Design of a holonomic five legged robot

Final Report

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Submitted as partial fulfilment of the requirements of Project EPR400
in the Department of Electrical, Electronic and Computer Engineering
University of Pretoria

November 2017

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Part 1. Preamble

This report is a description of the work I completed during the year on my final year project, Design of a holonomic five legged robot.

This report contains a copy of my approved project proposal and documentation on the technical parts of my project. These can be found in parts 3 and 4 respectively. The technical documentation contains a detailed recording of the steps taken to overcome design challenges. This includes circuit diagrams, algorithm flowcharts and test results. This section appears on the CD that accompanies this printed report.

This project does not build on any previous project. Instead it is a completely different approach to the holonomic exploration robot problem that was also addressed in earlier years. Although this project has a similar goal to that of previous years, it does not build on these as the locomotion is completely different.

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L. Steyn *Date*

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LIST OF ABBREVIATIONS

LED	light emitting diode

Part 2. Summary

This report documents the development of a robot intended for exploration in unknown terrain by moving holonomically and using legs for locomotion.

What has been done

What has been acieved

Findings

Part 3. Project identification: approved Project Proposal

This section contains the problem identification in the form of the complete approved Project Proposal, unchanged from the final approved version.

1 Problem statement

Motivation. Robots used for exploration need to be highly manoeuvrable to cross terrain not possible for humans and cars. The motivation for this project is to develop a robot using five legs, capable of crossing rough terrain, that can move holonomically. A robot like this can be used to explore autonomously and can also be used to carry supplies or equipment to remote places.

Context. A vehicle is considered holonomic if it does not suffer from a phenomenon called the parallel parking problem [?]. This phenomenon restricts the vehicle to forward and backward movements only, while slightly turning the front wheels. The vehicle is therefore capable of moving in arcs but never sideways. One approach to achieve holonomic movement in vehicles is to swop the cylindrical wheels found on most vehicles for spherical wheels [?]. While this solution solves the parallel parking problem, it introduces a new restriction of only functioning properly on relatively flat surfaces, unless very complicated suspension mechanisms are implemented. This solution is therefore not suitable for any off-road application. This project will extend on this to solve the problem of terrain without sacrificing holonomic movement. LS3 [?] and BigDog [?] are examples of existing legged robots that function in a way that mimics the way four legged animals walk. These robots were both developed by Boston Dynamics to help humans carry loads across terrain that is not accessible by car. They can therefore follow someone on a foot trail as well as being able to navigate to a given location using GPS.

Technical challenge. The aim of this project is to build a five legged holonomic robot which is capable of moving in any direction from a standing position as well as being able to rotate about its own axis. The control system of the robot will consist of a processor calculating all the required joint angles of all the legs to move the legs in a way that the robot moves in the desired direction. The engineering challenge in this project is the development of a control system algorithm that is fast enough to make the robot react in real time while still being thorough enough to ensure that the robot does not damage itself or its surroundings while moving.

Limitations. One of the technical limitations that makes this project challenging is the trade-off considering the length of the robot legs. Longer legs will mean more manoeuvrability for the robot and faster movements but will also mean increased torque required by the servo motors. This causes a larger power consumption and therefore a shorter battery life. It is also easier to construct a larger robot but this will again eventually lead to bigger power requirements.

2 Project requirements

ELO 3: Design part of the project

1. Mission requirements of the product

A five legged holonomic robot will be built in this project. The requirements of the robot that would determine whether the project is successful can be summarized in the list below.

- The robot should be able to move in any direction from a stationary position.
- The robot should be able to rotate about its own axis while remaining in the same position.
- The robot should be controlled remotely by using a smartphone application.
- The robot should use five legs to execute any of the required movements.
- The robot should be able to move on both smooth and coarse surfaces.
- The robot should be able to move on both flat and slanted surfaces.

2. Student tasks: design

The tasks that are vital to ensuring that the product meets the mission critical requirements are listed below.

- The mathematical analysis and design for the movement of the legs should be done on paper.
- The design should then be implemented in a graphical mathematics package such as Python for further refinement.
- Once the algorithm design is sound, electronic design can commence in a simulation environment such as LTSpice.
- The design can then be implemented in electronics using a microcontroller and support electronics together with some driving circuitry.
- A smartphone application should be developed to remotely control the robot.

- Each subsystem should be tested for isolated functionality as well as interaction with other subsystems to make sure all requirements are met.

ELO 4: Investigative part of the project

3. Research questions

The investigative section on this project will focus on the amount of legs of a legged robot and the effect on stability. Do five legs provide more stability when walking on slippery surfaces? Can the robot still work without some of its legs?

