Proc. of IEEE AESS ESTEL 2012

People Navigation System in Confined Spaces

Marco De Piante, Daniele Inserra, and Andrea M. Tonello
DIEGM - Università di Udine - via delle Scienze 208 - 33100 Udine - Italy
phone: +39 0432 558042 - fax: +39 0432 558251 - e-mail: {marco.depiante,daniele.inserra,tonello}@uniud.it

***Abstract*—This paper describes the architecture of a navigation system for people that need to be guided through indoor environments, e.g., public buildings, hospitals, where navigation is very critical. The system has to provide both navigation and context aware information to people that may be in difficult emotive state as it happens to patients and visitors in a hospital. This system is under development within the POR/FESR Project EasyMob, funded by Friuli Venezia Giulia region of Italy. In this paper we will first present the EasyMob system approach and discuss requirements and challenges. Then, we will focus on the navigation technology and we will describe the solutions that have been developed.**

I. Introduction

Orientation in large buildings is a critical issue, especially for visually impaired people. Furthermore, in certain buildings, e.g., hospitals, people can be in a bad emotive state. The deployment of an indoor navigation system is of great interest in such scenarios. There are several examples of navigation systems in the literature. In [1], a GPS-based positioning system gives precise position information that are elaborated by a talking map. This approach, however, cannot be implemented in an indoor environment due to the lack of coverage of the satellite system into buildings. Other approaches particularly suited for blind people are based on beacons [2],[3]. These systems generally use beacons placed in suitable locations that are triggered or queried by the blind travelers. Suitable speech and / or sound messages are then delivered to the users. Typically, these solutions employ infrared (IR) technology that is particularly suited to give precise position information due to its very high directionality.

In [4], an architecture called *Topaz* has been shown. This kind of architecture uses Bluetooth technology to locate tags (via trilateration) in indoor environment. Furthermore, in order to provide a room level accuracy, it exploits the IR technology. In fact, since the IR signals can't penetrate through the walls, coverage is offered at room level.

This paper describes the EasyMob [1] system [5] that is a fully integrated solution that comprises a system management software application, a network infrastructure and a number of technologies to deliver information and to allow the navigation of people. This system is under development within the frame work of the homonymous project, that aims at developing novel solutions and carry out a real deployment at the Oncology Reference Center (CRO) in Aviano, Italy. For what the navigation system is concerned, an ad-hoc hand held device comprises a joint radio and IR interface. The radio interface uses short range Bluetooth technology (which exploits the 2.4 GHz ISM RF band and does not exhibit co-existence problems with the other radio devices that are present into a hospital). Bluetooth is used only to provide the navigation instructions and not to provide navigation information as in [4]. The IR interface instead is a custom and novel solution developed in this project. It is used to accurately detect the position.

In this paper we will first present the EasyMob system approach and discuss requirements and challenges. Then, we will focus on the navigation technology and describe the solutions that have been developed, with particular emphasis to the IR device.

[1] Part of this work has been funded by the POR / FESR project EasyMob - Friuli Venezia Giulia region - Italy

II. The EasyMob System

The EasyMob system is a fully integrated solution in which different technologies have been considered since service has to be offered to a broad variety of persons with different needs, abilities, and physical/physiological status. These technologies can be divided into two categories: the first one includes colored visible light path guides (implemented by using RGB LEDs) that provide immediate information about paths, TFT displays that give context aware information, and QR codes to identify users and their associated routes. The latter technology set comprises wireless navigation devices, in particular mobile phones and ad-hoc hand held devices equipped with both IR and Bluetooth interfaces.

The visible light path guide uses a number of light points installed on every possible route. In this way the user has just to follow the color displayed by the light points that identify the correct route to reach its destination. The light points must be programmable in order to assure the path reconfigurability. Moreover, the light points should have a simple shape, e.g., an arrow or similar, that allow users to easily find the correct way.

TFT screens can be placed in some strategical points, i.e., where the probability to choose a wrong route is high. These displays can offer more detailed information about the destination and the route. Other context aware information can be also displayed.

Another considered technology is represented by the QR codes. The printed QR code is assigned to a given user. Then, along the route, a QR reader, with a display, enables to show the entire path to get with the instructions to reach the destination.

The EasyMob system also considers the use of mobile phones equipped with Bluetooth interface, as it will be explained in the following.

