Pedestrian Navigation System Using RFID-Tag: Architecture and its Evaluation Based on a Field Trial

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SUMMARY

There have been various attempts to develop systems that support pedestrians using information technologies. In particular, there is a high demand of pedestrian navigation: a system that integratedly provides navigation and information services for users who are not familiar with a visiting area.

The authors have developed a pedestrian navigation system that has a high accuracy of positioning (regardless of indoor or outdoor) and navigates users with pictograms and sound signals to desired destinations. The purpose of this paper is to examine if the system satisfies the demand as a universal system of pedestrian navigation, and to show future developments aiming at providing the service to the

public.

We have conducted a demonstration experiment in which the developed system was installed in a real urban environment, and with participation of public monitors (including disabled persons). This experiment proved its validity for a practical application. Especially it confirmed audio signals as a legitimate method of navigation regardless of having disability or not. We plan to improve the system based on the findings in the experiment so that we will be able to provide the service in practice.

1. INTRODUCTION

In recent years, we have observed active development researches and experiments that aim at practical applications of a major development area of ITS (Intelligent Transport Systems), the pedestrian ITS, involving efforts and coordination of both the government and private parties. While the ITS for motor vehicles has advanced more in the field of ITS than the pedestrian ITS, the current goal of the pedestrian ITS is to provide diverse services to pedestrians, with a slogan of “Support for Pedestrians”.[1]-[3] One of such services is a navigation system specifically for pedestrians. [4]-[8]

An example of the pedestrian navigation development, called “ITS experiment in regards to pedestrian support, such as barrier-free route information,” was conducted in 2001 at the underground commercial area of Umeda, Osaka city in 2001.

In general, it is essential to acquire an accurate location and moving direction of each user in order to provide an adequate navigation service. Various prototype systems that use following positioning technologies have been proposed. [10]

- GPS（Global Positioning System）
- Pseudolites
- PHS（Personal Handy-phone System）, cellular phones
- BlueTooth

These positioning technologies have sufficient accuracy to provide the vehicle navigation system. Nevertheless, an attempt to establish a pedestrian navigation system requires a positioning technology with higher accuracy. In particular, already-existing technologies are insufficient to navigate pedestrians seamlessly through different environments such as commercial areas, in buildings, and underground commercial areas. To solve this problem, we propose to locate low-power RFID-tags with a high density to achieve high positioning accuracy, so that we could realize sufficient positioning accuracy to provide a pedestrian navigation anywhere in urban areas.

This paper first proposes architecture to structure a universal pedestrian navigation system with showing a brief outline of the developed system. Next, a demonstration experiment in which the developed system is installed in a real urban environment, with participation of monitors including disabled persons. The experiment field is the commercial area in Chuo-Ku, Osaka city, and navigation service to approximately 70 facilities and stores was provided in November 2002. During experiment period of ten days, approximately 60 participants carried PDAs, and attempt to visit several destinations sequentially with navigation of the system in one hour. This experiment evaluation is made by based on the navigation results, system logs, stalking observation of participants, and questionnaires to the participants.

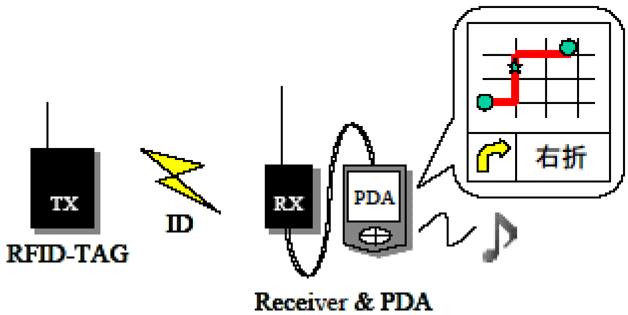
2. OUTLINE OF THE PEDESTRIAN NAVIGATION SYSTEM

(1) Physical Architecture

Figure 1 shows the equipments of the navigation system. RFID-Tags are located in the navigation service area as the basis of positioning, and users carry receivers, which receive signals from the RFID-Tags, and PDAs. The only information transmitted from the RFID-Tags is a tag-ID, and the PDAs carried by the users possess geographical information database. A PDA positions itself and determines the route navigation by referring to the tag-ID received and the geographical information database, and then navigates the users. For detailed explanation, refer to the reference [11].

