Gesturenomy: Touchless Restaurant Menu Using Hand Gesture Recognition

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Abstract

Hand gesture recognition is one of the more modern methods of human-computer interaction. However, study of its application in real world setting is sparse, especially its use in digital restaurant menus. We discuss various types of computer vision-based hand gesture recognition and decide on hand pose estimation as the method of recognition used. An analysis into the requirements show that respondents are concerned with the hygiene of touchscreen digital menus. We provide a description of the system being developed. The system passes the user acceptance tests given.

Keywords: digital restaurant menu, hand gesture recognition, hand pose estimation, human computer interaction

1. Introduction

A post-WIMP interface is any interface that does not use menus, forms, or toolbars but relies on more convenient interactions, of which hand gesture recognition is an example.[1] Hand gesture recognition has a few advantages, namely sterility as the user never touches the device, accessibility by people with physical handicaps, and efficiency from using three dimensions.[2] There are two main types of hand gesture recognition, with wearable technology or with computer vision.[3] While the first is simpler to implement, it may be intrusive and requires additional equipment. This project will use the latter.

Transmission of SARS-CoV-2 through inanimate surfaces is doubted[4], however other diseases may still be transmitted through fomites. Morens et al.[5] reported fomites or contaminated hands as the transmission method in a nursing home outbreak of influenza A. People should err on the side of caution. There are various ways of preventing disease transmission, such as through touchless technology. Transmission through this method is unlikely as no surface contact is performed.

This paper proposes the use of hand gesture recognition in digital restaurant menus. We discuss the analysis, design, implementation, and evaluation of the application.

We now state the research objectives:

- To investigate the current hand gesture recognition techniques.
- To design an application that utilizes the most suitable technique.

- To develop a prototype of a hand gesture control application.
- To evaluate the effectiveness of the prototype application.

The paper will be structured as follows. Section 1, this section, elaborates on the problem statement, the research objectives, and the report structure. Section 2 studies similar systems that have been developed in the past, ending with a comparison on each system. Section 3 explains the research methodology of the project, consisting of the software development life cycle model chosen and the method of requirements gathering. Section 4 shows the result of data gathering and the design of the system.

2. Literature Review

2.1. *Hand Gesture Recognition*

Oudah et al.[3] splits vision-based hand gesture recognition into seven categories:
Color-based recognition. The system determines hand gesture based on the color of each pixel. An example is by using color gloves whose colors are tracked with nearest-neighbor approach[6]. However, this still requires the subject to wear an additional glove, which is not suitable for some purposes. Another way is to use skin color. Perimal et al.[7] converts the image into YCbCr color space, determines which pixels are colored, removes parts that are not the tip of the finger, and counting the fingers.

- *Appearance-based recognition.* Features are extracted from the shape of the hand, giving the advantage of having similar behavior on varying skin colors. One way to do this is through edge detection. Kulkarni and Lokhande[8] converts the image into grayscale before performing edge detection and using neural networks to classify it into gestures.
- *Motion-based recognition.* Gesture is determined by seeing how the image changes from one image to another. Molina et al.[9] uses time-of-flight cameras to capture the depth data of an image. The closest point of the image is chosen as the point of interest. The system determines the trajectory of the hand and compares it with the synthetic patterns. The closest pattern is chosen as the gesture.
- *Skeleton-based recognition.* Geometric features of the hand such as joint orientation, space between joints, skeletal joint location, and angle between joints are extracted from the image. Konstantinidis et al.[10] extracts body and hand skeletal data from the image and compares the joint positions relative to the neck joint. Occluded joints use data from the previous frames.
- *Depth-based recognition.* Using depth information to extract gestures has a few advantages, namely that the system no longer needs to consider lighting, shade, and color. This category of recognition system usually uses depth-sensing devices such as Microsoft Kinect to get depth information. Ma and Peng[11] combines depth information and color information to obtain the region of interest and locates the fingertips.
- *3D model-based recognition.* The algorithm uses a 3D model to be compared to the 2D input. Ge et al.[12] uses constructs a 3D model of the hand using Graph CNN, which gives a more detailed output.
- *Deep learning-based recognition.* The usage of deep learning is useful as gesture recognition is a complex task, however gathering datasets to train the neural network requires much effort. Wu[13] used a double channel convolutional neural network, where one channel gets the denoised version of the image, and the other channel gets image after being processed through edge detection. The result has 98.02% recognition rate.