Finally, hand held device can also be distributed to users at reception points. In this paper we will focus on both the hand held device device and the navigation infrastructure. The hand held device is referred to MS in the following.

III. IR - BASED NAVIGATION ARCHITECTURES

A generic navigation system is composed by two main logical blocks: positioning infrastructure and navigation unit. The positioning infrastructure is implemented in order to give the position information. In this project, it is realized by placing a certain number of IR beacons (or illuminators) at known position. The navigation unit instead is the central core of the navigation system that elaborates the position information and decides which is the right route. In general, it will also be capable to recalculate the entire route if the user takes a wrong path. Several approaches can be used to implement a navigation system depending on the navigation unit placement. Obviously, this will influence the system complexity.

In this paper we show three possible solutions that have been studied:

- the navigation unit is implemented into the mobile device;
- the navigation information is delivered by a central processing unit. This solution relies on the availability of a bidirectional IR link;
- the IR link (unidirectional) is used for positioning, and a Bluetooth link serves as the communication channel between the centralized navigation unit and the users.

In order to implement these three solutions, three different architectures must be developed, i.e., both the navigation unit and the positioning infrastructure have to provide different features. Nonetheless, the IR link is common to all architectures. Its main blocks are depicted in Fig.1. The IR Transmitter is

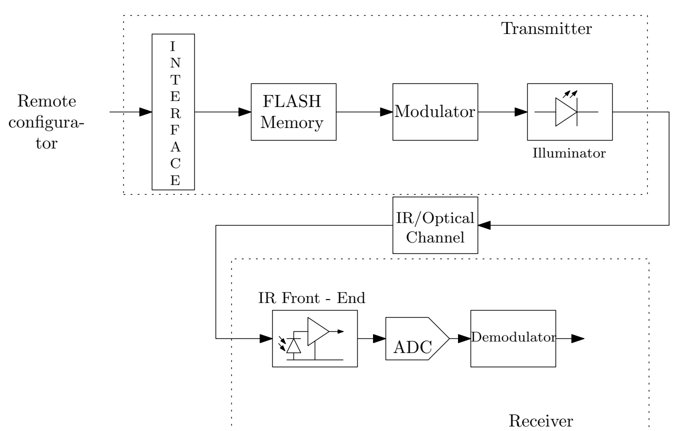

Fig. 1. IR communication system block diagram.

composed by an Interface block, used to program a FLASH Memory with data samples. Modulated data samples drive the Illuminator block, composed by a variable number of IR LEDs. This number depends on the light power required in order to achieve a certain space coverage. Moreover, the number of IR LEDs depends on the requested beam angle which is a function of the system accuracy.

The first block of the IR receiver is an analog IR front end, where IR photodiodes are connected to an amplifier. This optical transducer is connected, through an Analog to Digital Converter (ADC), to a demodulator.

Now, the three navigation architectures are discussed.

A. *IR unidirectional link*

For this architecture, which we refer to as *Local Navigation Architecture* (LNA), it is possible to make a parallelism with the GPS system, since navigation is locally, i.e., it is implemented in the hand held device. Fig. 2 shows a general environment where the LNA is implemented.

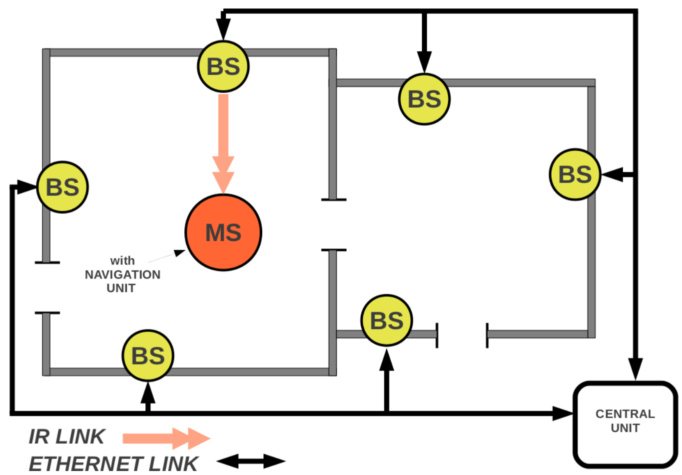

Fig. 2. Local Navigation Architecture (LNA) general environment.

