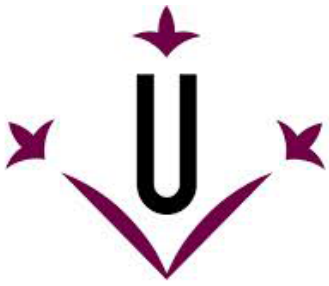
Improvement of the implementation of an Assistant Personal Robot

Javier Moreno Blanc



Universitat de Lleida

TESIS DOCTORAL

Improvement of the implementation of an Assistant Personal Robot

Javier Moreno Blanc

Memoria presentada para optar al grado de
Doctor por la Universitat de Lleida

Programa de Doctorado en Enginyeria i Tecnologies de la Informació

Directores:
Jordi Palacín y Jordi Casanovas

Abril 2017

Departament d'Informàtica i Enginyeria Industrial y Departament de Química
Escola Politècnica Superior
Universitat de Lleida

Improvement of the implementation of an Assistant Personal Robot

Memoria presentada para optar al grado de Doctor por la Universitat de Lleida redactada según los criterios establecidos en el Acuerdo núm. 67/2014 de la Junta de Gobierno del 10 de abril de 2014 para la presentación de la tesis doctoral en formato de artículos.

Programa de doctorado: Enginyeria i Tecnologies de la Informació

Directores de la Tesis: Dr. Jordi Palacín Roca y Dr. Jordi Casanovas Salas

El Dr. Jordi Palacín Roca y el Dr. Jordi Casanovas Salas, Profesores Titulares de la Escuela Politécnica Superior de la Universitat de Lleida.

CERTIFICAN:

Que la memoria "Improvement of the implementation of an Assistant Personal Robot" presentada por Javier Moreno Blanc para optar al grado de Doctor se ha realizado bajo su supervisión.

Lleida, 28 de abril de 2017

Agradecimientos

A mis directores de tesis, el Dr. Jordi Palacín Roca y el Dr Jordi Casanovas Salas, por su gran generosidad al brindarme la oportunidad de formar parte del equipo de investigación del Laboratorio de Robótica de la Universitat de Lleida. Su calidad humana y capacidad científica han contribuido no solo en la tutela de este proyecto de tesis doctoral, sino que han supuesto para mí un apoyo imprescindible durante todo mi periodo universitario.

A los doctores y compañeros de departamento, Tomas, Marcel, Dani y Eduard, con los que, además de muchas publicaciones, comparto una muy buena amistad.

Por último, un agradecimiento especial a mis padres y hermano, porque con su esfuerzo y cariño me dieron la posibilidad de llegar hasta este grado académico, apoyándome durante todo mi recorrido universitario.

Summary

This memory presents the research carried out with the objective of improving the implementation of an Assistant Personal Robot (APR) based on a mobile robot for applications in domestic environments. This implementation of new robotic technologies allows the development of new assistive devices, which can be applied to significantly improve the people´s quality of life, especially elderly people with mobility impairments.

The first part of the research focuses on the development of the mechanical part of the mobile robot. This research describes the holonomic mobility system used in the mobile robot which is based on the use of three omnidirectional wheels, shifted 120°. This holonomic system allows the development of complex trajectories and the development of the kinematic model enables the identification of the mobile robot displacements based on the information gathered from the rotation of the wheels.

The improvement of the location of the mobile robot in the XY plane is another of the objectives addressed in this memory. This research has been performed by means of the study and characterization of a low cost optical sensor based on the application of the Doppler Effect as a possible system to obtain the displacement of the robot on the ground level.

One of the most characteristic elements of a care robot is its control unit. The performed research has explored the possibilities of a Tablet with Google Android as a control system. The use of commercial devices with an open operating system allows a constant evolution of their characteristics, bringing together in a single body several sensors and interactive elements such as an interactive multitouch screen, a camera vision, microphones, loudspeakers, accelerometers and light intensity sensors, allowing information of the environment and the evolutions of the mobile robot.

The last section of the memory has been focused on the study of the problem of moving the mobile robot through closed rooms of the house, overcoming the limitations of doors in domestic environments. To this end, a mechanical accessory

has been incorporated into the basic design of the mobile robot in order to mechanically open a conventional door.

Resumen

Esta memoria presenta la investigación realizada con el objetivo de mejorar la implementación de un Asistente Personal Robótico (APR) basado en un robot móvil para aplicaciones en entornos domésticos. La implementación de nuevas tecnologías robóticas permite el desarrollo de nuevas aplicaciones de asistencia personal, lo que puede aplicarse a mejorar de manera significativa la calidad de vida de las personas, sobre todo de personas mayores o con movilidad reducida.