The method used in this project is through pose estimation, which has an advantage of the ease of adding or modifying new gestures to recognize. Such systems typically follow two steps: first, the neural network (NN) is used to find the location of the hand, which is used to crop and resize the image to contain only the hand. Another NN will perform the actual pose estimation. Zimmerman and Brox[14] treats the image as a segmentation problem, whose output is used to determine the position of the hand. The cropped RGB image is fed into an encoder-decoder model (PoseNet) that outputs 21 two-dimensional score maps. These score maps are used as input into PosePrior which regresses the 3D coordinates of each 21 joints and a 3x3 transformation matrix between the canonical coordinates and the viewpoint coordinates. Malik et al.[15] feeds a depth map into a convolutional neural network (CNN) to get a feature map, which is fed into a regression network to get the hand joint position, hand mesh vertices, and structural constraint. Spurr et al.[16] proposes the use of biomechanical constraints to increase the accuracy of already existing pose estimation system, allowing it to be weakly supervised. The biomechanical constraint function can be added as a loss function to an already existing model. Zhang et al.[17] presents a real time hand pose estimation solution with RGB input. The hand detection system only detects the palm, as it has a simpler shape compared to the entire hand. In addition to being cropped and resized, the image is also rotated so that the hand is always in the same direction. The hand landmark detection outputs 21 landmark, like Ref. 14. It also outputs the probability of a hand being present and its handedness (left or right). The system achieves real-time performance, even on mobile devices.

2.2. *Digital Restaurant Menus*

The most basic form of restaurant menu is paper based. However, this has the drawbacks where the customer needs to wait to order food. In addition, it also wastes paper, as a different customer needs a different piece of paper to track the order[18]. Some digital restaurant menu systems are built to counteract these drawbacks.

Şahin[19] classifies digital menus into touchscreen menu systems which allow for self-service and non-touchscreen menu systems which require interaction with the staff to place an order. However, this classification may be misleading as this paper describes a touchless self-service system, hence we will refer to these as *interactive* and *non-interactive* respectively.

There are two types of non-interactive menus. A static digital menu board only uses static images that may change periodically to show different items, while a dynamic digital menu board has part of or the entire screen moving (i.e. motion graphics or videos). Interactive menu boards commonly use tablets, tabletop touchscreen devices, mobile apps, and kiosks. Bhargave et al.[18] built an Android-based digital ordering system where the restaurant provides a tablet at each table to browse the menu. This reduces paper waste and allows for self-service.

Rusdi et al.[20] uses a mobile phone as a digital menu, which gives the convenience of having the entire menu on the customer's phone, reducing the need for tablets as Ref. 18 does. However, the customer might not have an internet connection or sufficient battery power. Downloading an application may not be attractive to some users.

2.3. *Comparison of Hand Gesture Recognition Systems*

We compare various existing systems that use hand gesture recognition. Desai and Desai[21] used hand gesture recognition to control a home automation system. The recognition is performed by using Microsoft Kinect as input. Four gestures are chosen to represent switching on/off lights, fan, phone charger, and TV set. A fifth gesture is used to shut down all appliances that were on. The accuracy of the system is 88%.

Suriya and Vijayachamundeeswari[22] used hand gesture recognition to control mouse on a desktop computer. Skin color detection is used, and the fingers are located by using convex hull algorithm. A linear discriminate analysis is performed to classify the gestures. The gestures being tracked are Arabic numerals alphabet.

Gestix[23] is a hand gesture-based interface used by doctors to navigate electronic medical record (EMR) databases without coming into contact with the computer. The system uses color and motion data to segment the image to determine the shape of the hand. A state machine is used to determine which gestures are being made. Surgeons' focus was shown to be improved and the interface proved to be intuitive.

