Care4HIP: an embedded system design for discerning hear-impaired people in traffic

Care4HIP: trafikte duyma engelli kişileri fark etmek için gömülü bir sistem tasarımı

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Highlights
- Care4HIP consists of three main modules including the server, mobile and embedded system.
- Haversine Formula presents the positional distance between the embedded system and the hearing-impaired person.
- Care4HIP detects the hear-impaired people in traffic.
- Care4HIP finds the direction of the hear-impaired person with respect to the vehicle.

Graphical Abstract
This study focuses on discerning the hear-impaired people in traffic. The proposed system in this study provides a safe environment for the hear-impaired people living in big cities and thus facilitate their lives.

Figure. a) Overview of the proposed study b) The angular difference between the new and old position of the embedded system, b) the angular difference between the new position of the embedded system and the position of the hear-impaired person c) Determining the position of the hear-impaired person relative to the embedded system.

Aim
The aim of this study is to present an embedded system that discerns hear-impaired people living in big cities and thus facilitate their lives.

Design & Methodology
There are three main modules in the proposed system; One is the embedded system side which sends its location information to the server, The second one is the mobile side which sends the location information of the hear-impaired person to the server, The other one is the server side that calculates the distance between the vehicle and the hear-impaired person, and also finds the direction of the hear-impaired person with respect to the vehicle.

Originality
By considering the literature, it is obviously seen that there is no study aiming to eliminate the negativities faced the hear-impaired people in streets where there is heavy traffic. At this point, the Care4HIP offers an original and practical solution.

Findings
The experimental tests carried out on the 8 directions show that the Care4HIP successfully runs with 100% accurate detection.

Conclusion
This study focuses on the problem which detects the hear-impaired people in traffic. Experiments show that Care4HIP is reliable. Besides, the survey results indicate that Care4HIP is a valuable system.

Declaration of Ethical Standards
The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.
**Care4HIP: An Embedded System Design for Discerning Hearing-Impaired People in Traffic**

*Araştırma Makalesi / Research Article*

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**ABSTRACT**

Embedded systems are designed for many different applications including navigation, thief warning, smart home, parking. We designed an embedded system, Care4HIP, Care for Hearing Impaired People, which presents a solution for discerning the hearing-impaired people in traffic. Our solution aims that drivers will be able to notice the hear-impaired people. Care4HIP calculates the locational information of these people which close to the vehicle and determines the direction of these people with respect to the vehicle. Location information refers to the latitude and longitude data of each person’s location. The proposed system involves server, mobile and embedded system based applications. We think that Care4HIP offers an original and practical solution with minimal overhead for hear-impaired people.

**Keywords:** Hearing-impaired people, traffic, embedded system, Raspberry Pi 3+

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**Care4HIP: Trafikte Duyma Engelli Kişileri Fark Etmek İçin Gömülü Bir Sistem Tasarımı**

ÖZ

Gömülü sistemler, navigasyon, hırsız uyarıları, akıllı ev, izleme gibi birçok farklı uygulama için tasarlanmıştır. Trafikte işitme engelli kişiler ayırt etmek için bir çözüm sunan Care4HIP, işitme engelli insanların fark edilmesi için tasarlandı. Çözümümüz, sürücülerin işitme engelli insanların fark edilmesine neden olduğu durumları içerir. Care4HIP, araca yakın olan bu kişilerin gelen konum bilgilerini hesaplar ve bu kişilerin aracına göre yönünü belirler. Konum bilgisi, her bir kişinin bulunduğu konumun enlem ve boylam verileri ifade eder. Önerilen sistem sonucu, mobil ve gömülü sistem tabanlı uygulamaları içerir. Care4HIP’in duyma engelli kişiler için minimal ek yük ve pratik bir çözüm sunduğu düşündürebiliriz.

