c) Remote control interface for TV

Figure 3: Screenshots of the PnC

The Room List page of the PnC is shown in Figure 3 (a), which itemizes the rooms that had been configured by the user (In Figure 3 (a), the living room and the office are listed). The user may click on button "+" ((1) in Figure 3 (a)) to add a new room to be configured. Then the PnC enters the room coordinate system setup phase described below.

Phase 1. Room coordinate system setup: For each room, the PnC creates a coordinate system, and maps the room's layout to this coordinate system by the compass orientations of four pre-defined reference points. Then the user adds the home appliances in this room and the PnC calculates each coordinates of home appliances. The details will be described in Subsection 2.1.

In Phase 1's establishment, the PnC builds up the coordinates of every home appliance. If the user is in a configured room, she can control home appliances by selecting the room from the list. If so, the PnC enters the remote control phase.

Phase 2. Remote control: The PnC first identifies the position of the user in the room. To obtain the position of the user, the PnC shows the room's layout on the screen and then the user touches the screen to indicate her approximate position U' (Figure 3 (b)). The PnC assumes that U' is the actual position of the user. When the user points the smartphone to a home appliance, the PnC's selection is based on position U', the current compass orientation and the coordinates of home appliances calculated in Phase 1. Then after exercising a selection rule, an appliance is selected, and the PnC shows the remote control interface of that appliance (Figure 3 (c)). The details will be elaborated in Subsection 2.2.

2.1 Room Coordinate System Setup in the PnC

This subsection describes how the PnC creates its coordinate system. The PnC uses an angle-based positioning algorithm with the following steps:

Step 1.1 Identifying reference points: The PnC uses four reference points to calculate the aspect ratio of the room and the user's position. As illustrated in Figure 4, we assume that the room is rectangular. Let U be the user's actual position whose coordinates are (x_U, y_U), and assume that the user faces the wall with a door. Define four reference points with reference to U : R_0 (the right front corner), R_1 (the front side), R_2 (the left front corner), and R_3 (the right rear corner). Let $\theta_{i,j}$ be the angle $\angle R_i U R_j$ for each pair of reference points (R_i, R_j) where $0 \leq i \neq j \leq 3$. Angle $\theta_{i,j}$ is calculated as follows. To add a new room configuration, the user clicks the button "+" (see (1) in Figure 3 (a)), and points the smartphone to the reference point R_i. Then the PnC invokes the built-in electronic compass function to obtain the direction of line $\overrightarrow{UR_i}$, and $\theta_{i,j}$ can be calculated from the directions of lines $\overrightarrow{UR_i}$ and $\overrightarrow{UR_j}$.