(2) Logical Architecture

RFID tags are located with a high density throughout the service area. Each tag transmits its own ID signal with 100ms interval when there exists a PDA nearby. The reception distance is approximately 20 meters.



Receiver, RFID-Tag, PDA

Fig. 1 System Structure

Navigation process is summarized in Figure 2. A receiver can position itself by receiving an ID from the nearest RFID-Tag.

Next, it determines its latest moving direction based on the geographical relation of the starting position and a location after moving for a little while, and then the user inputs a destination. Also, a navigation route matrix is estimated based on the database which the PDA possesses.

Thereafter, the PDA checks the matrix data each time it acquires the current location, and it determines a route direction and navigation timing to provide navigation by audio signals and display information until it reaches the destination or it deviates from the route enough to be determined as an “OB”. For detailed explanation, refer to the reference [12].

(3) User Interfaces

In order to achieve the convenience of walking in which one can enjoy window-shopping, sight-seeing and so on, basic navigation is conducted with through audio signal in this system. This is due to our consideration that referring to a PDA and operating the device while walking may be bothersome, or hence it may increase danger of accidents. [13], [14] Meanwhile, audio signal, which can contain limited amount of information, is not always sufficient to realize a safe and smooth navigation. Therefore, this system provides both display information and audio signals to the users.

The following paragraphs explain a) audio signals, b) display information and c) navigation information.

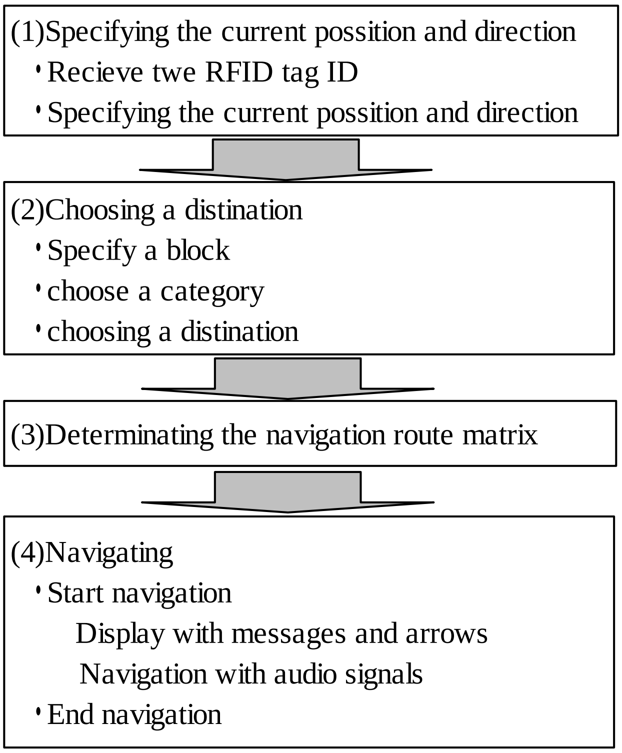


Fig.2 Navigation Process

a) Audio signals

The audio signal consists of short signals and long signals (just as the Morse code) (Fig.3), and is supplied along with route direction (straight, right, left, goal, OB, etc.). It is supplied more than

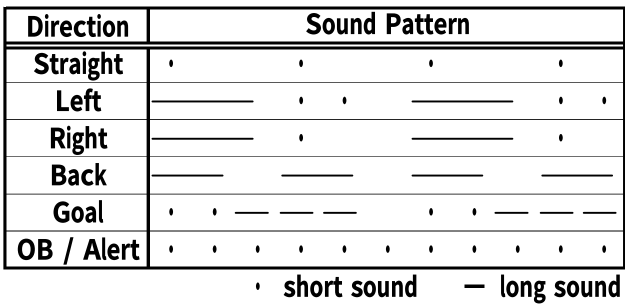


Fig.3 Audio Signals

one time because an audio signal may fail to be heard by the user because of noise city environment.

When it is difficult to navigate users only with audio signals, such as inter-floor movement that requires use of stairs or escalators or cross-section with more than four directions, the portable device outputs a beep to advises users to refer to the display.