**Anahtar Kelimeler:** İşitme engelli bireyler, trafik, gömülü sistem, Raspberry Pi 3+

**1. INTRODUCTION**

Hearing impairment or disability is a global health problem [1]. Hearing disability is an individual's inability to use verbal language functionally in daily life due to a problem in the hearing system [2]. According to the World Health Organization (WHO), hearing loss is one of the major diseases that increase the global disease burden. In general, this situation is becoming more important than ever in society. Hearing loss is not only due to the aging in the population, but also because young people are increasingly spending time in activities that expose them to excessive noise in their free time [3]. According to the WHO 2019 data [4], 6.1% (466 million people) of the world population suffer from hearing loss. 93% (432 million) of them are adults and 7% (34 million) are children. In addition, the number of hearing impaired people is estimated to increase to 630 million in 2030 and 900 million in 2050. According to TurkStat, Turkey Disability Survey in 2002, the proportion of disabled hear-impaired population in Turkey is 0.4%. A survey on problems and expectations of disabled people which performed in 2010 by TurkStat showed that 26.8% of the hearing impaired people aged 15 years and over are from working class [5].

People with disabilities face many difficulties in business and social life [6]. Similarly, the hear-impaired or deaf people try to overcome these difficulties in social life. Hearing-impaired people face the difficulties of life, especially in big cities. One of these difficulties is that they cannot discern the vehicle behind them while walking on the street and therefore deadly accidents occur.

When the literature is examined, there are few studies aiming at developing tools to contribute to the social life of the hear-impaired people. For example, Ando et al. [7] developed a system which detects the sounds coming from people and objects around hearing impaired people using Raspberry Pi and USB microphone, and that sends them to their mobile phones in writing. The system operates with 100% accuracy for applause and intercom,
while it is with 80% accuracy for door sound. Furuhashi et al. [8] developed a wheeled robot that gives tactile warning in case of emergency for the hearing impaired people. The developed robot recognizes sounds such as fire alarms and gives tactile warning by hitting the hearing impaired person. Landicho [9] developed a mobile messaging application for visually and hearing impaired people to communicate with each other. In the developed application, the sound was converted to text or vice versa according to the obstacle situation of the user. Ertzgaarda et al. conducted a study on the prevalence and etiology of hearing impairment among primary school children in Tanzanian. They examined 403 children and screened those for hearing loss, and also they used otoscopy images on the children who failed the screening [10]. De Oliveira et al. evaluated the performance of adults having sensorineural hearing loss which is associated with speech perception [11]. Peddie and Kelly-Campbell investigated the hearing-impaired people in New Zealand whether and how used the internet to find hearing-related information with 11 participants having hearing impairment with various degrees [12]. Karmel et al. conducted an IoT based device for deaf, dumb and blind people using a Google API and Raspberry Pi embedded system. This system which has text to speech and speech to text modules provides an image to text conversion and speech synthesis [13]. Kim et al. examined the depression risk of the peoples in all age groups having hear-imairment. Hearing-imairment was conducted with a Cox-proportional hazard model [14]. In addition, the studies in [15-17] focused on the appropriateness of educational contents, and the role of information technologies in the education of the hearing impaired or deaf people.

Unlike these studies, this paper proposed a solution for hearing-impaired people (HIP) in traffic. This solution is a simple and reasonable approach to recognize these people. The proposed study eliminates the negativities that may be encountered in the streets where there is heavy traffic, which is one of their many problems faced in social life. The main focus of the study is to determine the HIP in traffic and to contribute to the prevention of risky situations. For this purpose, an embedded system was designed for vehicles in traffic. The developed system can be explained as the calculation of the locational information coming from the hear-impaired person and the embedded system, and the activate the real time warning system considering the threshold limit value. It is thought that this system will be especially beneficial for the hear-impaired people and drivers in big cities. The hosting of information of the HIP in a centralized system, and accessing this information by the embedded system through the internet of things are the main procedures carried out in this study.

The rest of the paper is organized as follows: Section 2 presents the problem statement and its workflow process. After giving an overview of the proposed study, each procedure is explained in the sub-sections. Section 3 presents an experimental evaluation of the proposed study. Finally, Section 4 addresses the conclusion and future works.