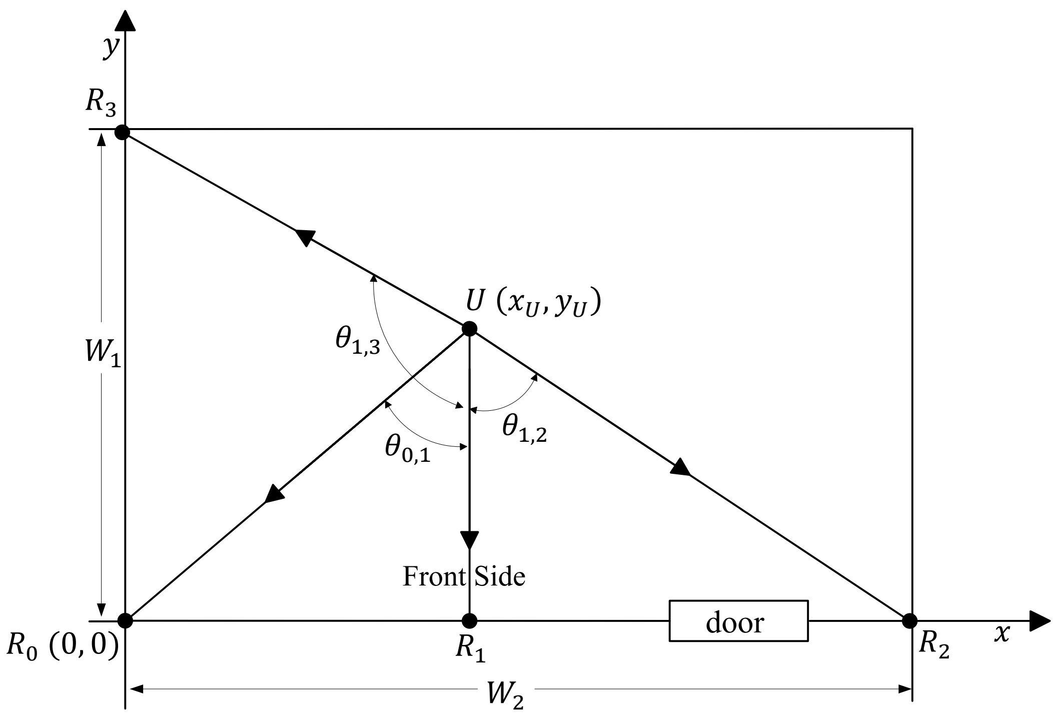


Figure 4: The PnC coordinate system

Step 1.2 Constructing the PnC coordinate system: As depicted in Figure 4, the PnC uses the reference point R_0 as the origin of the coordinate system. Line $\overrightarrow{R_0R_3}$ is designated as the y-axis, and line $\overrightarrow{R_0R_2}$ is designated as the x-axis. Assume that the lengths of walls $\overline{R_0R_3}$ and $\overline{R_0R_2}$ are W_1 and W_2, respectively. Through $\theta_{i,j}$, the coordinates of U (i.e., (x_U, y_U)) are normalized by W_1 as follows. From Figure 4, it is clear that

$$\tan(\theta_{0,1}) = \frac{x_U}{y_U} \tag{1}$$

$$\tan(\theta_{1,2}) = \frac{W_2 - x_U}{y_U} \tag{2}$$

and

$$\tan(\theta_{1,3} - \frac{\pi}{2}) = -\cot(\theta_{1,3}) = \frac{W_1 - y_U}{x_U} \tag{3}$$

Equation (1) can be re-written as

$$x_U = \tan(\theta_{0,1}) y_U \tag{4}$$

Substitute (4) into (3) to yield

$$-\cot(\theta_{1,3}) = \frac{W_1 - y_U}{\tan(\theta_{0,1}) y_U} \tag{5}$$

By re-arranging (5), y_U is expressed as

$$y_U = \frac{W_1}{1 - \cot(\theta_{1,3})\tan(\theta_{0,1})} \tag{6}$$

Substitute (6) into (4) to yield

$$x_U = \left[\frac{\tan(\theta_{0,1})}{1 - \cot(\theta_{1,3})\tan(\theta_{0,1})}\right] W_1 \tag{7}$$

From (2), (6) and (7), W_2 is computed as

$$W_2 = \left[\frac{\tan(\theta_{0,1}) + \tan(\theta_{1,2})}{1 - \cot(\theta_{1,3})\tan(\theta_{0,1})}\right] W_1 \tag{8}$$

Equation (8) gives the aspect ratio of this room.

Step 1.3 Determining the coordinates of home appliances: Let N be the number of home appliances to be controlled in the room. Assume that each home appliance k located at point P_k with coordinates (x_k, y_k), where $k = 1, 2, \ldots, N$. In Figure 5, $N = 2$. The PnC instructs the user to point the smartphone to the home appliance k and invokes electronic compass function to calculate $\phi_{U,k}$, the angle between the positive x-axis and line $\overrightarrow{UP_k}$. The equation of line $\overrightarrow{UP_k}$ can be expressed as

$$\overrightarrow{UP_k} : a_k x + b_k y = c_k \tag{9}$$

In (9), if $\phi_{U,k} \mod 90^\circ = 0$ (i.e., $\overrightarrow{UP_k}$ is a vertical line), then $a_k = 1$, $b_k = 0$ and $c_k = x_U$. Otherwise, $a_k = \tan(\phi_{U,k})$, $b_k = -1$ and $c_k = -y_U + \tan(\phi_{U,k})x_U$. As shown in Figure 5, it is clear that $\overrightarrow{UP_k}$ intersects with one of four walls, and the intersection point is the position of the home appliance k. Therefore, the PnC can calculate the coordinates (x_k, y_k) of P_k by computing the coordinates of the intersection point of the wall and $\overrightarrow{UP_k}$.