This system utilizes simple audio signal rather than voice navigation not only because it enables disabled people and foreign tourists to directly use the system but because of possible development to a navigation system with cellular phones that uses vibration function. In short, it is a result of consideration seeking to universal design.

b) Display information

This system displays maps, starting position, destination, current position, route information, current direction with arrows and characters on the display to navigate users. Current position is optional for users to display on the devise.

c). Navigation information

Fig.4 shows the combination of navigating arrows, message information and audio signals when navigating. Here,“OB” signifies inability to continue navigation because of a large deviation of a user from the pre-determined route.
When reaching the destination, it may be more convenient for the users, if the system can informs not only that the user has reached the destination but also the direction of the building from his/her position. Therefore, it outputs the direction of the destination facility from the direction which the user is coming from with message information. Meanwhile, it also displays a message saying “approaching the goal” along with the direction of the destination, soon before reaching the destination.

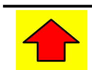
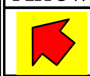
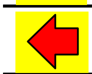
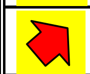
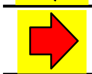
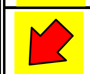
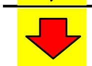
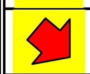
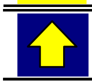
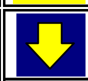
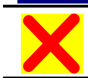
Symbol, Arrows	Audio signals	Messages	Symbol, Arrows	Audio signals	Messages
	Straight Goal	直進 ゴール　前方		Alert Goal	左前方直進 ゴール　左前方
	Left Goal	左折 ゴール　左		Alert Goal	右前方直進 ゴール　右前方
	Right Goal	右折 ゴール　左		Alert Goal	左後方戻れ ゴール　左後方
	Back Goal	戻れ ゴール　後方		Alert Goal	右後方戻れ ゴール　右後方
	Alert	地上へ		Alert	地上へ
	OB	OB ナビ終了せよ		upper: on guiding lower: on arrival	

Fig.4 Display Messages

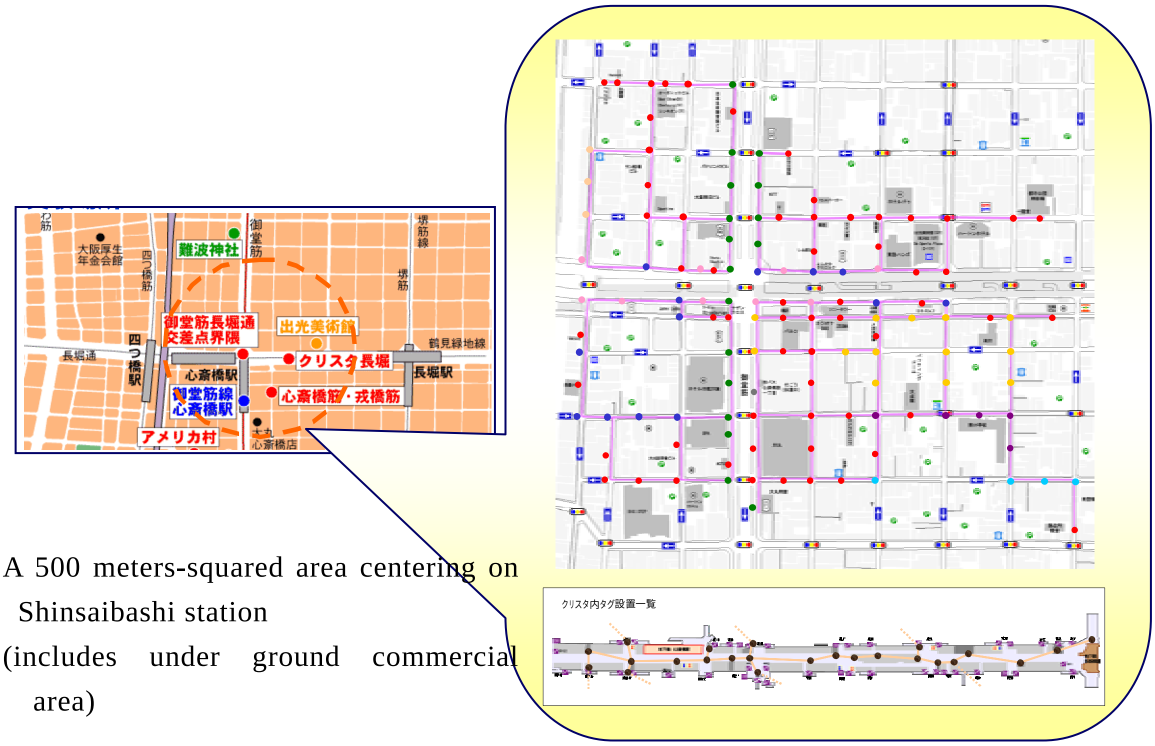
3. DEMONSTRATION EXPERIMENT

(1) Outline of the demonstration experiment

We have conducted a demonstration experiment with public monitors (including disabled persons) to verify the validity of the developed prototype system at a commercial area in Chuo-Ku, Osaka city in November 2002.