La primera parte de la investigación se centra en el desarrollo de la parte mecánica del asistente personal, presentando un sistema de movilidad holonómico basado en el uso de tres ruedas omnidireccionales desfasadas entre sí 120º, permitiendo al APR efectuar complejas trayectorias y aplicar un modelo cinemático para estimar la localización del robot en función de la rotación de las ruedas.

La mejorara de la ubicación del robot móvil en el plano XY es otro de los objetivos abordados en esta memoria. Se ha realizado el estudio y caracterización de un sensor de bajo coste empleado en algunos ratones de ordenador y basado en la aplicación del efecto Doppler como posible sistema para obtener el desplazamiento del robot sobre el plano.

Uno de los elementos más característicos de un robot asistencial es su unidad de control. En esta memoria se han explorado las posibilidades de utilizar una Tablet con Google Android como sistema de control. El uso de dispositivos comerciales con un sistema operativo abierto permite una evolución constante de sus características, a la vez que reúne en un único dispositivo varios sensores y elementos de interacción tales como una pantalla multitáctil interactiva, una cámara de visión, micrófonos, altavoces, acelerómetros y sensores de intensidad de luz, permitiendo obtener información del entorno y de la evolución del robot móvil.

El último apartado de la memoria se centra en el estudio del problema de la movilidad del robot por distintas habitaciones. El objetivo ha sido superar las limitaciones que suponen las puertas en los entornos domésticos. Para ello se ha incorporado al diseño básico del robot un accesorio mecánico que le permite abrir una puerta convencional.

Resum

Aquesta memòria presenta la investigació realitzada amb l'objectiu de millorar la implementació d'un Assistent Personal Robòtic (APR) basat en un robot mòbil per aplicacions en entorns domèstics. Aquesta implementació de noves tecnologies robòtiques ha permès el desenvolupament de noves aplicacions d'assistència personal que poden contribuir a millorar la qualitat de vida de les persones, sobretot en persones grans o gent amb mobilitat reduïda.

La primera part de la memòria es centra en el desenvolupament de la part mecànica de l'assistent personal, creat a partir d'un sistema de mobilitat holonómic basat en l'ús de tres rodes omnidireccionals desfasades 120º, permetent a l'APR efectuar trajectòries complexes aplicant el model cinemàtic del sistema per estimar la posició del dispositiu en funció de la rotació de les rodes.

La millora sobre la ubicació del robot mòbil en el pla XY és un altre dels objectius abordats en aquesta memòria. S'ha realitzat l'estudi i caracterització d'un sensor de baix cost utilitzat en alguns ratolins d'ordinador basat en l'aplicació de l'efecte Doppler com a possible sistema per obtenir el desplaçament del robot sobre el pla.

Un dels elements més característics d'un robot assistencial és el seu sistema de control. En aquesta memòria s'han explorat les possibilitats d'utilitzar una Tablet amb Google Android com a dispositiu de telecontrol. L'ús de dispositius comercials amb un sistema operatiu obert permet una evolució constant de les seves característiques i reunir en un únic dispositiu diversos sensors i elements d'interacció com ara una pantalla multi tàctil interactiva, una càmera, micròfons, altaveus, acceleròmetres i sensors d'intensitat de llum, permetent obtenir informació de l'entorn i de l'evolució del robot mòbil.

L'últim apartat de la memòria es centra en l'estudi d'una solució que permeti al robot desplaçar-se per les habitacions d'una casa u oficina, superant les limitacions que suposen les portes en aquests entorns. Aquesta solució es basa en la incorporació d'un accessori mecànic al robot que li permeti obrir una porta convencional.

Contents

List of Figures

Design, Implementation and Validation of the Three-Wheel Holonomic Motion System of the Assistant Personal Robot (APR)

Experimental Characterization of the Twin-Eye Laser Mouse Sensor

Evaluation of the Color-Based Image Segmentation Capabilities of a Compact Mobile Robot Agent Based on Google Android Smartphone

A Combined Approach to the Problem of Opening a Door with an Assistant Mobile Robot

List of Tables

Design, Implementation and Validation of the Three-Wheel Holonomic Motion System of the Assistant Personal Robot (APR)

Evaluation of the Color-Based Image Segmentation Capabilities of a Compact Mobile Robot Agent Based on Google Android Smartphone

Evaluation of the Color-Based Image Segmentation Capabilities of a Compact Mobile Robot Agent Based on Google Android Smartphone

Chapter 1

Introduction

The main objective of this thesis is the development of robotic technology applied to the implementation of assistant robots. That is expected to contribute especially to increase the people´s quality of life with mobility impairments and elderly people. In this direction, the reports from United Nations [1] and World Health Organization [2] postulated that people aged 60 or more would rise from 12% to 21% during the next 35 years because of a clear increase of human life expectancy. In such context, the development of new robotic technologies can foster the development of new applications that contribute to improve the people´s quality of life in general and specifically to maintain the current assistance standards to elderly people.

