Sensing Fork: Eating Behavior Detection Utensil and Mobile Persuasive Game

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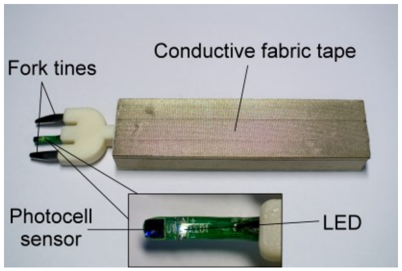
Abstract
We propose a fork-type sensing device, Sensing Fork, which detects children's eating behavior (eating actions and chosen food) and a smartphone game to address children's eating problems. This paper describes the design and implementation of the Sensing Fork prototype and the play-based eating game called Hungry Panda.

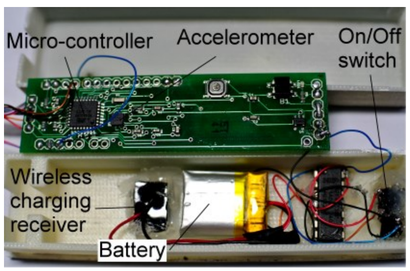
Author Keywords
chilren's eating behavior; gamification; persuasive computing; mobile computing; eating action detection; food recogniction

ACM Classification Keywords
H.5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

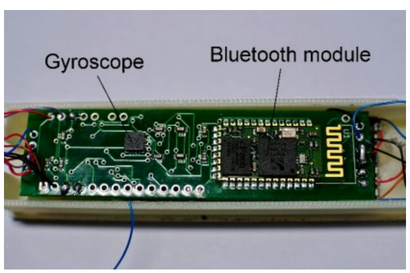
Introduction
Researchers have recently introduced a wide variety of mobile persuasion systems that leverage a smart phone and its built-in/off-phone sensors to observe human activities. Based on these sensed activities, the phone can provide feedback to motivate human behavioral changes. Examples of these systems include Playful Bottle, UbiGreen and OrderUP [1, 2, 3]. Our study



(a) Front view.



(b) Top view of circuit board



(c) Bottom view of circuit board

Figure 1. Sensing Fork prototype. Dimensions: L143xW27xH16 mm

targets young children's eating behavior, a most common concern of parents [4, 5, 6] because children's eating behaviors are highly associated with their nutritional health and development.

The prior study developed an interactive fork, called "EaTheremin [7]", which improves dietary habits of children. Hapifork [8] provides tactile feedback of "quick-eating" behavior based on the biting interval. However, the prior systems cannot detect sufficient behaviors because of the limitation of sensors. Specifically, this study focuses on the design and implementation of a Sensing Fork that embeds various miniature sensors, including an accelerometer, a gyroscope sensor, a photocell sensor, and electrodes, to detect children's eating actions and chosen (or avoided) food. The Sensing Fork includes a wireless radio to communicate sensor data to a phone or a mobile device. The mobile device then analyzes the sensor data while providing children with gameplay interactivity to address their eating problems. The Sensing Fork is compact and portable, and is designed for use with a mobile device in various places where food is served, such as homes, nurseries, schools, and restaurants. Although there are utensils other than a fork for embedding smart sensing and activity recognition technology, we selected the fork because it is one of the most basic utensils that young children use to learn self-feeding skill development.

Sensing Fork Prototype Design

The Sensing Fork system has two main components shown: a sensor-embedded fork (Fig. 1) and a mobile phone. The mobile phone contains three software components: (1) an eating action detector that recognizes the state of a fork by analyzing sensor data from the Sensing Fork and then infers a child's eating action from the fork state; (2) a food recognizer that distinguishes a food item that touches the Sensing Fork; and (3) a parent-configurable eating game, called Hungry Panda, which helps parents address a child's eating problem. We start with the description of the design and prototype of the Sensing Fork below.