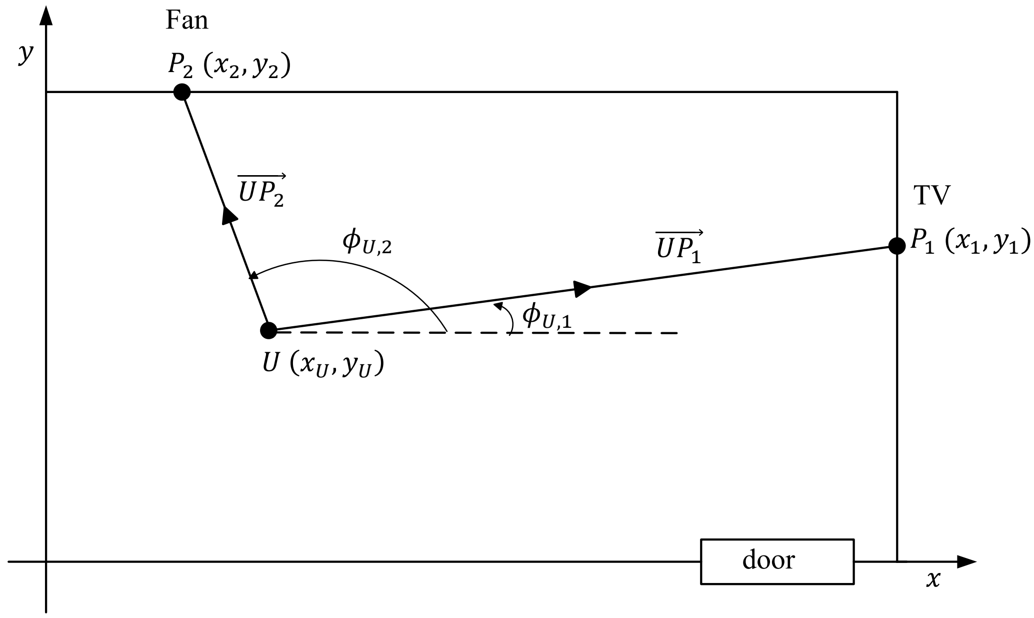


Figure 5: Determination of the coordinates of home appliances

2.2 Remote Control in the PnC

This subsection describes how the PnC selects a possible home appliance pointed by the smartphone with the following steps:

Step 2.1 Identifying the position of the user: When the user selects a room from the Room List page (Figure 3 (a)), the PnC shows the layout of the room and the position of the door (Figure 3 (b)). Based on the door's position, the user can roughly identify her current position U' in this room by touching the screen in the area of the room (e.g., (2) in Figure 3 (b)). The PnC assumes that U' is the position of the user, and calculates the coordinates (x'_U, y'_U) of U' by the room's aspect ratio mentioned in Phase 1. Note that the actual position U of the user may be different from the touched position U'.

Step 2.2 Selecting the home appliance: When the user points the smartphone to a home appliance she wants to control (e.g., the TV located at point P_1 in Figure 6), the PnC obtains $\phi_{U,1}$, the angle between the positive x-axis and $\overrightarrow{UP_1}$ by the electronic compass function. Based on U' and $\phi_{U,1}$, the PnC calculates the pointed home appliance's position at P along $\overrightarrow{U'P}$ with the slope $\tan(\phi_{U,1})$. Because the touched position U' may not be the user's actual position U, point P may not be the position of the pointed home appliance. We use an example in Figure 6 to describe this situation. Define $\phi_{U',k}$ as the angle between the positive x-axis and $\overrightarrow{U'P_k}$ $(1 \leq k \leq N)$. In Figure 6, $k = 1, 2$. The PnC first calculates every $\phi_{U',k}$ from the coordinates of P_k and U', and then finds a $\phi_{U',k}$ that is closest to $\phi_{U,1}$. In our example, $\phi_{U,1}$ is closer to $\phi_{U',1}$ than to $\phi_{U',2}$. Therefore, the PnC selects the TV at P_1, and the remote control interface of the TV is shown on the screen (Figure 3 (c)). From the selection algorithm described above, we have the following fact:

Fact 1. Let $\phi_{U,k}$ and $\phi_{U',k}$ be the angles between the positive x-axis and $\overrightarrow{UP_k}$, and the positive x-axis and $\overrightarrow{U'P_k}$, respectively. Suppose that the smartphone is pointed to the home appliance at P_1. If