As it is shown in Fig. 2, the Mobile Station (MS) is the IR receiver of the user, and the Base Stations (BSs) are the IR transmitters. All the BSs are connected through Ethernet links to a central server, that can be used only in case of an ID reconfiguration.

In this architecture, the IR transmitter sends only its programmed ID, that is unique in the network. The receiver decodes the ID data and gives navigation instructions to the user.

Since the navigation unit is implemented into the MS device, its complexity is high. Furthermore, the entire user's route must be stored in the MS. An example of a possible hardware implementation of the IR receiver is depicted in Fig. 3.

The FLASH Memory stores the complete list of BS's IDs that the user may encounter in its route, and the Read Only Memory (ROM) block contains all the vocal messages used for the navigation. The Logical Routing Block (LRB) computes the logical steps listed in the following.

1) The recognized ID is compared with all IDs stored in the FLASH Memory;
2) if the decoded ID exists in the memory, the LRB will receive the index of the next message to play; otherwise it will receive the index of a "wrong route" message;

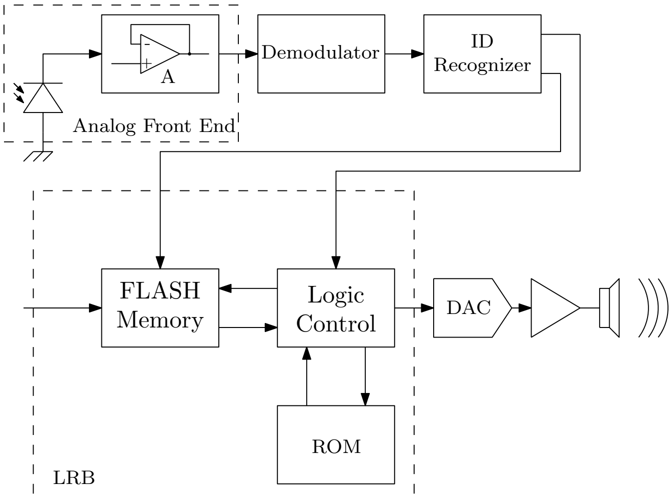

Fig. 3. IR Receiver for the unidirectional link architecture.

3) the LRB sends a query to the ROM memory with the message index;
4) the LRB sends to the Digital to Analog Converter (DAC) the vocal samples from the ROM.

Another key point of this architecture is the reduced BSs complexity. In fact, the BS comprises only a memory that stores the ID, an IR transmitter and an Ethernet network interface for the connection to the Central Unit (which is used only in case of an ID reconfiguration).

B. IR bidirectional link

This architecture, which we refer to as *Centralised Navigation Architecture* (CNA), uses the optical IR channel in two directions. The MS and all the BSs incorporate an IR transmitter and an IR receiver. Fig. 4 shows a general environment where the CNA is implemented.

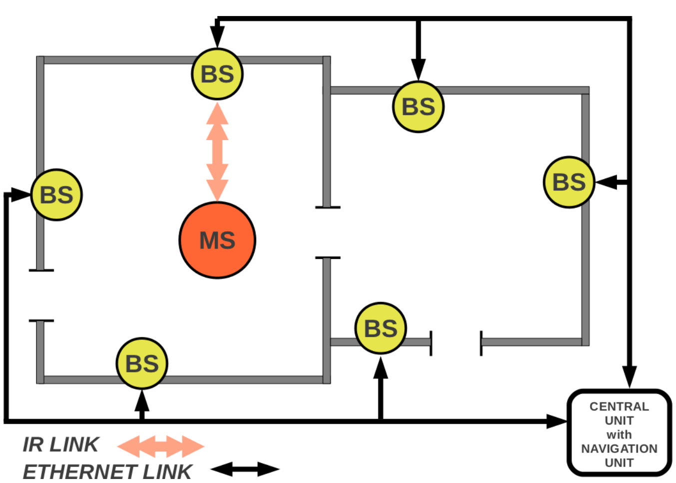

Fig. 4. Centralised Navigation Architecture (CNA).

Every MS device is firstly programmed with a static ID, unique for all the mobile devices.