The experiment field is, as shown in figure 5, a 500 meters-squared area centering on Shinsaibashi station of the Osaka subway system, including a large underground commercial area. In total, 152 RFID tags were located in the field, and the experiment provided navigation services to approximately 70 facilities. The facilities included public transportation facilities, banks, hotels, department stores, small businesses such as boutiques, restaurants, and sightseeing spots, etc.

The experiment lasted for ten days (2 periods of 5-day-experiment), and 60 monitors (male 50% and female 50%) participated. In addition three persons with visual impairment were partly participated. 39% of the participants have visited the field for the first time, while 45% of the participants visit the field for “less than few times” a year. It is, therefore, reasonable to say that the majority of the participants were unfamiliar with the experiment field. In the mean time, 65% of the participants had never used PDAs before. The monitors received a 20-minute-guidance to familiarize themselves with the device and the audio signals (including test-hearing) and then examined the navigation system for approximately an hour, starting from the Shinsaibashi station of the subway.



A 500 meters-squared area centering on Shinsaibashi station

(includes under ground commercial area)

Fig.5 Demonstration Experiment Area

(2) Research Procedure

It is necessary to recognize behaviors of the monitors in detail (such as when, where, and what) in order to evaluate validity of the navigation system. This experiment recorded behaviors of the monitors with system log files, stalking observations, and questionnaires to the monitors.

System log files are records of system behavior with accurate time stamp. A log file includes received tag ID, navigation output (display and audio signal), PDA operation by the monitors and other event information for each trip, and is recorded to memory of the PDAs.

The experiment included stalking observation to recognize behaviors of the monitors when they were walking in accordance with the navigation. Each monitor was followed by a tracer, and was recorded his/her each action and behavior on a map. Meanwhile, the tracer records monitor's subjective evaluation of navigation timing (too early or too late) after reaching the destination for each trip.

Furthermore, a questionnaire was given to the monitors about usability of the navigation system after all the trips completed. Two major types of the questions are personal experience of the monitors, usability of the system, and possibility of their use in the future. In order to supplement the result of the questionnaire, a 10-minute interview investigation was conducted along with the questionnaire.

4. RESULTS OF THE DEMONSTRATION EXPERIMENT

(1) Success Rate of the Navigation

Figure 6 shows success rate of monitors reaching the destination along with navigations of the system.

Success rate exceeded 80% even in the early phase of the experiment, and later phase of the experiment observed the success rate reaching 90%, which proves validity of the pedestrian navigation system.

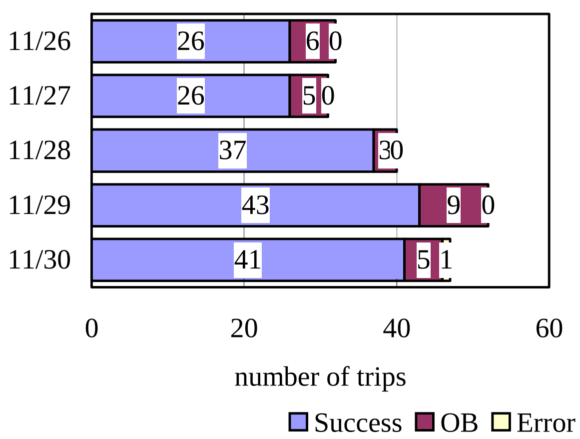


Fig.6 Success Rate of Trips

There was a tendency of "OBs" occurring in places in which RFID tags were located mutually too close, and in the underground commercial area. This indicates that, even if it is unreasonable to change special distribution of the tags to maintain the navigation accuracy, it is possible to improve performance of the system through measures to avoid interference of radio wave, such as adjusting power of the RFID tags.