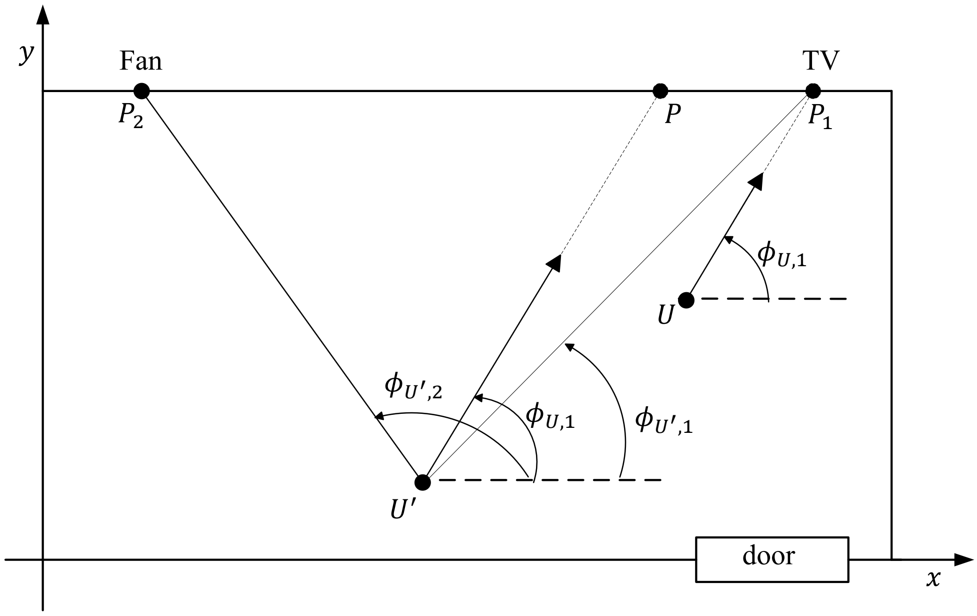


Figure 6: Home appliance selection

$d = 0$, then from the home appliance selection algorithm, $|\phi_{U',1} - \phi_{U,1}| = \min_{1\le k\le N}\left(|\phi_{U',k} - \phi_{U,1}|\right) = 0$ is satisfied, and the PnC will correctly select the appliance at P_1.

Note that if d increases, it more likely that $|\phi_{U',1} - \phi_{U,1}| \neq \min_{1\le k\le N}\left(|\phi_{U',k} - \phi_{U,1}|\right)$, and the PnC may select a wrong home appliance. In the next section, we will quantitatively show how the d value affects the accuracy of the home appliance selection.

3 Accuracy of Home Appliance Selection

As mentioned in Subsection 2.2, if the touched position U' is different from the user's actual position U, the PnC may select a wrong home appliance. As defined in Subsection 2.1, $\phi_{U,k}$ and $\phi_{U',k}$ are the angles between the positive x-axis and $\overrightarrow{UP_k}$, and the positive x-axis and $\overrightarrow{U'P_k}$ ($1 \le k \le N$), respectively. For the same distance d between U and U', the $\phi_{U,1}$ value may be different depending on the user's actual position U. In Figure 7, $\phi_{U,1}$ for U_b is smaller than that for U_a. In this section, we first show that for any d, there exists the minimum and maximum values of $\phi_{U,1}$ (i.e., $\min(\phi_{U,1})$ and $\max(\phi_{U,1})$) such that $\min(\phi_{U,1}) \le \phi_{U,1} \le \max(\phi_{U,1})$. Then based on the range of the $\phi_{U,1}$ values, we derive d^*, the maximum d value such that if the distance $|\overline{UU'}| = d < d^*$, the PnC always selects the home appliance correctly.

For any d, $\min(\phi_{U,1})$ and $\max(\phi_{U,1})$ are derived as follows. In Figure 7, U locates at a point on the circle with the center U' and the radius d. We can obtain two tangent lines through point P_1 on the circle (e.g., $\overline{U_aP_1}$ and $\overline{U_bP_1}$ in Figure 7). It is clear that $\phi_{U,1} = \max(\phi_{U,1})$ when $U = U_a$ and $\phi_{U,1} = \min(\phi_{U,1})$ when $U = U_b$. Let $\Delta\phi_{U,1} = |\phi_{U,1} - \phi_{U',1}|$, we know that $\max(\Delta\phi_{U,1}) = \max(|\min(\phi_{U,1}) - \phi_{U',1}|, |\max(\phi_{U,1}) - \phi_{U',1}|)$. In Figure 7, $|\min(\phi_{U,1}) - \phi_{U',1}| = \angle U_bP_1U'$ and $|\max(\phi_{U,1}) - \phi_{U',1}| = \angle U_aP_1U'$. From the property of the tangent line, $\angle U_aP_1U' \cong \angle U_bP_1U'$. Therefore, $\min(\phi_{U,1})$ and $\max(\phi_{U,1})$ can be expressed as

$$\min(\phi_{U,1}) = \phi_{U',1} - \max(\Delta\phi_{U,1}) \text{ and } \max(\phi_{U,1}) = \phi_{U',1} + \max(\Delta\phi_{U,1}) \quad (10)$$