Sensing Fork

The Sensing Fork uses the following sensors and hardware components packaged together on a small PCB board:

- Single-pixel photocell sensor:
This sensor (Fig. 1(a)) detects four color channels: red, green, blue, and clear. Color serves as a feature to distinguish different food items that touch the fork. The photocell sensor is enclosed in a tiny circuit board, and the board is attached to the tip of the fork's middle tine. When the fork tine is buried within a food item, a tiny white LED illuminates the food color. For food safety and waterproof requirement, we coated the circuit board with transparent dental resin.

- Three-axis accelerometer and gyroscope:
These motion-related sensors provide six degrees of inertial measurements. These motion sensor data are used to determine the fork's motion and state during a child's eating activity. From the fork's motion and state, our system further infers a child's eating action (or inaction). The details of the eating action detector are explained in the section of "Eating Action Detection".

- Electrodes and resistance sensing:
The two outer tines of a fork are wired with electrodes to measure the resistance value of any food item that touches both of the fork's outer tines (Fig. 2). Because

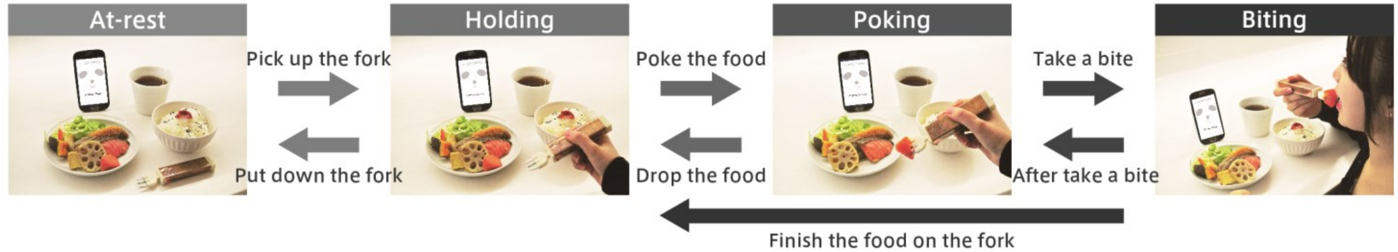


Figure 3. State transition diagram of eating actions.

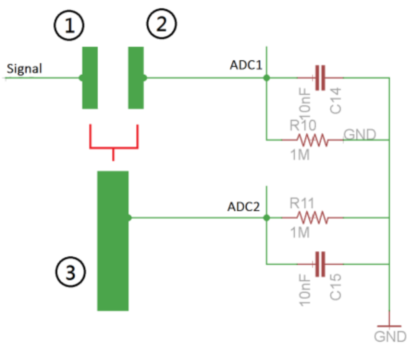


Figure 2. Electrodes and resistance sensing schematic. Marker 1 and 2 represent two fork's tines. Marker 3 is the fork's grip.

food items have varying degrees of electrical conductivity, a food's resistance value can be used as a feature for food recognition. The fork grip is wired with an additional electrode. When the fork touches a child's mouth, it completes an electrical circuit that goes from the fork grip to the child's hand and mouth, through the food item on the fork, and finally back at the fork tines. The eating action detector uses these electrodes to infer the fork's state and whether it touches a child's mouth.

The Sensing Fork also contains a Bluetooth radio to periodically transmit sensor readings to a mobile device for data analysis. The Sensing Fork is powered by a 120 mA single-cell lithium battery. We tested the Sensing Fork's battery life to be over two hours at a radio transmission rate of five samples per second. To meet waterproofing and washing requirements, the Sensing Fork uses wireless inductive charging, so that there is no exposure of any electronic conductor on the outside of the device.

Eating Action Detection

The eating action detector analyzes sensor readings from the fork and determines the state of the fork during a child's eating action. Figure 3 shows each of these four fork states, and describes how the proposed system infers these four fork states.

- At-rest State:
The fork is at rest and not held by a child's hand. If the fork is the only eating utensil for the child, this state suggests that the child is not engaging in any eating action. The system infers the *at-rest state* by the lack of motion from the fork's accelerometer and gyroscope sensors.

- Holding State:
The child is holding the fork in his/her hand without any food on the fork. This state suggests that the child has lifted the fork and may be deciding which food item to grab with the fork. The system infers this *holding state* based on the detection of motion by the fork's accelerometer and gyroscope sensors.

