ChildGuard: A Child-Safety Monitoring System

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With the rapid development of urbanization and industrialization in China, the resident population in the countryside has gradually decreased, and a significant number of children are now living in or near cities. According to the bulletins of National Bureau of Statistics of the People's Republic of China, the urban population in China was 57.4 percent in 2016, up from 49.7 percent in 2010.\textsuperscript{1,2} Although cities can provide more opportunities, they can also present challenges to the safety of children. There are reportedly more than 200,000 children who die from accidental injuries each year in China.\textsuperscript{3} Most are due to drowning, traffic-related injuries, and dangerous activities (such as playing unsupervised in public places or playing near ledges, where falling is a possibility).

Parents and guardians thus need ways to better monitor their children, but typical security measures focus on preventing theft or other illegal actions and aren't well suited for monitoring children. For example, two typical measures include hiring manned guards or using video surveillance, but guards aren't practical or affordable when it comes to monitoring children, and video surveillance systems usually have blind zones. Furthermore, parents and guardians don't have permission to access surveillance videos to monitor their children.

Although some studies have looked into using personal monitoring methods for children based on wireless communication,\textsuperscript{4,5} these methods require specific platforms that are costly and difficult to use and maintain (see the “Related Work in Child Monitoring” sidebar for more information). We thus set out to develop a low-cost, easy-to-use system that could monitor the location and states of children in real time. To that end, ChildGuard is a security method for monitoring children that uses ubiquitous computing devices, such as smartphones or wearable devices—which are growing in both popularity and performance. We exploit such devices to monitor the location and activities of children and to proactively notify children and guardians of potential safety risks.

System Structure and Functions

The ChildGuard system is structured into three parts and provides two main functions (see Figure 1). The three parts are a guardian application (which appears on the guardian's mobile device), a child application (which appears on the child's mobile device), and a web server. The main functions are in-path safety and region safety.

When children go out alone, guardians can use the in-path safety function. The system collects a child's geographical coordinates in real time and sends them to a guardian application that then displays the child's real-time movements on a map. When the mobile device of a child detects abnormal behavior, such as playing in the road, the system sends a voice reminder to the child—telling him or her to stay off the road, pay attention to the traffic light, or watch for oncoming traffic, for example. The system can also send a text alarm to the guardian. The web server transfers such information between the child and guardian applications via the Internet.

Using the region safety feature, a guardian can be alerted if a child moves beyond a certain region. The child will also receive a reminder to return to the designated area.

Common Functions

The following functions are implemented in both the guardian and child applications.

Communication

Currently, a mobile phone can access the Internet via a mobile Internet service or Wi-Fi, and...
there is no distance limit between the guardian and child; the applications will work regardless of the distance. This leads to fewer costs than communication via short messages or phone calls. However, in this kind of communication, the mobile device’s Internet Protocol (IP) address is a public IP address that cannot remain constant when using a mobile Internet service or Wi-Fi.

We used the instant messenger software development kit (iMSDK) to set up a web server for information transit between the guardian and child applications of the Child-Guard system. iMSDK doesn’t need to know the IP addresses of the sender and receiver and can let them communicate by sending and receiving user names registered by both applications.

Positioning and Line Drawing
The child application uses GPS, Wi-Fi, and a base station to obtain coordinate positions, which are sent to the guardian's application every three seconds. The guardian application then receives and saves these location coordinates and draws polylines to track the real-time movement of the child. When the guardian application receives a new position

Related Work in Child Monitoring

Pramod Ganjewar and his colleagues proposed a wireless video surveillance system using a motion detection method.1 The system can be deployed rapidly and used to supplement more traditional monitoring systems. The system uses J2ME technology and does not use specific websites to check the live events in a timely way.

Zhiyuan Fang and his colleagues proposed a kindergarten safety system.2 It includes a cloud server, RFID tags, readers, cameras, and displays, which enables guardians and schools to monitor children. This system includes three major functions—school bus management, child monitoring, and kindergarten monitoring. RFID card readers and cameras are installed near the hazardous areas. When the card-reading threshold is exceeded, the system issues a light and sound alarm and starts taking pictures to collect information.