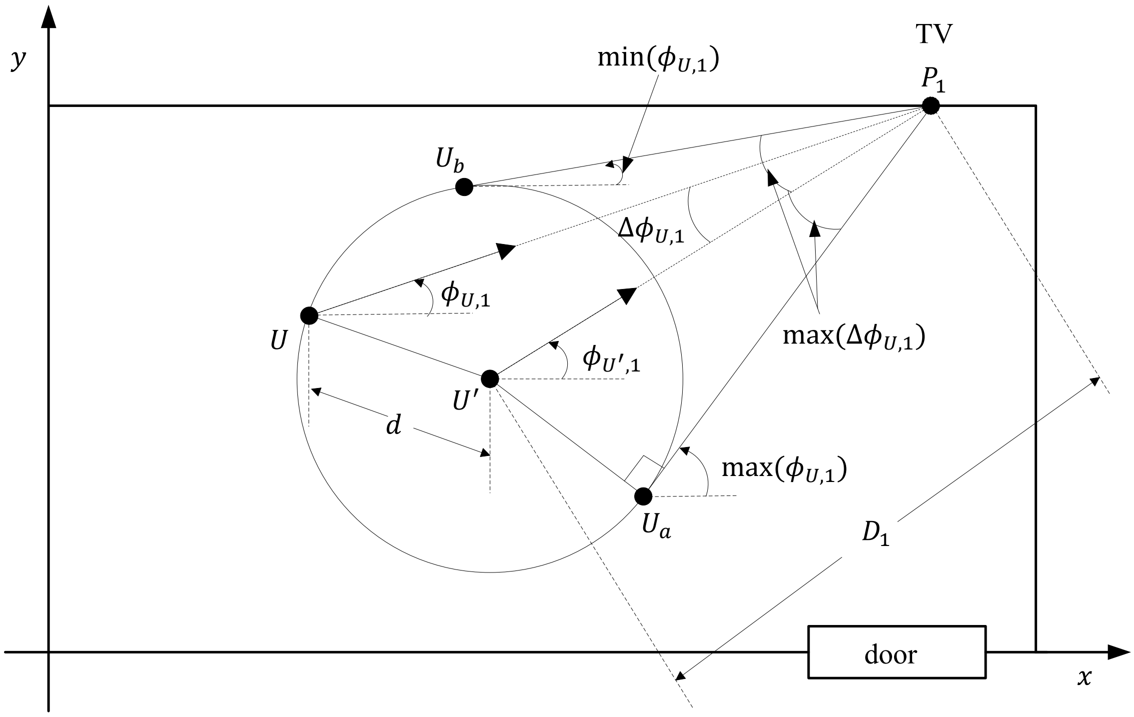


Figure 7: Relationship among $\Delta\phi_1$, $\max(\Delta\phi_1)$ and d

According to the property of the tangent line, the radius $\overline{U'U_a}$ is perpendicular to the tangent line $\overline{U_aP_1}$, and the relationship between d and $\max(\Delta\phi_{U,1})$ is expressed as

$$d = D_1 \sin(\max(\Delta\phi_{U,1})) \tag{11}$$

where $D_1 = |U'P_1|$ is the distance from U' to P_1.

Suppose that the room contains N home appliances, and appliance k locates at point P_k, where $1 \le k \le N$. As illustrated in Figure 6, the PnC assumes that the pointed home appliance is located at P. However, the target appliance is actually located at P_1. Figure 8 redraws Figure 6 to show the condition such that the PnC always selects the home appliance correctly. The condition is given in the following theorem.

Theorem 1. For point P_k $(2 \le k \le N)$, let $\Delta\phi_{1,k}$ be the angle $\angle P_1U'P_k$ and $\Delta\phi_{U,1} = |\phi_{U,1} - \phi_{U',1}|$. Suppose that the smartphone is pointed to the home appliance at P_1. If $\min_{2\le k\le N}(\Delta\phi_{1,k}) > 2\max(\Delta\phi_{U,1})$, then the home appliance at P_1 is correctly selected.