(2) Navigation timing

The questionnaire revealed in regards to navigation timing, which is an important element of pedestrian navigation, that many participants felt that the navigation was given slightly later than they would have expected. There were also some responses of "comfortable level."

If we analyze this result, monitors' evaluation might differ in accordance with change in reception condition due to traffic of general public, difference of walking speed, difference of monitors' preference of navigation timing and so on, even if they walk the same location to the same direction. In addition, only 7% of the participants evaluated the navigation timing as too early or too late. Overall, the questionnaire did not indicate any problem and in fact, it supports the validity of the navigation system from the perspective of the navigation timing.

(3) Walking velocity of the monitors

Figure 8 shows the average velocity of the monitors throughout their trips from the starting location to the destination. While 75% of the trips were with the speed over 3km/h, 30% of the trips were with the speed from 4 to 5km/h.

With consideration that the average speed of people walking is approximately 4km/h, the navigation of this system conducted mainly with audio signal and without necessity of checking the display would not decrease users' normal walking velocity, even in the commercial areas which includes obstacles such as other pedestrians and illegal parking of bikes.

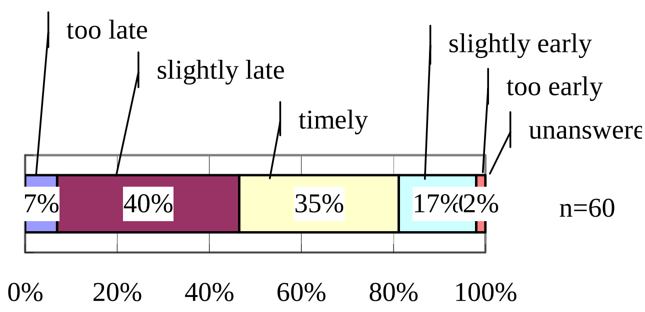


Fig.7 Evaluation of Navigation Timing

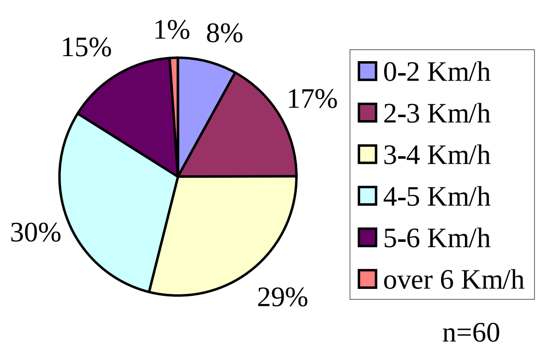


Fig.8 Average Walking Velocities

(4) Reference to PDAs

Figure 9 shows the time which the participants spent to check the PDA monitors per trip. Approximately 50% of all trips were conducted with reference to PDAs for less than five seconds, although average time of PDA reference is 26 seconds.

This result suggests that arrows and messages on the PDA were used just for a glance or even without depending on the display. Out of trips with the speed of higher than 4km/h, trips with more than 5 seconds of display-reference time consists only 31%, while reference time of less than 5 seconds consists 55%. This confirmed our assumption that audio signal-based navigation contributed considerably to smooth walk of the participants.

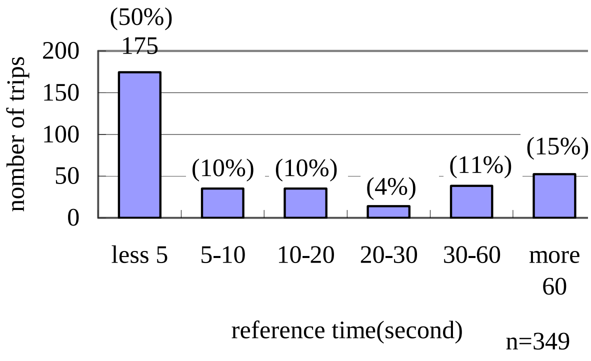


Fig.9 PDA Reference Times

(5) Uncomfortableness, anxiety of the users

Figure 10 shows users' evaluation on the user-interface and desired navigation method. Navigation through audio signals received less evaluation than navigation through messages and arrows. It is possible to analyze that this was because the participants were not accustomed enough to navigation with audio signals, and this was supported by the fact that the latter half of the one-hour experiment observed many users who reached the destinations only with audio signals. Fifty percent of all trips required less than five seconds to refer to the PDAs, which confirmed that navigation was sufficiently conducted only with audio signals.