Karunya Sundaraganapathy and his colleagues developed an embedded device called Embedded Lockets to monitor the tracks of children on the path between home and school.3 The system sends an SMS to inform a parent of the student’s position and sends an alert if the child crosses a predetermined boundary. It also periodically sends pictures to the parent via email, and the child can call a parent when in danger. The system can also be used by adults—by a woman being harassed, for example, or by an elderly person who has lost his or her way.

Aditi Gupta and Vibhor Harit proposed a children monitoring system that can provide children's location to their parents via SMS, and the parents can see child’s location on Google Maps.4 Another feature of this system is its support for geo-fencing, which restricts children within a circular region. When the children cross the geo-fencing boundary, their parents receive an alert. Moreover, children can send predefined SMS messages to their parents when they are in danger.

These current systems have high costs, have fixed infrastructures, or are difficult to use, so we aimed to develop an easy-to-use, low-cost child safety monitoring system based on Android mobile devices.

References
coordinate point, it connects the recent two coordinate points to create a straight line segment. Because three seconds seemed to be a short-enough time interval for tracking children, the polylines can be regarded as the children's tracks. The real-world tests we conducted supported this relationship between the drawn polylines and the actual tracks.

Voice Reminding and Alerting
ChildGuard’s voice reminding and alerting mainly comprise three function modules: the in-path safety reminding, the region safety reminding, and the state information announcing. The first two function modules are implemented in the child application, and the state information announcing function is implemented in the guardian application.

In the in-path safety reminder function, we set alarm points at intersections and warning lines on high-risk roads. A voice is played to remind children to observe the surrounding environment when they appear in these alarm areas. If children are far away from a designated road, or if they’re running too fast or staying in high-risk areas for too long, ChildGuard will sound an alarm, which the child will hear.

In the region safety reminder function, if a child is too close to the outer boundary of the safety region, ChildGuard will broadcast
a reminder to stay in the safety region. If the child moves beyond the safety region, ChildGuard will sound an alarm, alerting the child to return immediately.

When a guardian presses the “state information” button, ChildGuard will announce the time and the child’s current position coordinates and direction. ChildGuard will also notify the guardian of any abnormal behavior by sending an instant message.

Determining the Shortest Distance
ChildGuard uses the latitude and longitude information provided by GPS to obtain the distance between two points. Assuming that the latitudes and longitudes of two points A and B are \((j_A, w_A)\) and \((j_B, w_B)\), respectively, and knowing that the radius \(R\) of Earth is approximately 6378.140 km, then the shortest distance between A and B is

\[
D(A,B) = R_{\text{arc}} \cos \left( \sin(w_A) \sin(w_B) \right) \cos(w_A) \cos(w_B) \cos(j_A - j_B). \tag{1}
\]

Equation 1 is used to calculate the distance between two points in the spherical coordinate system. The differences of latitudes and longitudes between A and B is very little, so \(j_A - j_B \approx 0\). By assuming that \(j_A - j_B = 0\), then

\[
D(A,B) = R |w_A - w_B|. \tag{2}
\]

Therefore, the smaller the latitude difference between A and B, the shorter the distance between A and B.

Assume that the values of \(\sin(w_A)\), \(\sin(w_B)\), \(\cos(w_A)\), \(\cos(w_B)\), and \(\cos(j_A - j_B)\) are greater than or equal to 0. However, the cosine function is a monotonically decreasing function in the range 0–90 degrees. So, the closer the values of \(j_A\) and \(j_B\) are, the smaller the distance between A and B will be.

For the sake of reducing the calculation overhead of the minimum distance between children and the polyline roads, we propose the MinSquare algorithm (see Figure 2). This algorithm can determine the polyline set with minimum bounding square between the child’s coordinate point and the polyline (road tracks or regions). To calculate the minimum distance from an endpoint to a polyline set, we propose Theorem 1.