Proof. Let $\angle PU'P_t = \min_{2\le k\le N}(\angle PU'P_k)$. As indicated in Figure 8,

$$\begin{aligned}\Delta\phi_{1,t} &= \Delta\phi_{U,1} + \angle PU'P_t \\ &= |\phi_{U',1} - \phi_{U,1}| + |\phi_{U',t} - \phi_{U,1}|\end{aligned} \tag{12}$$

From the hypothesis, we know that

$$\Delta\phi_{1,t} > 2\Delta\phi_{U,1} \tag{13}$$

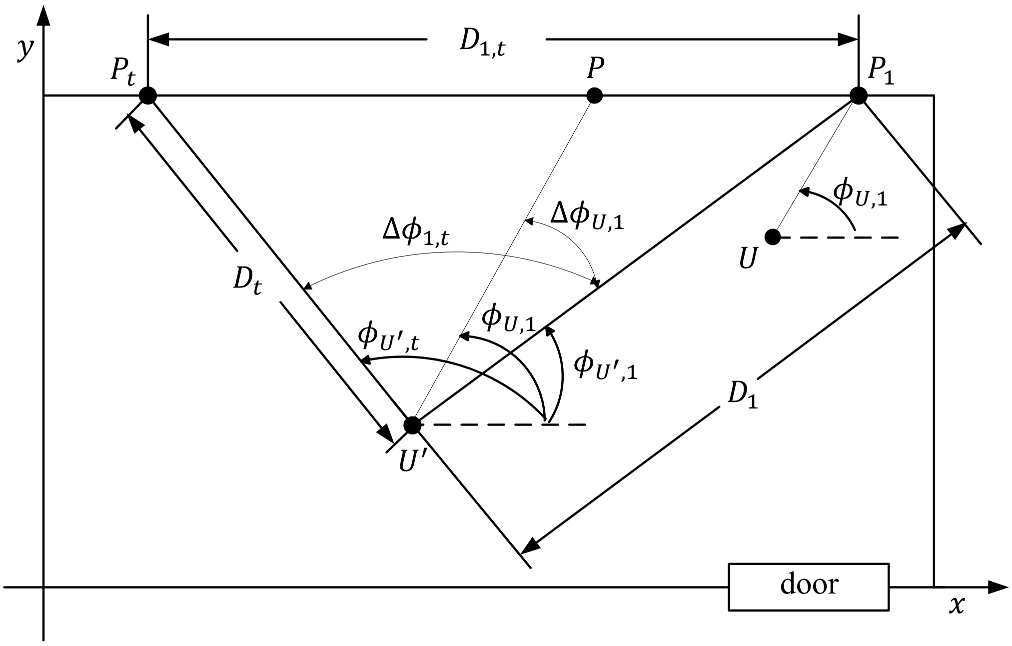


Figure 8: Relationship among D_1, D_t and $D_{1,t}$

By re-arranging (13), we obtain

$$\Delta\phi_{1,t} - \Delta\phi_{U,1} > \Delta\phi_{U,1} \tag{14}$$

Substitute (12) into (14) to yield

$$|\phi_{U',1} - \phi_{U,1}| + |\phi_{U',t} - \phi_{U,1}| - \Delta\phi_{U,1} > \Delta\phi_{U,1} \tag{15}$$

Since $\Delta\phi_{U,1} = |\phi_{U',1} - \phi_{U,1}|$, (15) can be re-written as

$$|\phi_{U',t} - \phi_{U,1}| > \Delta\phi_{U,1} \tag{16}$$

From (16), it is clear that $\phi_{U,1}$ is closer to $\phi_{U',1}$ than to $\phi_{U',t}$. Since $|\phi_{U',t} - \phi_{U,1}| = \min_{2\le k\le N}(\angle PU'P_k)$, we know $|\phi_{U',1} - \phi_{U,1}| = \min_{1\le k\le N}\left(|\phi_{U',k} - \phi_{U,1}|\right)$. Then according to the home appliance selection algorithm described in Subsection 2.2, the PnC selects the home appliance at P_1. □

Based on Theorem 1, we derive d^*, the maximum d value such that the PnC can select the home appliance correctly in Theorem 2.

Theorem 2. Suppose that the room contains N home appliances, and the user points the smartphone to the appliance at P_1. Let $\angle PU'P_t = \min_{2\le k\le N}(\angle PU'P_k)$. Define D_1, D_t and $D_{1,t}$ as the length $\overline{U'P_1}$, $\overline{U'P_t}$ and $\overline{P_1P_t}$, respectively (see Figure 8). Let

$$d^* = \sqrt{\left(\frac{D_1}{4D_t}\right)\left[D_{1,t}^2 - (D_1 - D_t)^2\right]}$$

then for any $d < d^*$, the home appliance at P_1 is correctly selected.