Al et al.[24] use hand gesture recognition to control a Universal Robot (UR3) arm. The system uses proximity sensors to detect the position of the hand. The data is transferred from the Arduino to a MATLAB instance to be classified by an artificial neural network (ANN) into *up*, *down*, *left*, or *right*.

Zhang et al.[25] uses hand gesture recognition to control the movement of a player in a VR game. The input is gathered using the Leap Motion controller mounted in front of an Oculus Rift headset. The system was found to be intuitive, easy to learn and use, and causes low fatigue. The immersion of the player is improved and motion sickness is reduced.

Out of the system described above, the one that will most resemble this project is Gestix, due to it only using color and motion data to control a graphical user interface. The system described by Ref. 21 is also similar in spirit, in that each gestures are mapped to one action. In addition, the gestures are used to navigate a menu, in comparison to HRI or DHGI, which interacts with a robot arm or a VR player respectively.

3. Research Methodology

3.1. *System Development Life Cycle*

The project is developed on the *prototyping* model. It is an iterative development model which is used when details of the system (i.e. input, process output) are not clearly defined yet. The first step is *requirements* *gathering and analysis*, where the developer gathers expectations from users. The process of requirements gathering in this project will be elaborated in the next subsection.

The second step is *quick design*, where a simple version of the system is designed to get a brief idea of the software. In this project, this is done by listing some required features. The first prototype, for example, could only view the menu, scroll it left to right, and swap between recommended menu and the entire menu.

The fourth step is *user evaluation*, where the prototype is shown to the client or end user. The user gives feedback such as user experience or adding new features. The fifth step is *refining prototype*, which uses the feedback to refine the requirements and design of the prototype. After building a new prototype, user evaluation is performed again. This process is repeated until the result is satisfactory.

The sixth step is *product implementation and maintenance*, where a final implementation is built with care into building a high quality and maintainable system. This project stops at product implementation, as maintenance is out of the scope of the project.

3.2. *Questionnaire*

The process of requirements gathering is done through a questionnaire. The questionnaire is shared through UCSI CourseNetworking page to UCSI University undergraduate and masters students and gathered a total of 29 responses. Questions that are asked include the respondent's opinions on digital restaurant menus, what features they think should be in a menu, their concerns of the hygiene of conventional menus, and their opinions on what advantages and disadvantages using hand gesture recognition has. Most of the questions are in long form to gain a deeper understanding than possible with multiple choices.

4. Analysis and Design

4.1. *Analysis*

We analyze the findings from the questionnaire as described in the previous section. The first question asks whether restaurants should use digital restaurant menus, ranging from 1 (strongly disagree) to 5 (strongly agree). The result can be seen in Figure 1. Fifteen respondents chose 4 (agree), and the average score is 4.17. We conclude that most people agree restaurant should use digital restaurant menus.

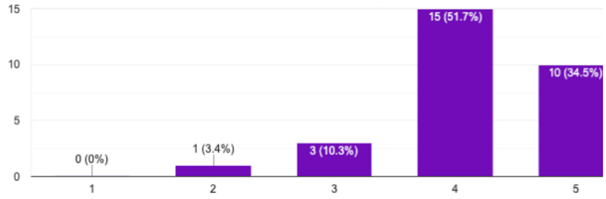

Fig. 1. Chart of responses to whether restaurants should use digital restaurant menus.

Two questions were asked relating to features that should be in a digital restaurant menu. The first question lists features found in other digital menus, while the second asks for any other features needed in a restaurant menu. Table 1 shows the average score for each features, where 1 is very undesirable and 5 is very desirable. Other features that have been requested (in decreasing frequency) include: dish price, special offers, special sets, digital payment methods, cart system, waiter notification system, and description of the freshness of the ingredients.