Another factor in favor of audio signal navigation was indicated from the users' desired navigation methods in the questionnaire. Only 13% of all participants desired navigation only with displayed information, while the majority favored navigation with both audio signals and display. This supports validity of the navigation system mainly with audio signals.

By the way, there were some specific opinions of desirable development of the system, such as that "no navigation signal was output at diverging roads," "there needs confirmation signals after making a turn at cross roads," and so on.

There needs some adjustment of the RFID-tags alignment to maintain certain reception area at diverging points (cross roads, etc.) so that portable devices receive positioning signals from the RFID tags for sure, in response to the previous opinion in the above paragraph. In response to the latter opinion, there needs additional tags that confirms users' direction after the users pass diverging points of the road.

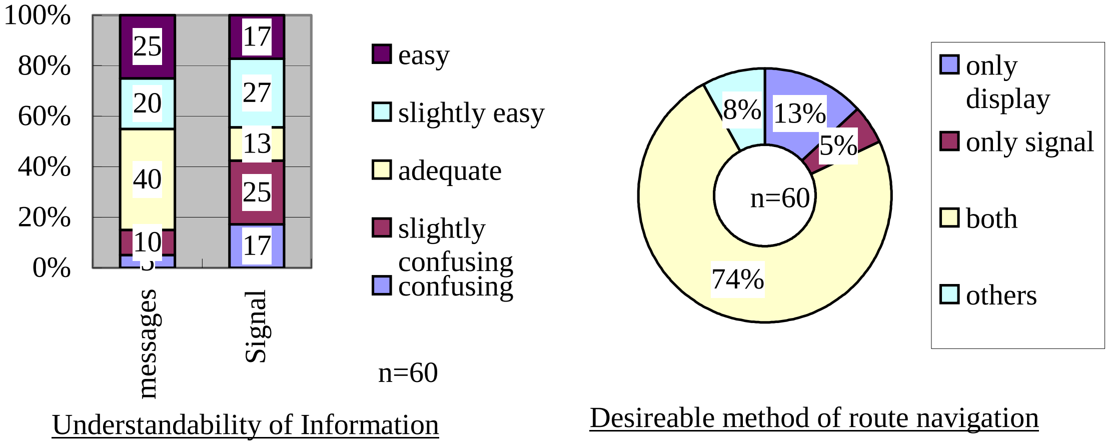


Fig. 10 Evaluation of User Interface

5. EVALUATION OF THE DEMONSTRATION EXPERIMENT

Following results of the experiment confirms validity of the navigation system.

- Higher than 80% of navigation success rate to reach the destinations without any problem even in the real urban environment
- "Too early" and "too late" navigation timing consists only seven percent
- 75% of all trips sustained the speed of higher than 3km/h
- Average reference time of PDA was 26 seconds, and about fifty percent of all trips required less than five seconds of PDA reference time

Overall, the demonstration experiment proved the validity of the pedestrian navigation system. This was supported also with the result that 1) latter experiment observed higher success rate (exceeded ninety percent) through system calibration, 2) reputation of the monitors improved over time, 3) interviews to disabled participants revealed their positive response, such as that they could use the navigation system when going out. In particular, navigation with audio signals was confirmed its legitimacy regardless of disabled persons or persons without any physical difficulty.

6. FUTURE DEVELOPMENT

Possible development for the future may include;

- Implementing a rerouting function for deviation from the navigation route
- Adjusting density of RFID tags
- Elaborating navigation timing

- Some improvement to prevent uncomfortableness and anxiety of the users

As a navigation service for sightseeing spots, shopping malls, and commercial areas, it is crucial to collaborate with providing commercial contents such as local information and facility information. It is necessary to systemize navigation plus providing local information, and thus realizing this system function with cellular phones is desired.

It is possible to alternate the audio signal information with vibration, and this is useful not only for disabled persons but also for people without any physical disability. Therefore, sophistication of the signal function is desired.

For disabled persons (particularly visually impaired persons), it is necessary to provide information and support for their security in addition to the navigation function. Sharing the function with already-existing support system (such as textured paving block) is sufficiently helpful as support system. Yet realizing security support function is a considerable area of future development.

ACKNOWLEDGMENT

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