In this architecture, and differently to the LNA, the MS transmits its own ID, MS_{ID}, to a specific BS through the IR link, and the BS communicates with the Central Unit through Ethernet cabled network, providing both the BS_{ID} and the MS_{ID}. In this way, the position (given by the BS_{ID}) is provided to the navigation unit implemented into the Central Unit. Obviously, the destination and the entire route of each user are stored in the Central Unit where all the destinations are indexed, and the database is refreshed every time that a new user approaches the system. Once the navigation unit has computed the correct route, it transmits this information to the linked BS that forwards it to the MS. Fig. 5 explains the navigation algorithm implemented into the Central Unit.

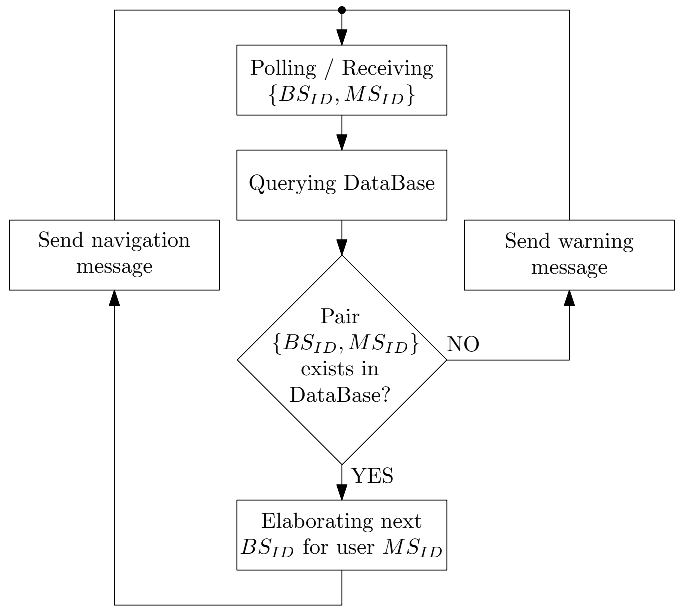

Fig. 5. Navigation algorithm for the CNA.

It should be noted that this algorithm is similar to the one implemented by the LRB in the LNA, but in that case it is implemented into the MS. The bidirectional link allows to simplify the hardware complexity at the receiver, because the navigation unit algorithm resides in the Central Unit. With respect to the LNA, in this case the navigation unit is common to all the users, and a multiple access technique has to be implemented. There are two levels of media access: the first is the Central Unit access, that is regulated by the Ethernet protocol (in particular CSMA-CD). The second level of access is at the BSs. Nevertheless, the probability that two or more users transmit at the same time their MS_{ID} is very low. In fact, the analog front end of a BS cannot have a wide angular aperture since it provides the correct navigation information only when the user is in a position where this information is useful. A more probable event is that the BS transmits the navigation data to two (or more) users. For this reason, the MS must be capable of recognizing and demodulating only its own navigation message. This can be simply implemented with an ID comparator used to identify the correct message.

The use of a Central Unit increases latency and delays. Moreover, CNA is more sensible to the Central Unit faults, and the main requirements are the software robustness and system stability.

C. Bluetooth - IR link

This architecture is similar to the one discussed in the previous section. However, at the physical layer, two wireless technologies are used, i.e., Bluetooth and IR. Particularly, the IR link is unidirectional from the BS to the MSs, and Bluetooth is used in bidirectional mode. In order to implement this BlueTooth CNA (BT-CNA), the positioning infrastructure requires additive components, i.e., the Bluetooth Access Points (BT-APs), that are placed in several points in the building. The main idea (Fig.6) is to use the IR unidirectionally, to send the BS_{ID} to the MS device, in order to transfer the position information, from the BS to the MS. Then, the BT interface is triggered and it transmits to a BT-AP the $\{BS_{ID}, MS_{ID}\}$ pair. Similarly to the CNA, this information reaches the Central Unit that computes the route and sends the navigation information to the MS through the BT link.

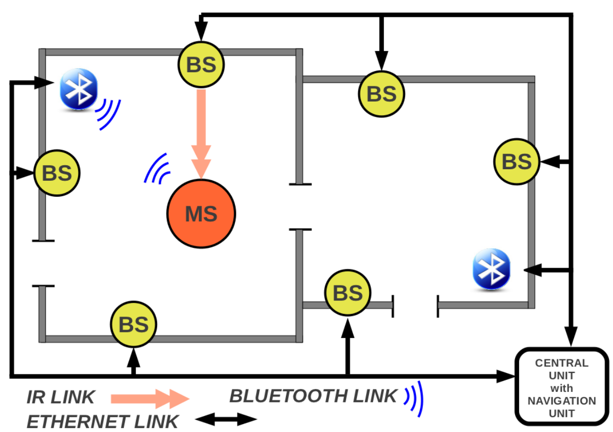

Fig. 6. Bluetooth Centralized Navigation Architecture (BT-CNA).