Table 1. Average score of each features

Feature	Avg. Score	Feature	Avg. Score
Image of the dish	4.52	Non-allergy warnings (e.g. spicy food)	4.59
Description of the dish	4.34	Recommended	4.38
Nutritional content	3.76	List of ingredients	4.17
Dish variations	4.14	Estimated preparation time	3.93
Allergy warnings	4.59		

Next, the respondents are asked about their concerns of the hygiene of touchscreen digital restaurant menus. Seventeen respondents expressed concerns about the hygiene of touchscreen digital menus. Reasons for the concern include the fact that the device is used by many people, who may leave virus or bacteria on it. Some expressed their distrust in the restaurant's ability to manage the hygiene of their touchscreen surfaces. Respondents who do not have hygiene concerns have trust in the restaurant's hygiene policies.

The next question asks whether the respondents believe that gesture recognition could solve this problem. There are 19 responses that agree with this, most citing the lack of surface contact as the reason. Three respondents are neutral. Four responses expressed distrust in the technology, and that there needs to be more testing to evaluate its feasibility.

The last question asks whether the respondents have any worries about issues that may arise from the use of this technology. Fifteen respondents have concerns with the recognition systems, as there is a risk of low accuracy and slow performance. Ease-of-learning was a concern in 7 of the responses. Maintenance issues was brought up by 2 responses. Two responses are concerned with the possibilities of making mistakes. Five responses have no concerns about any issues.

4.2. *Design*

In this section, we look at the system's design created to fulfill the requirements. Figure 2 shows the use case diagram of the system. It consists of two main parts; the customer-facing parts and the staff-facing part.

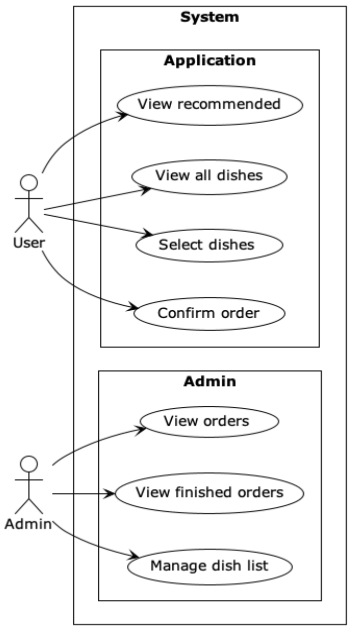

Fig. 2. Use case diagram of the system.

Figure 3 shows the activity diagram of the user's experience interacting with the system.

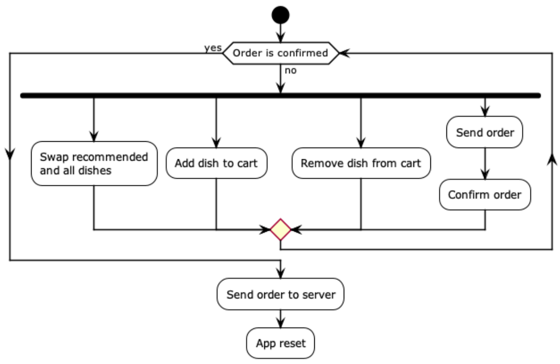

Fig. 3. Activity diagram of the user's interaction with the system.

5. Implementation and Evaluation

In this section, we look at the list of features that the system has and the list of tests that are performed to ensure the system is satisfactory.

5.1. *Implementation*

The customer-facing application is designed as follows: most of the screen is taken up by the menu itself. Below it, the gesture that is detected is shown as feedback to the user. There is also the cart. This cart shows which items the user has picked, how many of each, and the total price.

The user may swap between viewing the recommended screen and viewing all offered dishes by holding a peace sign. To prevent accidentally swapping, the user must hold this gesture for approximately one second. The user can scroll through the menu by making a fist gesture and moving it left to right.

To select an item, the user performs a "point up" gesture. A pointer that moves with the user's hand is shown when it is visible. By aiming this pointer, the user can add items into the cart. To add multiple, the user can redo the gesture again or hold the gesture. The "point down" gesture behaves similarly, but removes items from the cart instead.

Removing an item from the cart is intuitively done by performing a "point down" gesture. Removing multiple items can be done similarly to adding multiple items.

When the user is ready selecting, they can perform the "thumbs up" gesture. When this is done, the user will be asked to confirm whether they are sure of this action. To decline, a "thumbs down" gesture can be done. This will send the user back to the original screen. Otherwise, the user can do the "thumbs up" gesture again. This will send the user's order to the staff. A thank you screen is shown, along with the total price and the order number.

