DESIGN AND IMPLEMENTATION OF EMBEDDED MULTI-SENSOR OUTDOOR ROBOT LOCALIZATION SYSTEM USING FPGA

By

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LIST OF ABBREVIATIONS

ADC	Analog Digital Converter.
ADAS	Advanced Driver Assistance Systems.
AGVs	Automated Ground Vehicles.
AOA	Angle-of-Arrival.
AP	Access Point.
BT	Bluetooth.
CAD	Computer Aided Design.
CVB	Capacitor Voltages Balance.
CLB	Configurable Logic Block.
CB	Connection Blocks.
CRC	Cyclic Redundancy Check byte.
CPU	Central Processing Unit.
DRES	Distributed Real-time Embedded Systems.
DVB-S2	Digital Video Broadcasting – Satellite – Second Generation.
DCS	Distributed Control Systems.
EKF	Extended Kalman Filter.
EEPROM	Electrically Erasable Programmable Read-Only Memory.
FPGA	Field Programmable Gate Array.
GPS	Global Positioning System.
GW	Gravitational-Wave.
GRFs	Global Reference Frames.
HDL	Hardware Description Language.
IR	Infrared.
I/O	Input/ Output.
IMU	Inertial Measurement Unit.
LED	Light-Emitting Diode.
LUT	Look Up Tables.
LB	Logic Block.

LOS	Line of Sight.
LFSR	Linear Feedback Shift Register.
LRF	Local Reference Frames.
LADAR	Laser Radar.
MPC	Model Predictive Control.
PLL	Phase Locked Loop.
PWM	Pulse Width Modulation.
PPM	Path-Planning Module.
PLC	Programmable Logic Controllers.
PSD	Position Sensitive Locator.
PALMS	Personal Activity and Location Measurement System.
RAM	Random Access Memory.
ROM	Read Only Memory.
RFID	Radio Frequency Identification Reader.
RISC CPU	Reduced Instruction Set Computing Central Processing Unit.
RISC IP	Reduced Instruction Set Computing Intellectual Property.
ROS	Robot Operating System.
RSS	Received Signal Strength.
RSSI	Received Signal Strength Indication.
RSM	Radio Signal Mapping.
SLAM	Simultaneous Localization and Mapping.
SIMD	Single Instruction Multiple Data.
SBC	Single Board Computer.
SSE2	Streaming SIMD Extensions 2.
SAs	Sorting Algorithms.
STTRAM	Spin Torque Transfer RAM.
SB	Switch Block.
SDRAM	Synchronous Dynamic Random Access Memory.
SDF	Signed Distance Functions.
TOA	Time-Of-Arrival.
TOF’s	Time -Of –Flight.

2-D	Two Dimension.
3D	Three Dimensions.
TTL	Transistor–Transistor Logic.
TDOA	Time-Difference-of-Arrival.
US	Ultrasonic Sensor.
UART	Universal Asynchronous Receiver/Transmitter.
USB	Universal Serial Bus.
VHDL	VHSIC (Very High Speed Integrated Circuit) Hardware Description Language.
WSNs	Wireless Sensor Networks.
WLANs	Wireless Local Area Networks.