Thus, in the BT-CNA case, the MS device not only includes an IR receiver, but also a Bluetooth transceiver used to transfer and to retrieve the correct navigation information to and from the Central Unit. The main steps for the navigation are briefly reported in the following.

1) The user approaches the system with an MS device;
2) through the IR link, the user receives the BS_{ID} that implicitly includes the position;
3) the pair $\{BS_{ID}, MS_{ID}\}$ is sent to the Central Unit via a Bluetooth uplink channel;
4) the Central Unit runs the algorithm of Fig. 5 and sends navigation information to the BT-AP where the navigation query has been sent;
5) the BT-AP delivers navigation information to the linked MS device, and the user will listen the correct navigation step.

The number of BT-APs is lower than the number of IR BSs: in fact BSs are used only to give the correct user position in points where the orientation is difficult, while the BT-AP handles many links, and it is capable to manage all users present in the same area. It should be noted that the complexity of the MS device increases, in order to interface IR and Bluetooth technologies. Particularly, the IR demodulator must be equipped with a ID recognizer interfaced with the Bluetooth baseband elaboration block, in order to send through the Bluetooth link the received BS_{ID}. Obviously, costs will increase for this MS hardware architecture, but latency and delays to retrieve the navigation information are limited, mainly for the possibility to send an entire navigation instruction (for example coded as a WAV file) with a higher bit rate than the IR link. Moreover, the power consumption does not increase significantly, since the BT transceiver switches on only when a BS_{ID} is received.

Finally, since BT is largely diffused in smart phones, the BT-AP infrastructure can in principle also be used for trilateration.

IV. Selection of the Architecture

In the previous section, three main architectures have been discussed, and in the following we discuss the pros and cons for each one. It should be noted that every single architecture previously shown is capable to navigate an user in an indoor confined environment. However, for the EasyMob project, a choice must be done in order to give a concrete and definitive project architecture. In Tab. I, the three architectures are grouped, and for each architecture pros and cons are shown.

For what the LNA concerns, the major limitation of this architecture is the complexity of the MS. In fact, the MS is a hand held device, so it has to be handy and its size has to be limited. It should not require a high power consumption, and, preferably, it has to be inexpensive. Hence, the LNA was considered unsuitable for the EasyMob project.

Now, we compare the two centralized solutions. In the CNA, both the MS and BS are equipped with the IR transmitter and IR receiver. In the BT-CNA instead, the MS has the only IR receiver, and the BS has the only IR transmitter. Moreover, the MS requires a BT transceiver, and some BT-APs have to be installed. However, the presence of a BT transceiver does not increase significantly the power consumption, since it is not always switched on. Anyhow, it increases the link bit rate, facilitating the transmission of more data, for example a high quality audio message, and reducing the latencies.

For these reasons, the BT-CNA is preferable, and it has been chosen as the navigation architecture of the EasyMob project.

V. Prototype Implementation

Since BT-CNA uses an IR transmitter and receiver, a prototype has been developed on FPGA demo board, with external ADC and DAC blocks.

In Fig.7, the FPGA board with the IR transmitter front end is shown on the right side. The IR front end, composed by a certain number of IR LEDs driven by a current amplifier, is connected to the FPGA board.

TABLE I
TOP LEVEL ARCHITECTURES' COMPARISON

Architecture	Pros	Cons
LNA	• Simple BS transmitter; • Active Central Unit not necessary; • BS_{ID} can be set without a network cabling and left in this state as long as new reconfiguration is needed;	• High MS hardware complexity;
CNA	• Navigation logic resides in the Active Control Unit: MS device does not need the Navigation Logic;	• Requires an Active Central Unit; • Every BS must be cabled and connected to the Central Unit; • BSs and MSs must implement both IR front - ends • Latency and delays in message delivering become important;
BT-CNA	• Simple IR transmitter; • IR BS_{ID} can be programmed like in LNA; • Latency and delays are reduced using BT-AP; • Navigation service can be delivered even through Bluetooth trilateration with smart phones;	• MS hardware complexity grows up; • Requires an Active Central Unit;

On the left side of Fig.7 instead, the FPGA board with the IR receiver front end is shown. Here, the analog front end amplifies the signal at the output of the photodiode. The resultant signal is brought to an ADC and successively to the demodulator implemented on the FPGA. When the samples of the audio message are recovered, they are sent to an external DAC that drives an audio interface.