2. EXPERIMENTAL DESIGN

HIP detecting system can be used by the related people with daily activities in city center, specifically. For this reason, we offer an embedded system design having a new technological infrastructure in order to carry out detection of hear-impaired people and feedback to driver in this study. There are three modules in this system; the one is the embedded system side which sends the location information to the server. The second one is the mobile side which sends the location information of the hear-impaired person to the server. The other one is the server side that calculates the distance and angle between the embedded system and the hear-impaired person.

In this section, we explain how to design the system, hereafter Care4HIP, step by step. Overview of the study, the connection schema of the embedded system, and the requirements of the Care4HIP are illustrated in Figure 1. Each of the main steps is described in the following sub-sections, in detail.
2.1. System Design
The schematic design of the proposed study is introduced in Figure 2. According to this schema:
1) The embedded system connects to the server over an HTTP connection to send its location information (Figure 2, arrow 1).
2) The hear-impaired person connects to the server over an HTTP connection via mobile phone to send his/her location information. (Figure 2, arrow 2).
3) The server-side application detects the hear-impaired person who close to the vehicle and triggers the embedded system to alert (Figure 2, arrow 3).
4) The android programming was used to send the hear-impaired person’s locational information while Python was used for both server side and embedded system side.

Figure 2. The schematic design of the proposed study.
In this system:
  a) Positional information includes a latitude and longitude data (e.g., 41.99393, 34.92023).
  b) All requests are performed with HTTP URL.

To initialize the system, first, the socket server application is started via port number 37037. Location information from the embedded system and mobile application are then sent to the server in every second.

2.2. Server Side
In this sub-section, we explain the calculation process of positions retrieved from person’s smart phone and the embedded system. The server side has three main tasks:

1) The server stores and updates the location and time information of the HIP continuously.
2) The HIP who is close to the vehicle is ignored if the difference between the sending times of last position and previous position is less than the 5 seconds waiting time that is defined in the system settings. The reason for this is to prevent the system gives alert repeatedly for the same person.

3) When the location of any vehicle is sent to the system, the server sends the direction information of the HIP located near this vehicle to the embedded system.

Server-side socket programming was carried out with Python. The server queries if there are any hear-impaired individuals near of any vehicle. Figure 3 shows a list of locations of the HIP near the embedded system. Server side module checks the distance between the HIP and embedded systems by using the location information of both of them, and triggers the embedded system by performing the following two steps, respectively.

Step 1: Calculation of the distance of hearing-impaired person to the vehicle: Positions distance between the embedded system and hearing-impaired person was calculated using the latitude and longitude values of them on earth with the help of Haversine formula coined by James Inman in 1835 [18, 19]. This formula is given in Pseudo Code 1.

Pseudo Code 1. Convert the distance to the meter

```
begin
  Input: latitude_1, longitude_1, latitude_2, longitude_2
  R = 6378.137 // The radius of the world
  distanceLatitude = latitude_2 x \frac{\pi}{180} - latitude_1 x \frac{\pi}{180}
  distanceLongitude = longitude_2 x \frac{\pi}{180} - longitude_1 x \frac{\pi}{180}
  a = sin(distanceLatitude/2) x sin(distanceLatitude/2) + cos(latitude_1 x \frac{\pi}{180}) x cos(latitude_2 x \frac{\pi}{180}) x sin(distanceLongitude/2) x sin(distanceLongitude/2)
  c = 2 x atan2(sqrt(a), sqrt(1 - a))
  d = R x c
  return x 1000 // meter value
end
```

Step 2: Calculation of the position of hearing-impaired person to the vehicle: First, the angular difference of the previous and last position of the GPS module, which was obtained at one second intervals, is calculated using Equation 1 (see Figure 4a). Then, the embedded system is moved to the plane of origin 0 for each calculation. The angular difference of the hear-impaired person to the new position of the embedded system is then calculated using Equation 2 (see Figure 4b).
The angular difference \( (ES_{\text{new position}}, ES_{\text{old position}}) \) =
\[
\text{atan2} \left( ES_{\text{new position}}_x - ES_{\text{old position}}_x, ES_{\text{new position}}_y - ES_{\text{old position}}_y \right) \cdot \left( \frac{180}{\pi} \right)
\]
(1)