**Theorem 1.** When calculating the shortest distance from a point to a straight line segment, the point must appear in the range of two vertical lines that cross the two endpoints of the line segment. When a point C is in R3, the vertical foot is D, which lies in the extension line of AB. The minimum distance from C to AB is not CD, because CD is not a reachable shortest distance.

**Proof.** Without loss of generality, we take Figure 3 as an example to prove Theorem 1. In Figure 3, the line segment AB is a part of a polyline, and the straight line that passes through the point A, perpendicular to AB, is L1. The straight line that passes through the point B and is perpendicular to AB is L2.
The area between L1 and L2 is R2. The area above L1 is R1, and the area below L2 is R3. Here, we prove Theorem 1 by contradiction. Because R1 and R3 are symmetric regions, without loss of generality, we assume that point C is located in the region R3. We connect A and C, and B and C, to form a triangle DABC. We assume that the angle between AB and L2 is denoted as $\alpha_1$, and the angle between BA and BC is $\alpha_2$. Because AB is perpendicular to L2, $\alpha_1$ is equal to 90 degrees. For $\alpha_2$, because C is located in R3, $\alpha_2 > \alpha_1$—that is, $\alpha_2$ is an obtuse angle. The vertical line from C to AB is located in the extension line of AB. As shown in Figure 3, the foot of the perpendicular line is the D point. Thus, the vertical foot from C to AB appears on AB if and only if $C \in R2 \cup L1 \cup L2$—that is, C must be in R2, L1, or L2.

If the vertical foot from C to AB is located within the two endpoints of AB, we can calculate the shortest distance from C to AB using the following method.

According to Heron’s formula (http://mathworld.wolfram.com/HeronFormula.html), the area of $\Delta ABC$ is

$$\Delta = \sqrt{s(s-a)(s-b)(s-c)},$$  

where $a$ is the length of BC, $b$ is the length of AC, $c$ is the length of AB, and $s$ is defined as

$$s = \frac{1}{2}(a + b + c).$$  

From Equations 3 and 5, we can derive the following:

$$D(C, AB) = 2\sqrt{s(s-a)(s-b)(s-c)}.$$  

If the vertical foot from C to AB is located outside the region of $R2 \cup L1 \cup L2$, we first calculate the distance from C to the two endpoints A and B of AB. The shortest distance from C to AB is

$$D(C, AB) = \min(D(C, A), D(C, B)).$$  

Therefore, when calculating the shortest distance from the position point of children (CP) to the polyline roads (PR), we first calculate the polyline set PIS in the minimum square surrounding CP and PR through the MinSquare algorithm, and then calculate the shortest distance between CP and all straight line segments in PIS according to Equations 6 or 7.

### The In-Path Safety Function

Figure 4 shows the flow chart of the in-path safety function.

First, the child application acquires the child’s location coordinates using GPS, Wi-Fi, or a base station. After that, it sends the location coordinates to the guardian application via

![Figure 4. The flow chart of the in-path safety function.](image-url)
the web server. If the child is near the alarm points, such as a traffic light intersection, the child application reminds the child by voice to pay attention to safety. If there are other abnormal conditions, such as the child’s speed reaches that of a moving car (indicating a possible abduction), or if the child seems to excessively deviate from the designated path or is loitering in a high-risk area, the child application sends warning messages to the guardian application via the web server and sends a voice warning to the child.

When the guardian application receives the location coordinates, it draws the child’s tracks and announces the child’s state if the state information button has been pressed. If the child’s state is abnormal, it also warns the guardian to take measures (to get in contact with the child, for example).