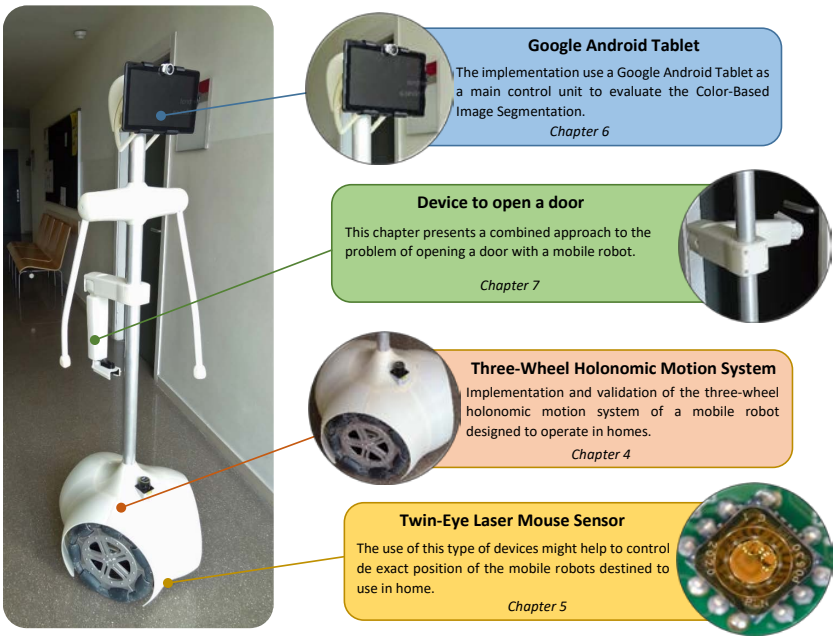


Figure 1.1. Graphical representation of the area of application of each individual article described in this memory.

This thesis has been written according to the regulations 67/2014 of the University of Lleida that define the memory in chapters based on published papers in the context of developing new robot technologies. Figure 1 shows a photo of the mobile robot assistant implemented in this research, named Assistant Personal Robot (APR). Figure 1.1 also shows a graphical representation of the area of application of each individual article described in this memory.

The first selected article for this thesis memory consist on the design, implementation and validation of a new mobile robotic assistant, designed to operate and navigate in tight spaces such as in domestic environments mainly thanks to a three-wheel holonomic motion system. This design includes several resemblances with humans to improve the application of the mobile robot as a personal assistant robot. In this proposal, the motion system of the APR is based on the use of three omnidirectional wheels shifted 120°, see Figure 1.2, with operation principles are based on kinematic models.

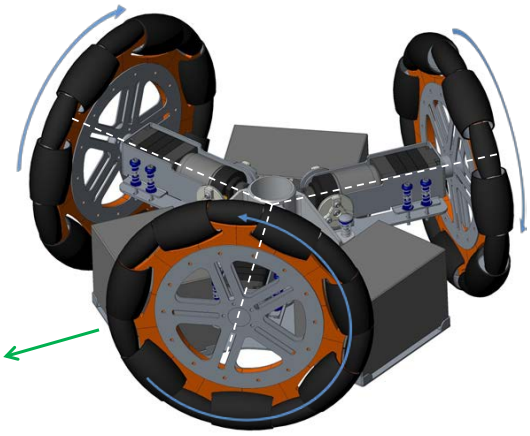


Figure 1.2. CAD model of the motion system, add detail of the labeling and positive angular velocity of the wheels. The green arrow depicts the front of the mobile robot.

On the one hand, the direct kinematic model was based on the analysis of the rotation of the wheels in order to estimate velocity, direction and rotation of the mobile robot to estimate the displacement of the APR. On the other hand, the inverse kinematic model allows the development of complex trajectories in indoor spaces. Both models will be used to control the motion of the APR in a real-time operation.