Example:
The angular difference \( (ES_{\text{new position}}, ES_{\text{old position}}) \) =
\[
\text{atan2}(-2, 5) \cdot \left( \frac{180}{\pi} \right) = 45°
\]

The angular difference (Hear-impaired person, \( ES_{\text{new position}} \)) = \text{atan2} (\text{Hear-impaired person}_x - \text{ES}_{\text{new position}}_x, \text{Hear-impaired person}_y - \text{ES}_{\text{new position}}_y) \cdot \left( \frac{180}{\pi} \right)
(2)

Example: The angular difference (Hear-impaired person, \( ES_{\text{new position}} \)) = \text{atan2} (1, -2) \cdot \left( \frac{180}{\pi} \right) = -108,43°

Figure 4. a) The angle difference between the new and old position of the embedded system. b) the angle difference between the new position of the embedded system and hear-impaired person’s position.

In cases where the angular difference is negative, 360° is added to this value and the angular difference is moved to the positive plane. Therefore, for this example, the angular difference is -153,43° + 360° = 206,57°. The direction determination of the hear-impaired person according to the embedded system was carried out via this angular difference. For this purpose, the calculations were made on 8 bows of 45° in the analytical plane. 22.5° tolerance was used to provide the required precision in these bows. After the distance and direction calculations, in case of the hear-impaired person exceeding the specified distance limit, the embedded system gives a warning sound with buzzer. In addition, the server sends the direction information of the HIP to the driver, such as ‘FORWARD’, ‘FORWARD_LEFT’, and also the embedded system notifies the driver by a sound in wav format. In Figure 5, it is assumed that the vehicle is in the center of the circle, and also it is moving in direction #1.
The direction of the hear-impaired person in position #1 relative to the vehicle is "FRONT".

2.3. Mobile Application Side
As seen in Figure 6, in this module, which is developed with Java language in Android studio platform, after entering the user name and password, ‘Start’ button is pressed and user information and location information are continuously sent to the server every second. Figure 7 shows the location information sending from the mobile application to the server.

2.4. Embedded System Side
The embedded system is located in the moving vehicle. This system consists of Raspberry Pi 3+, GY-NEO6MV2 GPS module and buzzer components. Raspberry Pi is a Linux-based, small-sized, low-cost device that can be used as a personal computer [21]. The GY-NEO6MV2 GPS module is used for location control and tracking in many applications, especially flight control systems. This module, which has high quality and sensitivity, is frequently used in applications requiring location
information with GPS. It has a sensitivity of approximately 5 meters [22]. The application was developed with Python language in this study. The communication between the Raspberry Pi 3+ and the GPS module is carried out via serial connections on the RX and TX pins. To ensure this communication, these pins are mutually cross-linked. The current location information received from the GPS module and the associated embedded system ID’s user name and password are sent to the server over the internet connection by embedded system.

3. EXPERIMENTAL EVALUATION

Assuming that the city inner speed limit is 60 km/h, the distance taken by the vehicle per second will rise to approximately 17 meters. Taking this information into consideration, it is ensured that the embedded system in the vehicle gives warning between 80 and 100 meters away. Under these conditions, the performance of the Care4HIP was tested with the 8 directions. The test results are shown in Table 1. The server calculated the distance and correctly determined the direction. The embedded system triggered the alarm circuit and also gave direction information in wav format from the speaker. When the actual and calculated direction information is examined, it can be said that the Care4HIP system runs successfully with 100% accurate detection. Overall, it was accepted that this system operated under criteria below:

a) The mobile application was installed in the smart phones of the hear-impaired people and these people known use the program.

b) Vehicles have embedded system.

c) Drivers followed the speed rules and have a smooth internet connection.