REKABENTUK DAN IMPLIMETASI SISTEM PELBAGAI SENSOR BERASASKAN PENYETEMPATAN ROBOT LUARAN MENGUNAKAN FPGA

ABSTRAK

Sejak kebelakangan ini, terdapat peningkatan minat yang signifikan terhadap robot. Walau bagaimanapun, mengemudi robot secara manual memerlukan perintis yang mahir dan mempunyai tahap perhatian yang tinggi untuk tempoh yang berterusan. Oleh itu, minat saintifik yang mendalam telah muncul dari segi mencari penyelesaian yang membolehkan robot dikemudi secara autonomi tanpa perlu penyeliaan manusia. Ianya sesuai digunakan untuk pelbagai aplikasi berpotensi seperti untuk tuuan pengawasan dan peninjauan, penggambaran dari udara, pemeriksaan visual terpencil di tapak perindustrian, dan juga untuk aplikasi ketenteraan. Berbeza dari manusia, robot tidak mempunyai kapasiti untuk merasa dan keupayaan untuk meneroka persekitaran dan menentukan lokasi. Oleh itu, sensor seperti Inframerah, ultrasonik, accelerometer dan GPS perlu digabungkan kedalam robot untuk meningkatkan persepsi persekitarannya. Robot tersebut perlu mempunyai keupayaan untuk menentukan destinasinya dan mencari jalan paling dekat untuk sampai ke sana. Algoritma Dijkstra diimplikasikan untuk memeriksa semua nod yang berkaitan disepanjang laluan robot menuju ke arah destinasi. Robot tersebut akan menandakan nod yang telah dikunjungi dan yang tidak dikunjungi untuk menentukan laluan mana yang sesuai diikuti. Tambahan lagi, robot itu mempunyai kapasiti untuk mengesan rintangan dalam lingkungan jalan kecil terhadap tempat dituju. Papan FPGA DE0 Nano digunakan kerana keupayaan mudah alihnya dan kuasa pengiraan yang meluas yang mengatasi kelewatan dan penggunaan tenaga dalam projek tersebut. Terdapat tiga modul dalam pendekatan perancangan laluan - yang pertama menjana laluan ke lokasi yang dikehendaki, yang kedua mengesan jika terdapat halangan di laluan tersebut, dan yang ketiga adalah untuk mengelak pertembungan. Sensor GPS telah digunakan untuk menentukan kedudukan semasa serta kedudukan lokasi-lokasi yang dikehendaki. DE0-Nano telah menghantar isyarat-isyarat yang sesuai ke L293D demi mengawal motor-motor robot mengikut isyarat-isyarat sensor. Hasil kajian menunujukkan bahawa bacaan voltan output sensor IR yang dipamerkan mempunyai tahap pemantulan yang tinggi untuk objek berwarna putih berbanding dengan warna-warna lain seperti hitam dan biru. Sensor IR dan ultrasonik telah ditentukur untuk mengesan halangan-halangan dan mewujudkan jarak di antara robot dan halangan tersebut sebanyak 30 cm hingga 50 cm. DEO Nano mencapai kekerapan operasi maksimum sehingga 1.3 GHz dan jumlah keseluruhan elemen logik adalah 6,032. Ini bermakna kekerapan keperluan platform robot telah dicapai di tahap 1.3 GHz.

DESIGN AND IMPLEMENTATION OF EMBEDDED MULTI-SENSOR OUTDOOR ROBOT LOCALIZATION SYSTEM USING FPGA

ABSTRACT

Recently, there has been a significant increase in the interest for robots. However, manually navigating a robot requires a skilled pilot who has high constant concentration levels for sustained periods. Therefore, strong scientific interest has emerged in terms of developing solutions that allow a robot to navigate autonomously without needing constant human supervision. This is useful for a variety of potential applications ranging from surveillance and reconnaissance purposes, aerial filming, remote visual inspection of industrial sites and military applications as well. Unlike humans, a robot does not have the sensing capacity and the ability to explore its environment and determine location. Therefore, sensors such as Infrared, ultrasonic, accelerometer and GPS need to be integrated on the robot to improve its environmental perception. The robot then needs be able to determine its destination and find shortest path to get there. Dijkstra algorithm is implemented to examine all related nodes along the robot's path towards destination. The robot is marking nodes as visited and unvisited to decide which path is proper to be followed. Furthermore, the robot has the capacity to detect obstacles within path toward destination. FPGA DE0 Nano board is used because of its portability and extensive computational power that overcome the delay and power consumption in the project. There are three modules in a path planning approach - the first generates a route to the desired location, the second detects if there are obstacles, and the third is for collision avoidance. The GPS sensor was utilised to determine the positions for the current and desired locations. DE0-Nano sent proper signals to the L293D to control robot's motors according to sensor signals. The result revealed that the output reading voltage of the IR sensor exhibited high reflectivity for white coloured objects compared to other colours like black and blue. The IR and ultrasonic sensors already calibrated to detect obstacles and keep the distance between the robot and obstacles from 30 cm to 50 cm. The DE0 Nano achieved a maximum operating frequency up to 1.3 GHz and total logic elements were 6,032. This means that the robot's platform's frequency requirements were achieved at 1.3 GHz.