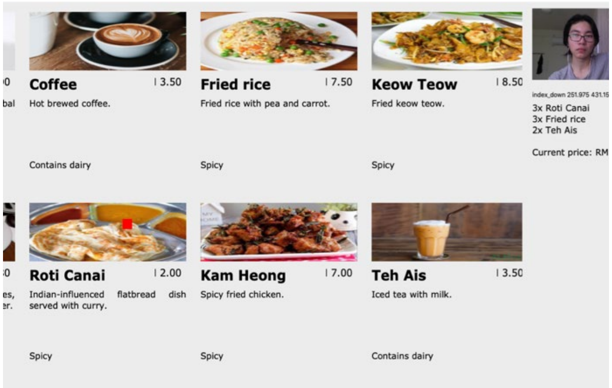

Fig. 4. Screenshot of the application with the cart being filled.

For convenience, if the cart is already filled when a user had just started using the system, they may do a "thumbs down" gesture on the menu screen to empty it.

The system is built using C++ using Qt as its GUI framework. The server uses Django backend with SQLite for its database. The two parts communicate using the REST API. Hand gesture recognition is performed by calling Python functions from the C++ application.

5.2. *Evaluation*

We describe the user acceptance tests that are conducted to deem this system satisfactory. Table 2 shows the tests that are designed to verify that each piece of the system is functioning correctly.

Table 2. The user acceptance test along with each result

No.	Description	Result
1	Start the application. Application connects to server correctly. App shows a list of recommended dishes.	Pass
2	Perform a peace sign. The menu should refresh and show more dishes that weren't in the recommended section.	Pass
3	Perform a peace sign again. This should show less items.	Pass
4	Perform a grabbing and dragging motion. This should scroll the menu in the correct direction, i.e. to the user's left if the user drags it to the left, and vice versa.	Pass
5	Move the user's hands around. The red square on the screen should follow the user's motion accurately.	Pass
6	Point up at an item. After a moment the cart should update to show that item.	Pass
7	Point up at another item, this time holding it longer. The cart should increment that item until the user stops.	Pass
8	Point down at the item specified in Test 6. This should remove that item from the cart.	Pass
9	Perform Test 7 on a different item, then point down at that item, holding it longer. This should decrease that item one by one. If the user still holds down when the item is no longer in the cart, nothing should happen.	Pass
10	Scroll the menu as described in Test 4. Point up at an item. This should update the cart with the correct item.	Pass
11	Perform a thumb up. The screen should show a dialog box confirming the user's decision.	Pass
12	Perform a thumb down. The screen should go back to the menu.	Pass
13	Perform Test 11 and perform another thumb up gesture. The screen should now show a dialog box with the total price and the order number.	Pass
14	Perform Test 6 to 10, then perform a thumb down gesture. The cart should be emptied.	Pass

6. Conclusion

We have discussed the need for a digital restaurant menu with hand gesture recognition interface, and proposed such system. An application is designed and implemented. The user testing evaluation shows that the application functions as intended.

There are many limitations present in the current system. Starting from the analysis step, the sample size and demographics of the questionnaire means that this result may not be an accurate representative of the public. Highly rated features as dish variations were not present. In addition, a more in-depth user testing would be beneficial, such as to test the intuitiveness and ease-of-use of the system.

This project contributes to the knowledge base by providing one case study of the use in hand gesture recognition in digital restaurant menus, as research in this application of gesture recognition is currently minimal. The author hopes that this project can open the doors for more research into this topic.

In the future, research into how this system affects businesses can be looked into, including its effects on the maintenance costs, efficiency of running the restaurant, and public reception. Analysis could be done more accurately by using a larger and more diverse sample size. The effectiveness of each hand gesture can be looked into more deeply, as people of different backgrounds could have different understandings on which gestures would feel more intuitive. A way to customize which gestures correspond to an action would be beneficial for this purpose. More of the features requested in the questionnaire could be implemented.

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