In addition, we offered a questionnaire form based on the evaluation of the designed system. This form consists of 5 questions and it is ‘Likert’ scale type; Strongly Agree (5 scores), Agree (4 scores), Neutral (3 scores), Disagree (2 scores), Strongly disagree (1 scores). A questionnaire form was applied to 22 participators to evaluate the Care4HIP. The average scores obtained from each participant’s answers given to the questions are shown in Figure 8. As can be seen in this figure, 15 participants gave a positive opinion while 4 participants gave a negative opinion. In addition, the number of people who gave a neutral opinion about the designed system is 3. According to these evaluations, the majority of the participants had positive opinions about the overall Care4HIP system, while only a few of them had negative opinions.

![Figure 8. Mean survey score of the participants](image-url)
### Table 1. Calculations on the sample synthetic data

| Tests | Distance | The first position of embedded system (latitude and longitude) | The last position of embedded system (latitude and longitude) | The position of hearing-impaired person (latitude and longitude) | The angle of embedded system | The direction of embedded system | The angle of hearing-impaired person | The angle between the hearing-impaired person and the embedded system | Calculated direction | Actual direction |
|-------|----------|---------------------------------------------------------------|---------------------------------------------------------------|---------------------------------------------------------------|-------------------------------|----------------------------------|----------------------------------|---------------------------------------------------------------|-------------------|------------------|
| #1    | 91.071774308756409 | 41.376605, 33.777010 | 41.37752517331584, 33.776200381633465 | 41.37671406927994, 33.77642777221075 | 41.34306931019844 | FORWARD_RIGHT | 170.0427511237337 | 211.38582043393353 | BEHIND_RIGHT | BEHIND_RIGHT |
| #2    | 85.701875460572142 | 41.376605, 33.777010 | 41.37636188864356, 33.777308673317464 | 41.3776506431182125, 33.77780294932325 | 61.4085306415019 | FORWARD_LEFT | 7.000148324648404 | 123.64232160679659 | BEHIND_LEFT | BEHIND_LEFT |
| #3    | 90.924760921217742 | 41.376605, 33.777010 | 41.37708821568443, 33.77611478622242 | 41.376430258841005, 33.77720580353532 | -129.14460373260013 | FORWARD_RIGHT | 67.47405921151093 | 67.47405921151093 | FORWARD_RIGHT | FORWARD_RIGHT |
| #4    | 93.41053278488113  | 41.376605, 33.777010 | 41.37722518715341, 33.77756392297327 | 41.37673430627457, 33.77820661934061 | 50.592232084682197 | FORWARD_LEFT | 99.26374153533541 | 99.26374153533541 | FORWARD | FORWARD |
| #5    | 99.26374153533541  | 41.376605, 33.777010 | 41.377334806424194, 33.77789823525199 | 41.377887099626335, 33.77789251086224 | 50.592232084682197 | FORWARD_LEFT | 59.25668325841786 | 59.25668325841786 | FORWARD | FORWARD |
| #6    | 93.50544380169437  | 41.376605, 33.777010 | 41.37659421803862, 33.7775991378127 | 41.37744314617591, 33.7776120121981 | 91.0484676289847 | RIGHT | 32.6632544136728 | 32.6632544136728 | FORWARD_LEFT | FORWARD_LEFT |
| #7    | 99.35528261926274  | 41.376605, 33.777010 | 41.3771622489058, 33.77730321709787 | 41.376599972785787, 33.77596920681741 | -149.3203012334509 | LEFT | 116.95397669208361 | 116.95397669208361 | REAR | REAR |
| #8    | 89.62601271551928  | 41.376605, 33.777010 | 41.3764947414782, 33.77693663282022 | 41.3764947414782, 33.77693663282022 | 50.592232084682197 | LEFT | 126.21119828016124 | 126.21119828016124 | LEFT | LEFT |