To draw the child’s tracks on the basis of drawing polylines, we included a method for drawing Bessel curves to fit the missing and abnormal coordinate points. We use the third-order Bezier curve formula to draw Bezier curves, which requires four points—a starting point, an endpoint, and two control points. A Bezier curve will pass through the starting point and the endpoint. The formula of the three-order Bessel curve\(^7\) is defined as

\[
B(t) = P_0 (1-t)^3 + 3P_1 t(1-t)^2 + 3P_2 t^2 (1-t) + P_3 t^3, \quad t \in [0,1],
\]  

where \(t \in [0,1]\), \(P_0\) is the starting point, \(P_1\) and \(P_2\) are the control points, and \(P_3\) is the endpoint. The value of \(t\) changes from 0 to 1.

The Region Safety Function

The safety region is a polygonal region. Guardians can designate areas in which their children should play.

Before using the safety region function, guardians need to set polygon safety regions in the child’s application. After that, the child application acquires from the device’s sensors the coordinates of the child’s current position (same as with the in-path function). If the child is near the boundary of the safety regions, ChildGuard will remind the child not to cross the boundary. If the child is crossing the boundary, ChildGuard will issue a voice alarm, telling the child to turn back immediately. ChildGuard will also send a warning message to the guardian application via the web server, telling the guardian to take appropriate measures.

We use the following method to judge whether a child is within a polygon. First, all vertices of the polygon and the child’s coordinate point are connected by straight line segments. Second, we calculate all angles between the child’s coordinate point and the adjacent vertexes of the polygon. Third, we calculate the sum of all angles. It should be noted that each angle has a direction, so there could be a negative value. Finally, according to the cumulative value of all angles, ChildGuard determines whether the point is within the polygon. At present, we can only get the distance between two points, so we use the cosine theorem to get the angle.

As shown in Figure 5, we assume the safety region is a heptagon region. We can split the heptagon ABCDEFG into seven triangles. Let’s take the triangle ABM as an example. The three sides of \(\triangle ABM\) are \(a, b, \) and \(m\). According to the law of cosines (http://mathworld.wolfram.com/LawofCosines.html), we can...
obtain the angle $\gamma$ of $\Delta ABM$ through a simple formula derivation,

$$\cos \gamma = \frac{(a^2 + b^2 - m^2)}{2ab}. \quad (9)$$

So the formula for calculating the angle $\gamma$ is

$$\gamma = \arccos \frac{a^2 + b^2 - m^2}{2ab}. \quad (10)$$

If the sum of all angles of the seven triangles in vertex M is a multiple of 360 degrees, the point M is in the polygon.

**Experiment and Analysis**

We compared our ChildGuard implementation with two similar systems, one called Embedded Lockets and another based on geo-fencing (which we refer to as the Geo-Fencing system). See the sidebar for a general description of these two systems. Note that we implemented the map display in Embedded Lockets and Geo-Fencing using Baidu Maps, because we couldn’t access Google Maps. Also, we based the platform for the ChildGuard applications on an Android mobile phone because Geo-Fencing is based on Android (and Embedded Lockets has no operating system), so we could fairly compare their performance.

The architecture of Embedded Lockets and Geo-Fencing relies on SMS for guardian-child communication. SMS comprises point-to-point communication, so it’s difficult to extend it to many (for example, if one child sends a message but several different guardians want to receive it). ChildGuard implements a three-tier structure through its web server, making it easier to extend to the one-to-many structure.

For communication, Embedded Lockets uses SMS and email, which is suitable for fewer messages and longer monitoring intervals. Geo-Fencing is similar to that of Embedded Lockets. ChildGuard uses instant messages (via 3G) and phone calls, offering stronger real-time characteristics, longer messages, and immediate voice contact. In terms of the cost, the SMS used in Embedded Lockets and Geo-Fencing has higher costs than the 3G instant messages in ChildGuard.

For positioning, Embedded Lockets and Geo-Fencing use GPS, which has larger positioning errors compared to the combination of GPS, Wi-Fi, and base stations. ChildGuard uses a combination of GPS, Wi-Fi, and a base station to obtain higher positioning accuracy and better flexibility.