- Poking State:
The child is poking a food item and placing the fork's tines in contact with some food. This state suggests that the child is in the process of grabbing food, but has not inserted it into his/her mouth. The system infers the *poking state* from two types of sensors: (1) the two electrodes on the fork tines measure the presence of some food item with a not-null food resistance value, and (2) the photocell sensor detects

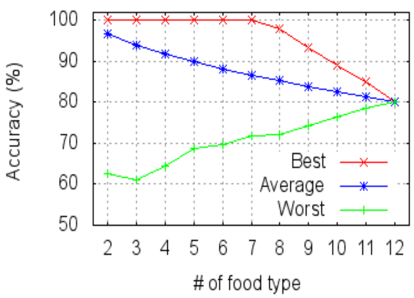


Figure 4. The food recognition accuracy of different number of food types.

the presence of some food color. When the fork touches some food, the system triggers the food recognizer (described in the next section).

- Biting State:
The fork holding a food item touches a child's mouth. This state suggests that the child is biting or tasting food on the fork. The system infers the *biting state* from measuring non-zero readings on the fork circuit connecting a child's hand, the fork, and his/her mouth. To reduce inference errors for the biting state, the system incorporates three mechanisms. (1) The fork's circuit ensures that the fork-holding person must be the same as the eating person. In other words, a child feeding another person does not trigger a biting state. (2) To prevent a child from faking an eating action (i.e., by licking the fork's tines without any food), the system sets a constraint that the *holding state* cannot directly transit to the *biting state*. (3) Accelerometer and gyroscope readings check if the fork's orientation and motion are consistent and conforming to those produced by children's eating gesture. Detecting eating gesture enables the system to filter out similar but non-eating actions such as when a child removes the food on the fork by hand.

The system also logs a child's eating frequency, time interval between subsequent bites, and the food selection sequence.

Food Recognition

The food recognizer first trains a model to classify different food items. This model uses two features: food color from the fork's photocell sensor and the food resistance value from the fork's electrodes. Training this food recognition model is performed prior to the start of a meal, in which a child's parent uses the Sensing Fork to gently poke each food item. The Sensing Fork then collects sample data, including each food item's color and resistance values, and sends this information to a mobile phone that trains a support vector machine classification system [9].

Because the clear channel measures the intensity of light, the sensed RGB readings increase linearly with light intensity. Therefore, the system normalizes the RGB readings based on the light intensity value. The normalized RGB readings serve as features for classification. When food touches the fork, the food recognizer computes the average value over a sliding window of 15 data samples to filter out noise.

We tested the accuracy of the food recognizer in identifying 12 food items purchased from a campus restaurant: spinach, fish balls, white gourd, bitter gourd, eggs, pork, pumpkin, tomato, green peppers, pig blood cake, tofu, and chicken nuggets. Each food item was poked once to acquire a single-point training datum (collecting multiple training samples at multiple points of a food item, or additional parental effort, is likely to produce better classification accuracy). After training data were collected, we poked each food item 10 times to collect testing data.

Figure 4 shows the average case, the best case, and the worst case accuracy of different food combinations and various food items. For example, when classifying two food items, the number of all possible two-item combinations from 12 food items is 66. More food items leads to lower classification accuracy. Some food items are more difficult to distinguish because they have similar color, such as fish balls and chicken nuggets (62.5%).