The second selected article for this thesis memory analyses the experimental characterization of a laser mouse sensor used in some optical mouse devices. This analysis was performed in order to validate the use of a laser mouse sensor as a low cost localization system with application to any mobile robot. The main advantage of this inexpensive analysed sensor is the capability of measuring x and y axis displacements, and the poor sensitivity to z axis changes originated by small ground height irregularities. It is expected the future application of this low cost localization system in the APR as an alternative redundant planar displacement measurement system.

The third selected article for this thesis memory consists on the implementation of a mobile robot agent based on a Google Android Smartphone as a central control unit. This implementation was proposed since the final APR implementation was expected to include a Google Android Tablet as a main control unit and as a remote unit.

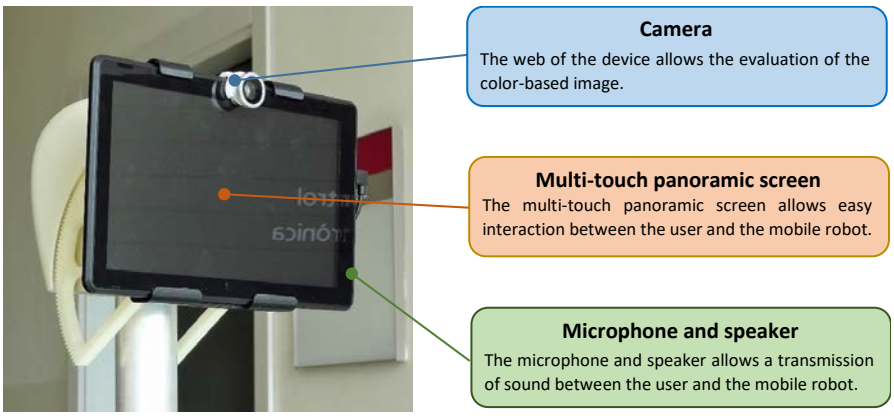


Figure 1. 3. Google Android Tablet proposed as a main control unit and different features and applications.

Figure 1.3 shows the technical characteristics of these devices that allow a very good adaptation between user and robot, some examples are: touch screen for the user to interact with the robot, the artificial vision system provided by the camera, the microphone and the speaker for voice recognition and sound generation.

The fourth selected article for this thesis memory is focused on the development of mobile robot capabilities that could be required in a robot operating as a personal assistant at homes. This proposal analyses the limitations that suppose a door for a mobile robot that has to move along different rooms of a house. This proposal has

studied the main difficulties in achieving complete mobility taking into account the three main limitations: conventional environments are designed for humans, the limited ability and force of the robots and the uncertainty of the environmental parameters which difficult automatic robotized operation. As an example, Figure 1.4 shows a device attached to the APR for opening a conventional door.

Figure 1.4. Several steps to open a door with an accessory device.

Future work will be focused on the enhancement of safety and sensor integration. In particular, the results of previous research works proposes the incorporation of adhered micrometric films as artificial skin for the mobile robot with the possibility to operate as sensors and actuators since these substances are capable of detecting external stimuli and of triggering some response mechanisms in response, such as colour, volume or electrochemical changes.

At this moment, the application of adhered micrometric films is a novel technology with promising applications in assistant mobile robots. There are two main technologies that can be applied in the APR: (1) vapour sensors based on conducting polymers capable of detecting vapours of organic solvents and acids in the ambient which may include pollution or toxic gases. Polymeric compounds based in polypyrrole derivatives have already been synthesized and tested in this field. These polymeric compounds form weak interactions with the analytes at the polymer-air interface that can be detected because they alter the response of the surface upon oxidation and/or reduction process. (2) Pressure sensors based on thermoresponsive polyacrylamides hydrogels. In this case, the sensing mechanism involves a volume change, which is caused by a conformational transition that occurs when the hydrogel temperature increases above a critical value. This temperature may be selected to be between 32 and 35 °C, so contact with human body causes the conformational change, what can be interpreted as if it were a switch.

References

[1] United Nations. World Population Ageing 2013. Available online: http://www.un.org/en/development /desa/population/publications/pdf/ageing/WorldPopulationAgeing2013.pdf (accessed on 15 December 2015).

[2] World Health Organization. World Report on Ageing and Health, 2015. Available online: http://apps.who.int/iris/bitstream/10665/186463/1/9789240694811_eng.pdf (accessed on 18 February 2016).