CHAPTER 1

INTRODUCTION

1.1 Overview

Nowadays, there is rapid growth in the widespread utilisation of auto-navigation. Autonomous robots refer to robots that perform tasks on their own in an unstructured environment. There has also been a rapid increase in the navigational aids that allow an autonomous robot to navigate to its destination without requiring human intervention. Autonomous also means that the robot is capable of self-piloting in order to perform different tasks under unstructured or structured environments. In the absence of human-guidance, the robot must still be able to make decisions based on on-board data processing.

The embedded systems are considered as a type of reactive system, which means that these systems continuously react to the environment and that most of them have the real-time response characteristics. The current trend in the development of embedded systems is veering away from being restricted to one particular function and is instead focused allowing flexibility to modify, add, and even delete some of the embedded system's sub-functionality units. As a matter of fact, these changes could even be taking place while this research is being written. Thus, the goal is to make embedded systems that are as fast and small as possible by provide low complexity and high speed processing. One of the several application areas that are covered by embedded systems is the mission critical area, which includes robot localisation (Rajwade & Rangarajan, 2013).

Furthermore, global positioning system (GPS) is another component that is needed on autonomous robots. The GPS is responsible for finding the robot's default direction. It does this by utilising GPS navigation to generate the shortest path for the robot to be able to reach its goal based on its current position. GPS and detection sensors work independently from each other. However, GPS is also limited because it does not work indoor or in areas that are obstructed. Nonetheless, object detection, path planning, and obstacle avoidance during accurate navigation are important concerns for mobile robot localisation systems. The current platform faces many issues, which include the problem with accuracy as the robot tries to reach the destination.

It is vital for autonomous robots to know their location and be capable of navigating to other locations. Localisation refers to the process of finding one's location on a map. However, how can a robot be able to localise on its own? The popular type of navigation and localisation is to utilise a map and to combine this information with sensor readings and some type of closed-loop motion feedback. Nonetheless, a robot must be able to do more than just localising on its own. Often, the robot must also have the ability to avoid obstacles, go back to the main path, and accurately reach its destination by using multi sensors.

DE0 Nano solves the problems of constrained I/O and resources and low processing speed. DE0 Nano is becoming the leading processing unit for this system of localisation. The robot has to be able to avoid obstacles, go back to the main path, and reach the destination accurately. In order for the robot to master those sensors, one has to test the characteristic of the sensors and how they impacting the robot’s stability. Afterwards, the DE0 Nano interface was integrated with the sensors and the robot. Then, to overcome design challenges, HDL and other mega-core function modules were used.

The code was divided into individual parts and every part was considered an independent process concurrently executed. In this project, GPS was utilised to calculate the current and desired location. Then data is saved and a map with the shortest path to the destination was drawn. The GPS then forwards the data to the PWM, which controls the robot's movements. During the navigation process, IR and ultrasonic sensors were used to detect if there is any obstacle and avoid from collision.

1.2 Problem Statement

Autonomous robots functioning without human guidance need to handle unexpected occurrences, but the robot does not have the sensing ability to explore its environment like humans. Robots aiming to achieve auto-navigation must be able to overcome obstacle detection, stability, localisation, and interfacing with all supported devices.

However, the robot has to determine its current location also needs to know where it is going and how to get there. Thus, the robot must have the capacity to generate paths and decide which one to take in order to reach its destination. The localisation part is divided into two types - outdoor and indoor. In the related work the researcher used Wireless sensor network (WSN) (Kuo, Chen, Cheng, & Lu, 2016). Also they used The Laser Radar (LADAR) (Li, Liu, Wang, & Qiao, 2016) which has problem in limitation. GPS is utilised only for outdoor to helps navigate and mapping the shortest path to reach the destination and the GPS not able to work in indoor. In addition, the robot should be able to detect obstacles and avoid collisions. The lack of sensing for robot localization has been considered a critical problem recently.