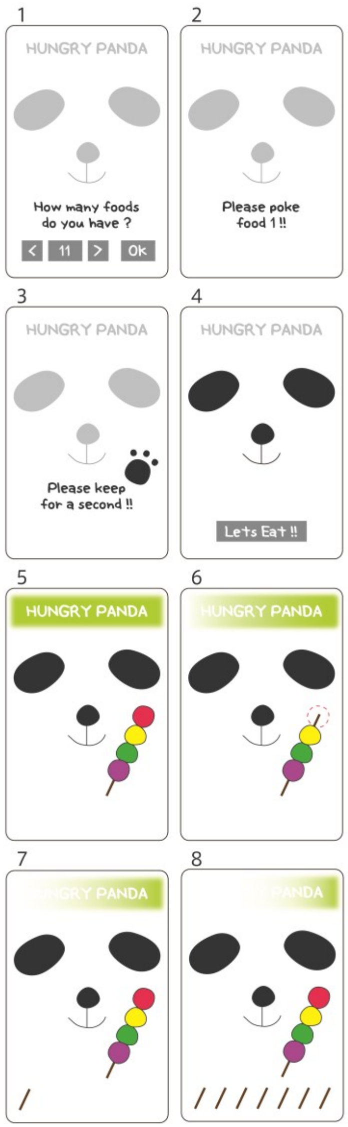


Figure 5. The procedure of Hungry Panda

Hungry Panda Eating Game

Most children in Japan learn proper nutritional balance in kindergarten. For example, teachers may use the red-yellow-green chart. Red foods (e.g., meat, fish, and eggs) enable our body to "produce blood and muscle," yellow foods (e.g., rice, bread, and potato) enable our body to "produce power and body heat," and green foods (e.g., vegetables, fruits, and mushrooms) enable "conditioning the body."

According to a recent survey of nutritional status and eating behavior for children conducted by the Japanese government [10], the main children's eating problems that parents are concerned about include (1) distraction in eating, (2) picky eating, (3) irregular eating, and (4) slow eating. However, the traditional approach of enforcing proper eating behavior in children often leads to an unbalanced nutritional intake and negative behavioral responses from children [11]. To help parents develop desirable eating behaviors in their children, we designed a play-based eating game, called the Hungry Panda game, to be used with the Sensing Fork. The Hungry Panda game applies the gamification [12] concept to help parents address the discussed four eating problems, and to help in dietary education during mealtimes. We chose the panda motif because it is familiar to Asian children. Figure 5 shows several screenshots of the Hungry Panda game. This game includes the following steps.

1. A mother enters the number of food items.
2. The mother uses the Sensing Fork to poke each food item. This step collects each food's color and resistance sample data for food classification.
3. The mother repeats this step for each food item that will be served to the child.
4. The mother pushes the "Let's Eat" button to start the game.
5. The Hungry Panda game appears with the four-colored Dango[1]. The child is now ready to eat and play the game. Three of the four-colored Dangos represent the red/yellow/green food groups corresponding to the educational food chart. The purple Dango represents a child's dislike of the food, which the parent programs into the game to encourage the child to eat.
6. When the child eats fish (the red food group), the Hungry Panda also eats the red Dango.
7. After the child eats one round of each of four food groups, he/she receives a new Dango and one empty stick.
8. When the child consumes more foods in a balanced manner, he/she is awarded with additional empty sticks.

Finally, the mother pushes the "Finish" button on the game, and the Hungry Panda dances with the sticks awarded to the child.

The green title bar on top of the screen disappears over time, reminding children to complete the meal within a proper timeframe. The parent can program this duration. When time is up, the Hungry Panda says goodbye to the child, and the game is over. The Hungry Panda says some terms (e.g., "I am hungry," "I want to eat more," and "Yummy") based on the child's eating behavior and the status of the Sensing Fork (Fig. 3).

Thus, the system can help parents understand their child's eating behavior in daily life. Moreover, in addition to the above reward given by the system, the

[1] "Dango" is skewered rice dumplings and Japanese sweet.

parents may give external rewards (e.g., sweets) based on the improvement of the child's eating behavior.

Conclusion and Future Works

This study presents the design and implementation of a Sensing Fork that automatically recognizes a child's eating behavior without using any cameras or wearable sensors. To provide feedback to encourage good eating behavior, we designed and prototyped the Hungry Panda game to target four major eating problems. The objectives of our future research will be to reduce the size and weight of the Sensing Fork and improve the user interface design of the Hungry Panda game for children. Finally, we will conduct a user study to determine how well the Sensing Fork and the Hungry Panda game work in changing children's eating behavior.

Acknowledgment

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