Chapter 2

Objectives

The main objective of this thesis is the improvement of the implementation of an assistant mobile robot by developing and validating new robotic technology applied to the development of assistive robots in order to contribute to increase the people´s quality of life with mobility impairments and elderly people. The complete development of this kind of mobile robot will allow the implementation of new application in the domestic environments.

The specific objectives of this PhD Thesis are:

a) **Omnidirectional wheel:** Design, implementation and validation of a omnidirectional wheel, whose the principle of function is based in providing traction in the normal direction to the motor axis, and the use of inner passive rollers that can slide in the direction of the motor axis. These inner passive wheels, balls or rollers are placed along the periphery or the main wheels.

   The main features of these wheels are that they can resist the weight of the structure of the mobile robot, the passive rollers must have an elastic cover in order to improve the adherence, the design the different parts of the wheel must ensure that the gap between the rollers is as small as possible.

b) **Motion system:** Mechanical implementation of the motion system based in the use of three omnidirectional wheels, shifted 120° and composed of passive rollers.

The main objective of the motion system is to have the ability to perform holonomic movements in the XY plane with the aim of allowing a movement in domestic environments also avoiding the collision with the elements of the environment.

c) Kinematics models: Describe the kinematic model of the motion system proposed to the mobile robot in order to develop complex trajectories in indoor spaces and estimate de localization of the mobile robot according to the rotation of the three different wheels.

d) Main control unit: Implementation of a Google Android Tablet as a main control unit in order to develop several task based on image processing and direct actuator control.

The advantages of using a commercial devices with an open operating system allows a constant evolution of their characteristics, bringing together in a single body several sensors and interactive elements such as an interactive multi-touch screen, a camera vision, microphones, loudspeakers, accelerometers and light intensity sensors, allowing information of the environment and the evolutions of the mobile robot. This aspect is very important to assistance task

e) Device to open a door: Design, implementation and validation of the mechanical device proposed in order to hold a handle and open a conventional door.

On the one hand, this objective is focused on the study of the main difficulties in achieving complete mobility analyzing the limitations that suppose a door for a mobile robot that has to move along different rooms of a house. On the other hand, the objective is the development of a mechanical accessory incorporated into the basic design of the mobile robot in order to mechanically opening a conventional door.

Chapter 3

PhD Thesis structure

The development of this PhD Thesis has been developed in the Robotics and Signal Processing Research Group associated with the INSPIRES UdL center (Institut Politècnic d'Innovació i Recerca en Sostenibilitat, centre de recerca de la Universitat de Lleida). This thesis has been partially funded by the Recercaixa 2013 research grant, and by the Government of Catalonia (Comissionat per a Universitats i Recerca, Departament d'Innovació, Universitats i Empresa) and the European Social Fund.

This PhD Thesis is structured in four chapters corresponding to for four published papers, that represent the different faced perspectives to develop an Assistant Personal Robot (APR); according the Science Citation Index (SCI) one of the journal is classified as a Q1 journal and another as a Q3 journal. One of the other two journals is indexed as a Q2 and Q4 journals in the Scimago Journal Rank (SJR). The referenced papers are:

- J. Moreno, E. Clotet, R. Lupiañez, M. Tresanchez, D. Martínez, T. Pallejà, J. Casanovas, J. Palacín, **Design, Implementation and Validation of the Three-Wheel Holonomic Motion System of the Assistant Personal Robot (APR)**, *Sensors* (SCI indexed as Q1), 16 (2016), 1658.
- J. Moreno, E. Clotet, D. Martínez, M. Tresanchez, T. Pallejà, J. Palacín, **Experimental Characterization of the Twin-Eye Laser Mouse Sensor**, *Journal of Sensors* (SCI indexed as Q3), 2016, Article ID 4281397, 8 pages.
- D. Martinez, J. Moreno, D. Font, M. Tresanchez, T. Palleja, M. Teixido, J. Palacin, **Evaluation of the Color-Based Image Segmentation Capabilities**

of a Compact Mobile Robot Agent Based on Google Android Smartphone, *Advances in Intelligent Systems and Computing* (SJR indexed as Q4), 221 (2013), 25-32

- J. Moreno, D. Martínez, M. Tresanchez, M. Teixidó, J. Casanovas, J. Palacín. **A combined approach to the problem of opening a door with an assistant mobile robot**, Lecture Notes in Computer Science (LNCS 8867): *Ubiquitous Computing and Ambient Intelligence* (SJR indexed as Q2), 8867 (2014), 9-12

Chapter 4

Design, Implementation and Validation of the Three-Wheel Holonomic Motion System of the Assistant Personal Robot (APR)

4.1. Introduction

This chapter presents the paper focused on the implementation and validation of the three-wheel holonomic motion system of a mobile robot designed to operate at homes which has been published in the journal Sensors. This system represents a mobility improvement in the implementation of an assistant mobile robot.