VI. CONCLUSIONS

In this paper we have discussed the EasyMob system, which is a navigation system for people that need to be guided through indoor environments. The presence of several technologies makes this system capable of providing both navigation and context aware information, and to offer these services to a broad variety of people with different needs, abilities, and physical / physiological status. Particularly, we have analyzed three possible solutions to implement the navigation architecture, based on an IR beacon infrastructure, and a hand held device used to deliver navigation messages. The differences between these architectures have been discussed. Taking into account practical constraints and requirements, a centralized navigation architecture has been chosen.

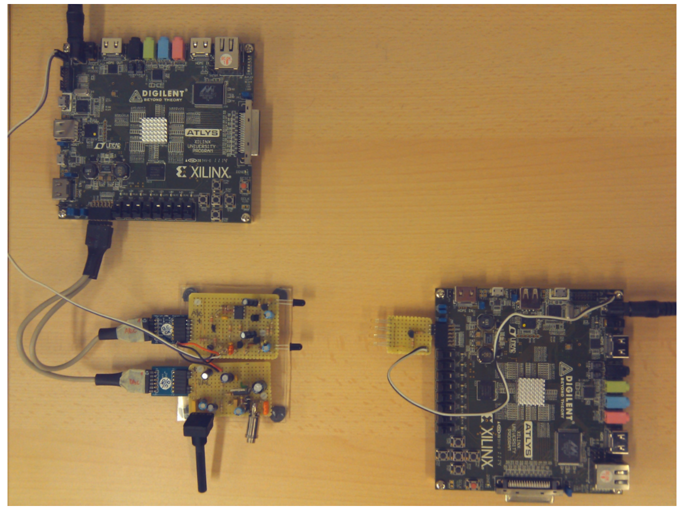

Fig. 7. FPGA demo boards and optical front ends.

ACKNOWLEDGMENT

The authors acknowledge the collaboration with the EasyMob project partners: Solari di Udine s.p.a., Oncology Reference Center (CRO) Aviano, L.U.C.I. s.r.l., MoBe s.r.l., Friuli Innovazione Centro di Ricerca e di Trasferimento Tecnologico, and Polo Tecnologico Pordenone.

REFERENCES

[1] T. Strothotte, H. Petrie, V. Johnson, and L. Reichart, "MoBIC: User needs and preliminary design for a mobility aid for blind and elderly travellers", in *Proc. 2nd Tide Congr., The European Context for Assistive Technol.*, I. Placeencia Porrero and R. Puig del la Bellacase, Eds. Amsterdam, The Netherlands: IOS Press, 1995, pp. 348 - 351.

[2] P. Blenkhorn and D. G. Evans, "A System for Enabling Blind People to Identify Landmarks: The Sound Buoy", *IEEE Transactions on Rehabilitation Engineering*, Vol. 5, No. 3, Sep. 1997.

[3] J. Brabyn, W. Crandall, and W. Gerry, "Talking signs: A remote signage solution for the blind, visually impaired and reading disabled", in *Proc. 15th Annu. Int. Conf., IEEE Engineering in Medicine and Biology Society*, 1993, pp. 1309 - 1310.

[4] Yanying Gu, Anthony Lo, Ignas Niemegeers, "A Survey of Indoor Positioning Systems for Wireless Personal Networks", *IEEE Communications Surveys & Tutorials*, vol. 11, no. 1, 2009, Pages:13 - 32.

[5] EasyMob project website, http://www.easymob.eu.

[6] D. Zhang, F. Xia, Z. Yang, L. Yao, W. Zhao, "Localization Technologies for Indoor Human Tracking", *Future Information Technology (FutureTech), 2010 5th International Conference on*, vol., no., pp.1-6, 21-23, May 2010, doi: 10.1109/FUTURETECH.2010.5482731.