Proof. For every $\Delta\phi_{1,k}$, we have $0^\circ \le \Delta\phi_{1,k} \le 180^\circ$. From (13), we have

$$\cos(\Delta\phi_{1,t}) < \cos(2\max(\Delta\phi_{U,1})) \tag{17}$$

Because $\cos(2\max(\Delta\phi_{U,1})) = 1 - 2\sin^2(\max(\Delta\phi_{U,1}))$, (17) can be re-written as

$$\cos(\Delta\phi_{1,t}) < 1 - 2\sin^2(\max(\Delta\phi_{U,1})) \tag{18}$$

According to the cosine formula, $\cos(\Delta\phi_{1,t})$ can be represented as

$$\cos(\Delta\phi_{1,t}) = \frac{D_1^2 + D_t^2 - D_{1,t}^2}{2D_1D_t} \tag{19}$$

Substitute $\cos(\Delta\phi_{1,t})$ in (19) and $\sin(\max(\Delta\phi_{U,1}))$ in (11) into (18) to yield

$$\frac{D_1^2 + D_t^2 - D_{1,t}^2}{2D_1D_t} < 1 - 2\left(\frac{d}{D_1}\right)^2 \tag{20}$$

By re-arranging (20), we have

$$d^* = \sqrt{\left(\frac{D_1}{4D_t}\right)\left[D_{1,t}^2 - (D_1 - D_t)^2\right]} \tag{21}$$

In other words, for any $d < d^*$, the PnC selects the home appliance at P_1 (i.e., a correct selection). □

Based on Theorem 2, we have the following corollary:

Corollary 1. The d^* value can be expressed as

$$d^* = D_1\sqrt{\frac{1-\cos(\Delta\phi_{1,t})}{2}}$$

Proof. From the cosine formula, we have

$$D_{1,t}^2 = D_1^2 + D_t^2 - 2D_1D_t\cos(\Delta\phi_{1,t}) \tag{22}$$

Substitute (22) in (21), we have

$$d^* = D_1\sqrt{\frac{1-\cos(\Delta\phi_{1,t})}{2}} \tag{23}$$

□

4 Numerical Examples

From our discussion in the previous section, it is clear that the larger the d^* value, the better the performance of the PnC. This section uses numerical examples to investigate how parameters D_1, D_t and $D_{1,t}$ affect the d^* value. For the description purpose, D_1, D_t and $D_{1,t}$ are normalized by W_1.

Effect of D_1 and D_t: Figure 9 plots the d^* value as a function of D_1 and D_t, where $D_{1,t} = 0.5\ W_1$. In this figure, a • mark represents the maximum d^* value for a specific D_t. This figure indicates that d^* increases and then decreases as D_1 increases. This phenomenon can be directly observed from (21). Specifically, when D_1 increases, the $\frac{D_1}{D_t}$ term in (21) increases, and d^* tends to increase. On

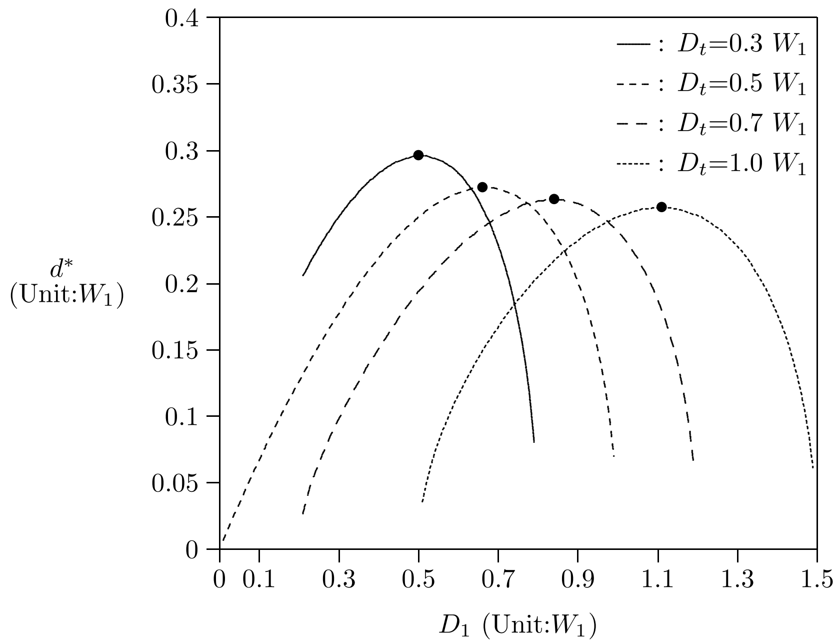


Figure 9: Effect of D_1 and D_t ($D_{1,t} = 0.5\ W_1$)