The development of mobile robot destined to be assistant robots might contribute to increase the people´s quality of life with mobility impairments and elderly people, in the future in which there is a proportion of people aged 60 or more will rise from 12% to 21% during the next 35 years as a result of a clear increase of human life expectancy.

This device will be used as a first prototype to test different systems to obtain a mobile robot. The paper analyzes the kinematics of the motion system and validates the estimation of the trajectory comparing the displacement estimated with the internal odometry of the motors and the displacement estimated with a SLAM procedure based on LIDAR information.

The main contributions in the article are:

a) The study of the various alternatives of mobility systems and omnidirectional wheels.
b) The design and manufacture of the mechanical set based on wheels and the structure of the mobile robot
c) Calculation and verification of the direct and inverse kinematics models for the control and the location of the personal assistant.
d) The validation of the three-wheel holonomic movement system based on the comparison of the mobile robot tray obtaining using alternative methods.

Pages from 23 to 46 contain the following paper:

J. Moreno, E. Clotet, R. Lupiañez, M. Tresanchez, D. Martínez, T. Pallejà, J. Casanovas, J. Palacín, **Design, Implementation and Validation of the Three-Wheel Holonomic Motion System of the Assistant Personal Robot (APR)**, *Sensors* (SCI indexed as Q1), 16 (2016), 1658.

http://dx.doi.org/10.3390/s16101658

ISSN: 1424-8220

Chapter 5

Experimental Characterization of the Twin-Eye Laser Mouse Sensor

5.1. Introduction

This chapter presents the paper published in Journal of Sensors, which consists in the experimental characterization of a laser mouse sensor used in some optical mouse devices in order to have a low-cost sensor to accurately control the mobile robots. The characterized sensor is called twin-eye laser mouse sensor and uses the Doppler effect to measure displacement as an alternative to optical flow-based mouse sensors.

The application of these low-cost sensors in a mobile robot represents an alternative implementation of an odometry system that can be used as primary or alternative motion sensor. The use of this type of devices might help to obtain an estimation of the position of a mobile robot based on ground displacement.

The main contribution is the design and implementation of the measurement system.

Pages from 49 to 64 contain the following paper:

J. Moreno, E. Clotet, D. Martínez, M. Tresanchez, T. Pallejà, J. Palacín, **Experimental Characterization of the Twin-Eye Laser Mouse Sensor**, *Journal of Sensors* (SCI indexed as Q3), 2016, Article ID 4281397, 8 pages

http://dx.doi.org/10.1155/2016/4281397

ISSN: 2194-5357

Chapter 6

Evaluation of the Color-Based Image Segmentation Capabilities of a Compact Mobile Robot Agent Based on Google Android Smartphone

6.1. Introduction

This chapter presents the paper published in the journal Advances in Intelligent Systems and Computing, which consists in the implementation of a mobile robot agent based on a Google Android Smartphone. This implementation will be used as a test for future enhanced implementations in the final APR design which may also contain a Google Android Tablet as a main control unit. This paper presents the first results obtained in the evaluation of the color-based image segmentation capabilities on a Google Android Smartphone. The work presented in this paper has been also validated with an additional implementation in a small soccer mobile robot in order to test the performances of the Smartphone in a real-time application and to evaluate the improvements of the proposed implementation.

The main contributions to the development of the following article focus on the design and manufacture of different test devices and the proposal and integration of control units based on Smartphone with Google Android to dispose in a single device the basic elements of interaction necessary to develop the tests.

Pages from 67 to 74 contain the following paper:

D. Martinez, J. Moreno, D. Font, M. Tresanchez, T. Palleja, M. Teixido, J. Palacin, **Evaluation of the Color-Based Image Segmentation Capabilities of a Compact Mobile Robot Agent Based on Google Android Smartphone**, *Advances in Intelligent Systems and Computing* (SJR indexed as Q4), 221 (2013), 25-32

http://dx.doi.org/10.1007/978-3-319-00563-8_4

ISSN: 2194-5357

Chapter 7

A Combined Approach to the Problem of Opening a Door with an Assistant Mobile Robot

---

7.1. Introduction

This chapter presents the paper published in the journal Ubiquitous Computing and Ambient Intelligence which consists in a combined approach to the problem of opening a door with a mobile robot.