# indicates the number of test.
Also, Figure 9 shows the frequency of responses of all participants to each questionnaire form. The first survey item asks whether the Care4HIP system is easy to use. When the answers given to this question are examined; while 12 participants stated that the Care4HIP was easy to use, only 5 participants expressed negative opinion and 5 participants expressed neutral opinion. In other words, more than half of the participants think that this system is easy to use. The second survey item asks whether it is quick to learn how to use the Care4HIP system. 12 participants gave positive opinion, 4 participants gave negative opinion and 6 participants gave neutral opinion. That is, more than 50% of the participants learned the use of the Care4HIP system quickly. The third survey item asks whether the Care4HIP system is useful. While 13 of the participants thought that this system was useful, only 1 participant thought that the system was not useful. The number of people who expressed neutral opinion is eight. That is, approximately 60% of respondents think that the Care4HIP system is useful, while only about 4.5% think it is not useful. The fourth survey item asks whether participants are satisfied with the Care4HIP system. While 15 of the participants expressed positive opinion, 2 of them expressed negative opinion and 5 of them expressed neutral opinion. In other words, nearly 70% of the participants are pleased to use the Care4HIP system. Only 9% are not happy with this system. The last survey item is about whether or not the participants would recommend Care4HIP to their friends. While 14 (more than 60%) of the participants stated that they could recommend this system to their friends, 1 (approximately 4.5%) of them could not recommend it, and 7 of them stated as neutral.

In addition, the correlation analysis was carried out and Pearson correlation coefficients (r) were calculated in order to determine the direction and severity of the relationship between the answers of the participants to the questionnaire items. It is generally accepted that there is a "strong relationship" between variables if r > 0.70, "moderately" between r = 0.40 and 0.70, "weak" if r = 0.20 and 0.40, and "negligible relationship" if r <0.20 [23]. The results of the correlation analysis for this survey are shown in Table 2.

| Items       | Q1   | Q2       | Q3    | Q4    | Q5    |
|-------------|------|----------|-------|-------|-------|
| Q1          |      | .941**   | .807**| .674**| .830**|
| Q2          | .941**|         | .897**| .821**| .882**|
| Q3          | .807**| .897**   |       | .876**| .854**|
| Q4          | .674**| .821**   | .876**|       | .924**|
| Q5          | .830**| .882**   | .854**| .924**|       |

** p< 0.01
As seen in this table, there is a middle-level positive relationship ($r = 0.674$) between the answers of the participants to the items Q1 and Q4. There is a strong and positive correlation between all answers to other items ($r > 0.70$). These correlation values can be interpreted as an indication that the participants’ answers to the questionnaire items are not random.

4. CONCLUSION AND FUTURE WORKS

This study focuses on detecting the hearing-impaired people in traffic. It is aimed to develop an embedded system that will contribute to providing a safe environment especially for the hearing-impaired people living in big cities and thus facilitate their lives. In this context, we designed three main modules in the proposed study: a) the server, which is the core beneficiary, calculates the distance and angle between an embedded system and the hearing-impaired person b) the mobile application, which sends the coordinate information of hearing-impaired people to the server in traffic and c) the embedded system which sends its location information and also warns the driver according to the trigger information from the server. Therefore, in addition to making the driver of the vehicle more careful, it is very vital for the hearing-impaired people. Care4HIP is quite important in terms of having a protective effect on the hearing-impaired people’s life considering that 6.1% of the world population suffers from hearing loss and these people cause various traffic accidents.

Experimental results show that the system is reliable. In addition, the survey results show that the Care4HIP is a valuable system. More than half of the participants stated that Care4HIP is easy to use and quick to learn; more than 60% stated that this system is useful, and they are satisfied with the use of the system and recommend it to their friends. As future improvement, we intend to develop new functionalities and to adapt the application to new requirements best fitting for the hearing-impaired people. A system that has stimulating signal to self via an electrode attached to the wrist to the person is among our aims in the future.

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DECLARATION OF ETHICAL STANDARDS

The author(s) of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

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