Regarding the scope of activities monitored, Embedded Lockets only monitors the path between home and school, and Geo-Fencing only monitors certain areas, designated as a circular region. ChildGuard can monitor arbitrary paths and regions consisting of polylines, so it has stronger flexibility and wider adaptability.

We tested these three systems’ real-time communication and accuracy in a real-world environment at Hangzhou Dianzi University. The child applications for all three systems used a Huawei H60-L02 mobile phone equipped with an Android 4.4.2 operating system and a built-in 3GB RAM system memory. The guardian applications used an MI 5 mobile phone equipped with an Android 6.0 operating system and a built-in 3GB RAM system memory.

The Degree of Real-Time Communication

Guardians want to know where their children are—and receive any alarms about potential

![FIGURE 6. Testing the degree of real-time communication. The overtime denotes the number of messages missing or with a time delay of more than six seconds.](image)
dangers—in real time. The message time delay between the child and guardian applications is important in any type of system focused on child safety, so we designed an experiment to test the message transmission delays. We sent 100 coordinates, one every three seconds, from the child application to the guardian application and recorded the time interval between when the data was sent and received.

As Figure 6 shows, 95 percent of the ChildGuard messages (sent via a server transfer) had a time delay within four seconds (and 81 of the 100 messages were received in one second). For Geo-Fencing, 96 percent of the messages (sent via SMS) had a time delay within four seconds (with 32 received in two seconds), and for Embedded Lockets, 84 percent of the messages (sent via email) had a time delay within four seconds (with 44 received in three seconds). So, generally speaking, all three systems meet the four-second time-limit requirement for monitoring children (we believe this is an acceptable time delay because a child can usually move no more than 10 m within four seconds).

ChildGuard uses TCP communication over 3G, so it had the shortest time delay (none of the Geo-Fencing or Embedded Lockets messages were received in one second), although it did have four “overtime” messages, which took more than six seconds. Geo-Fencing and Embedded Lockets use SMS and email to transmit messages, which takes longer because of the sending, transferring, and receiving queue. Geo-Fencing also had four overtime messages, and Embedded Lockets only had one. Note that Embedded Lockets can send photos, a function that ChildGuard and Geo-Fencing currently don’t support.

### The Degree of Accuracy

The current positioning methods in mainstream mobile phones include GPS, Wi-Fi, and base-station positioning, or a hybrid of these methods. ChildGuard supports all three methods, but Geo-Fencing and Embedded Lockets only support GPS positioning. So, we designed an accuracy experiment according to these three modes of mobile phone positioning.

We measured the precision according to the switching states of Wi-Fi, a base station, and GPS. We randomly found five test points on the Hangzhou Dianzi University campus. We changed the switching states of Wi-Fi, a base station, and GPS and then compared the distance difference between the map location points and the actual test points to determine the precision errors. We averaged the precision errors to determine the final accuracy (in meters). The experimental results are shown in Table 1.

Experimental results show that the positioning accuracy is approximately 2–10 meters using GPS (with and without other methods).

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<th>Test point 2</th>
<th>Test point 3</th>
<th>Test point 4</th>
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Table 1. Positioning accuracy (in meters).
If only Wi-Fi or base station positioning is used, the positioning errors can become very large—up to 123 meters. In addition, we found that Wi-Fi and base station positioning didn't significantly influence positioning accuracy. The positioning accuracy can reach 2–6 meters if GPS and Wi-Fi and/or a base station are used together. Note that the more Wi-Fi hotspots there are, the more accurate the positioning. Therefore, because ChildGuard can use one or more positioning methods, it offers better positioning accuracy than Embedded Locket and Geo-Fencing.

Our ChildGuard system for mobile devices can help guardians better monitor children. With future work, we plan to add scenario-sensing functions to detect the children's voices and to take pictures of the children being monitored. We also hope to and extend ChildGuard to indoor monitoring applications using indoor positioning and motion recognition. 

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References

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