The development of this capabilities that could be required to operating as a personal assistant at homes represents an improvement of the concept of an assistant mobile robot as widens the area of mobility along the different rooms of a house and enables the robot to perform a larger set of tasks.

This proposal has studied the main difficulties in achieving complete mobility taking into account the three main limitations:

a) Conventional environments are designed for humans.
b) The limited ability and force of the robots.
c) The uncertainty of the environmental parameters, which complicates automatic robotized operation, for example the door handle vary widely in their sizes and types.
d) The robot requires tight coordination between the motions of the arm and the base to open the door.

To this end, a mechanical accessory has been incorporated into the basic design of the robot, allowing it to open a conventional door.

The main contributions are; the complete study of the main physical and mechanical characteristics of the different types of door handles, such as its

morphology, location, accessibility and torque required for the opening of the handle, design, manufacture and validation of the mechanical device to open doors which is added to the basic design of the mobile robot.

Pages from 77 to 80 contain the following paper:

J. Moreno, D. Martínez, M. Tresanchez, M. Teixidó, J. Casanovas, J. Palacín. **A combined approach to the problem of opening a door with an assistant mobile robot**, Lecture Notes in Computer Science (LNCS 8867): *Ubiquitous Computing and Ambient Intelligence* (SJR indexed as Q2), 8867 (2014), 9-12

http://dx.doi.org/10.1007/978-3-319-13102-3_2

ISSN: 0302-9743

Chapter 8

Conclusions

This section summarizes the general conclusions of the results presented in the main chapters of this PhD Thesis memory.

8.1. Article: Design, Implementation and Validation of the Three-Wheel Holonomic Motion System of the Assistant Personal Robot (APR)

The conclusions of this section correspond to the results presented in the paper "Design, Implementation and Validation of the Three-Wheel Holonomic Motion System of the Assistant Personal Robot (APR)", published in the journal Sensors, which is described in chapter 4 of this thesis memory.

This paper presents the design and implementation of the mechanical design of the three-wheel holonomic motion system implemented in the Assistant Personal Robot (APR), a mobile robot designed to operate at home. For this objective, on the one hand, the paper analyzes the inverse and direct kinematics of the motion, then describes the control system and, on the other hand, shows the result of different experiments proposed to validate the complete motion system.

The trajectory of the mobile robot has been estimated by using the proposed kinematic model that is based on the use of the information of the encoders of the wheels, and then this trajectory has been compared with the trajectory obtained with a SLAM procedure based on the information obtained by an onboard LIDAR.

Results have shown a discrepancy in both estimates of less than 30 mm in distance, and less than 5° in angular orientation for absolute displacements of up to 1000 mm.

These results confirm the utility of the three-wheel holonomic motion system proposed for the implementation of an Assistant Personal Robot.

8.2. Article: Experimental Characterization of the Twin-Eye Laser Mouse Sensor

The conclusions of this section correspond to the results presented in the paper "Experimental Characterization of the Twin-Eye Laser Mouse Sensor", published in Journal of Sensors, which is described in chapter 5 of this thesis memory.

This work presents the experimental characterization of the twin-eye laser mouse sensor. The sensor specifically analyzed in this work was the PLN3032 model manufactured by Philips. This sensor uses a laser light to measure displacement based on the Doppler Effect by comparing the shifted phase modulation of the reflected light. The displacement is obtained by integrating the velocity into a plane movement over time and is returned as discrete displacement counts.

The inexpensive sensor analyzed and the better performance in the measurement of non-linear displacements combined with less sensitivity to changes in the sensor's height makes the twin eye sensor a candidate for future application of this low cost localization system in the APR as an alternative redundant planar displacement measurement system.

8.3. Article: Evaluation of the Color-Based Image Segmentation Capabilities of a Compact Mobile Robot Agent Based on Google Android Smartphone

The conclusions of this section correspond to the results presented in the paper "Evaluation of the Color-Based Image Segmentation Capabilities of a Compact

Mobile Robot Agent Based on Google Android Smartphone", published in the journal Advances in Intelligent Systems and Computing, which is described in chapter 6 of this thesis memory.

This paper presents the evaluation of the image segmentation capabilities of a compact mobile robot based on Google Android Smartphone. This proposal of a mobile robot takes advantage of the quality of the images provided by such devices. The time required to apply an image processing algorithm to the image acquired by the Smartphone has been analyzed and the effect of using a buffer in the preview callback function has been evaluated.