the other hand, when D_1 increases, the $D_{1,t}^2 - (D_1 - D_t)^2$ term decreases, and d^* tends to decrease. That is, D_1 has two conflicting effects on d^*. The net effect is that, d^* increases and then decreases as D_1 increases. Assume that the PnC works on the iPhone 4 (the width and the length of the iPhone 4 screen is 59.3 mm and 89.0 mm respectively), and the room aspect ratio is equal to that of the iPhone 4 screen (i.e., = 1.5). Figure 9 shows that the maximum d^* value ranges in [0.25 W_1, 0.30 W_1]. That is, the maximum allowable length between the touched position and the user's actual position on the screen ranges in [12.5 mm, 15.0 mm]. This result is good enough for practical operations of the PnC.

Effect of $D_{1,t}$ and D_t: Figure 10 plots the d^* value as a function of $D_{1,t}$ and D_t, where $D_1 = 0.5\ W_1$. From (21), it is clear that d^* increases as $D_{1,t}$ increases. The non-trivial observation is that for a fixed D_1 value, when D_t is small (e.g., the solid curve where $D_t = 0.3\ W_1$), d^* significantly increases as $D_{1,t}$ increases. This phenomenon is explained as follows. From (19), for a fixed D_1 value, $\Delta\phi_{1,t}$ increases as $D_{1,t}$ increases. Also, when D_t is small, $\Delta\phi_{1,t}$ is more sensitive to the change of $D_{1,t}$. According to Corollary 1, a larger $\Delta\phi_{1,t}$ implies a larger d^*. Therefore, when D_t is small, d^* significantly increases as $D_{1,t}$ increases. When D_t is not small (e.g., when $D_t > 0.3\ W_1$), Figure 10 shows that when $D_{1,t} \geq D_t$, the d^* values are in the range [0.25 W_1, 0.50 W_1]. Since the user generally controls home appliances within a certain area in the room (e.g., in the living room, the user always controls the TV or other appliances around the sofa), this result indicates that the d^* value is large enough, so that the PnC achieves a good performance in practical operations.

5 Conclusion

In this paper, we proposed a scheme called *Point-and-Control* (PnC) which can calculate the position of each home appliance and recognize it only by means of the compass orientation. The PnC provides a

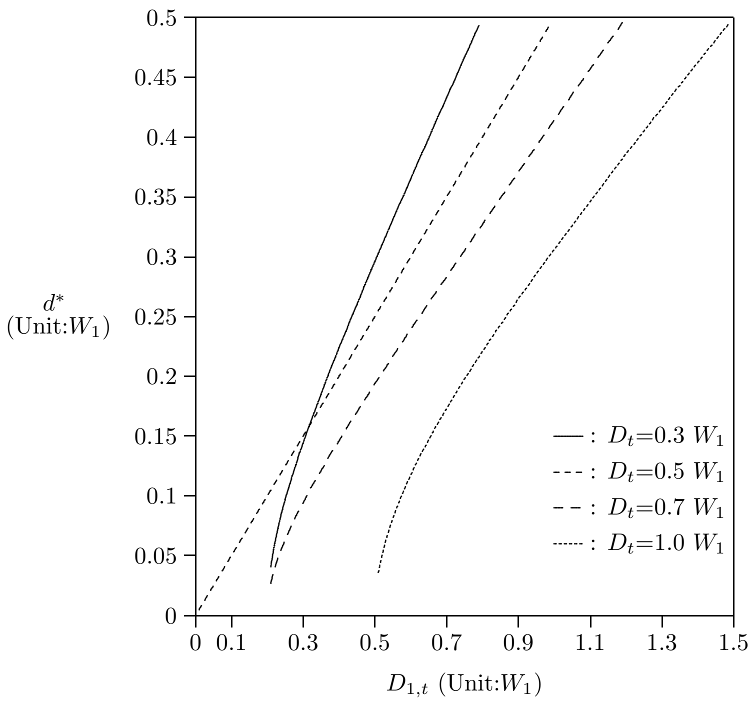


Figure 10: Effect of $D_{1,t}$ and D_t ($D_1 = 0.5\ W_1$)

user friendly interface, where the user can select a home appliance by simply pointing to that appliance. Since the user may move after her position was identified by the PnC, there may exist a distance d between the user's actual position U and the position U' assumed by the PnC. We utilize an analytic model to investigate d^*, the maximum d value such that for any $d < d^*$, the PnC always selects the target appliance correctly. We use some numerical examples to show that the PnC can achieve a good performance in practical operations.

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