Therefore multi sensor outdoor robot localization system is required to overcome all these localization problems because its increase the performance of obstacle detection and localization. FPGA DE0_Nano board that provides some benefits in term of high speed processing, execute parallelism processing, built in ADC and accelerometer.

1.3 Objectives

i. To design and implement of embedded multi sensor outdoor robot for localization system using FPGA DE0-Nano board.
ii. To implement an obstacles avoidance system by using multi-sensors.
iii. To implement the path planning algorithm for autonomous robot.

1.4 Scope

In order to resolve the problem of current technology of robot localization system like resources constraint, decision making, power processing and so on. The robot navigates by using path planning algorithm and was tested for 10 to 12 meter with 3 obstacles during the path. Three infrared range sensors and an acoustic sensor are planned to be obstacles avoidance sensors, GPS using for localization system and accelerometer sensor to control the stability of the robot. Different arrangement of sensors provides different result; thus many arrangements done to develop the optimal functionality of the sensor. Therefor the obstacles avoidance sensors were calibrated to keep the distance between the robot and obstacle from 30 cm to 50 cm.

1.5 Project Contribution

This project is interested with the problem of generalizing the interpretation of the data which receive from sensors and auto-navigation robot. There are some contributions of this thesis which as follows:

The first contribution of this thesis is to implement a general method for interpretation data of different types of sensors, such as IR sensors and acoustic sensors.

The next important contribution of the thesis is to implement an algorithm to perform the path planning task using the interpretation of the data that received by GPS.

For the embedded systems and in any design, a key factor would be the re-configurability feature. Based on this, the design and implementation of the system is done keeping in mind a reconfigurable embedded frequency localization system.

1.6 Thesis Outline

This project is divided into a few chapters and each chapter covers different part of the research. In this report, there are five chapters need to be developed and discussed in details.

For Chapter 2, it describes in the study of literature. The literature review reveal about referrals and information that have been researched and reviewed from journals, conferences, and websites. In this chapter explained about various types of obstacle detection sensors and localization method. Besides that, this chapter also discuss about different types of platform like Arduino, Raspberry Pi and also FPGA to implement auto-navigation robot. Besides, the comparison between the advantages, disadvantages and implemented platforms of the projects was discussed.

In Chapter 3 explains the research methodology for this project. It also provides the detail explanation about the architecture and characteristic of the platform of the project. Procedures and methods for completing this project have been considered in this chapter.

In Chapter 4, the final results of the project deeply explained in this chapter. The results of compilation and testing of the sensors in system memory reader show. Besides that, the sensors characteristic measured, and also the interfacing of robot motor displayed. At the end, the final result of this project was concluded in this chapter.

Last but not least, for Chapter 5, the overall summary for this project presents in this chapter. All the findings and results obtained during doing the project discussion. Besides that, the results evaluation done based on the findings and results obtained. Lastly, future work improvement and work on this project discuss in this chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Autonomous robot is a system for autonomous navigation which is an auto-piloted robot and devoid of human guidance. This practical autonomous system for navigation is very useful in the present human world. There are three primary components essential for autonomous robots: hardware (control unit for processing), mechanics (motion) and software (decision and control making). For a GPS-based autonomous robot, the barrier invariant navigation is controller-independent and it operates on its own, without any guidance of humans, and with the help of ultrasonic and infrared sensors to detect barriers.

As a result, to create a localisation robot, it is necessary to have knowledge of all conditions and requirements, so that it is essential to know the purpose of autonomous robot system, and what kind of platform is needed to control sensors and motion of the robot.

Thus, an autonomous robot should possess the intelligence or characteristics that are present in the cognitive and the perception level of senses: goal-directedness, localisation, flexibility, and self-control and it must be highly adapted to various environments. In order to attain the above goals, the robot should be capable of detecting the obstacles that enter its range of senses; move unharmed without any impact, and successfully follows the shortest path.

In the case of an autonomous robot, the key problems are that the robot cannot