The devices based on Google Android allows centrally controlled central units of control and constantly evolving in terms of image capture and processing. This advantage allows establishing the technology of artificial vision, necessary for the mobile robot, on a platform in constant growth and with ample support.

8.4. Article: A combined approach to the problem of opening a door with an assistant mobile robot

The conclusions of this section corresponds to the results presented in the paper "A combined approach to the problem of opening a door with an assistant mobile robot", published in the journal Ubiquitous Computing and Ambient Intelligence, which is described in chapter 7 of this thesis memory.

This paper addresses the problem of opening a door with a mobile robot. This proposal analyses the limitation which a door suppose for a mobile robot that has to move along different rooms of a house and proposes a mechanical device with an onboard camera in order to detect and guide the activation of the mechanical device.

A prototype device has been applied at the Polytechnic School; University of Lleida, Spain where the texture colors of the floor, walls and doors have simplified the segmentation of the doors and door handles in acquired images by defining a histogram based segmentation LUT. Finally, a morphological filter has been proposed in order to detect de handles of the doors in the images.

Chapter 9

Future work

This section presents and describes several research branches opened by the results of this thesis that can be addressed as future work. The development of an Assistant Personal Robot to domestic environments sets a basement for further development and integration of complex robot functionalities.

a) **Development and improvements on mechanical set:** Future works will be focused on the improvement of the motion system, which will include additional suspension in order to minimize the vertical vibrations caused by the gap between the omnidirectional wheels. The inclusion of a suspension system based on springs will allow the adaptation of the preload to different floor conditions.

   Following this line, the structural design of the APR will be based on the operating principle of a pendulum. This design will allow individual damping and pillar oscillation. The pivoting point will be placed over the center of mass, mainly formed by the batteries, so the forces that appear during the oscillations tend to put the body to rest, reaching the natural damping equilibrium of the device.

b) **Validation of the APR in real environments:** On the one hand the validation of the mobility system in domestic environments distributed in several rooms, where the robot must pass through doors, and on the other hand the study of the impact caused by mobile robot in environments inhabited by elderly people and how they affect this type of devices to their behavior

c) **Development of new applications based on personal assistance:** Based on the data obtained from the tests with real use, define and develop new applications aimed at improving the living conditions of people.

d) **Safety and on the enhancement of the functionalities of the APR:** In particular, previous research works have enabled the future incorporation of some chemical substances in the surface of the APR in order to operate as sensors and actuators. For example, using adhered micrometric films as artificial skin. That is to say, substances capable of detecting external stimuli and of triggering some response mechanisms such as direct color changes, volume changes, electronic responses, etc.With these objectives in mind, we are planning to integrate two different technologies into the APR: (1) vapor sensors based on conducting polymers capable of detecting vapors of organic solvents and acids in the ambient (which may include pollution or toxic gases). Polymeric compounds based in polypyrrole derivatives have already been synthesized and tested in this field. These polymeric compounds form weak interactions with the analytes at the polymer-air interface that can be detected because they alter the response of the surface upon oxidation and/or reduction process. (2) Pressure sensors based on thermoresponsive polyacrylamides hydrogels. In this case, the sensing mechanism involves a volume change, which is caused by a conformational transition that occurs when the hydrogel temperature increases over a critical value. This temperature may be selected to be ≈32–35 °C, so contact with human body causes the conformational change, what can be interpreted by a mobile robot as if it were a switch in this skin area.

Nomenclature

ABS	Acrylonitrile butadiene styrene	**LUT**	Look Up Table
APP	Application	**PI**	Proportional and Integral
APR	Assistant Personal Robot	**PID**	Proportional–Integral–Derivative
ARM	Advanced RISC Machine	**PWM**	Pulse-Width Modulation
CAD	Computer Asist Design	**RAM**	(Random Access Memory
CPI	Counts Per Inch	**RGB**	Red Green Blue
DC	Direct Current	**SCI**	Science Citation Index
DOF	Degrees of Freedom	**SDK**	Software Development Kit
DSP	Digital Signal Processor	**SJR**	Scimago Journal Ranking
FDM	Fused Deposition Modeling	**SLAM**	Simultaneous Localization and Mapping
GPS	Global Positioning System	**SPI**	Serial Peripheral Interface
HSV	Hue Saturation Value	**VCSEL**	Vertical CavitySurface Emitting Lasers
LED	Light-Emitting Diode	**USB**	Universal Serial Bus
LIDAR	Light Detection and Ranging	**IDE**	Integrated Development Environment