4. Student tasks: experimental work

The experiments that will be conducted to address the research questions above are listed below.

An experimental setup to test the ability of the robot to move on a variety of surfaces is required.

- The robot will be placed on both smooth and coarse flat surfaces to perform the same manoeuvres.
- The robot should be able to perform these manoeuvres with a similar degree of difficulty and in similar time.

Another experimental setup is required to test the robot's ability to handle small obstacles and bumps.

- The robot will be placed on a surface with bumps and small obstacles such as rocks.
- It should be able to execute the same set of manoeuvres mentioned in the experimental setup above in similar time.

3 Functional analysis

The functional analysis of the system can be shown best in a flow diagram. This can be seen in Figure 1 below.

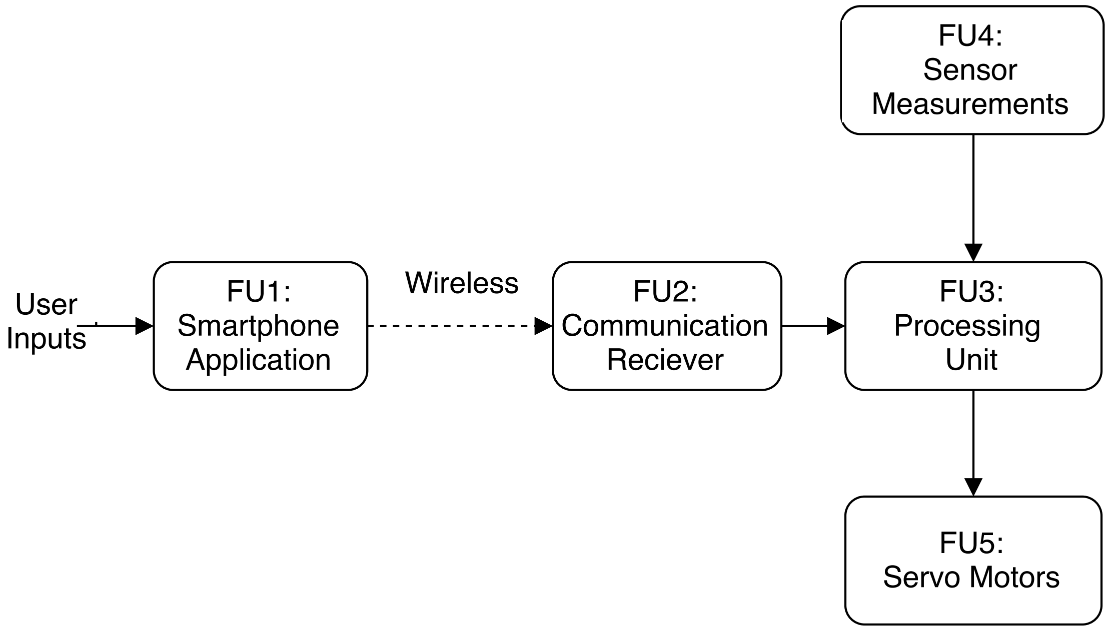

Figure 1. Functional block diagram of the product.

In Figure 1 above, the process is shown to begin with the input from the user into a smartphone application. This consists of a user interface on the screen of the smartphone that the user can interact with. The user interface will allow the user to make the robot translate as well as rotate. This information is sent to the microcontroller on the robot via wireless technology. The robot analyses this combination of translation and rotation commands and breaks it into a separate vector for each of the legs. The final position of each leg as well as the route to each individual leg destination is computed next. This makes use of a process called inverse kinematics. The manoeuvres requested by the user can be realized through a series of movements with servo motors installed on the joints of the robot legs. In order to make a limb move, the exact required angle of each joint is calculated and communicated to the servo. This process is repeated continuously to make the robot react to the varying inputs of the user.

4 Specifications

1. Mission-critical system specifications

SPECIFICATION (IN MEASURABLE TERMS)	ORIGIN OR MOTIVATION OF THIS SPECIFICATION	HOW WILL YOU CONFIRM THAT YOUR SYSTEM COMPLIES WITH THIS SPECIFICATION?
The robot should be able to move in a given direction in 30 degree increments from a stationary position.	Proving that the robot can move straight forward, left, backwards and right (directions spaced 90 degrees apart), will prove that the robot is holonomic.	The robot will be placed on a grid on the floor and instructed to move in one of the chosen directions at a time.
The robot should be able to rotate 90 degrees without translating the centre of the body by more than 5% of the body diameter.	Rotating 90 degrees proves that the robot does not suffer from the parallel parking problem. 5% of the robot diameter can still be considered negligible and prove that no translation is required to rotate.	The robot will be placed on the grid on the floor and instructed to rotate. The translation of the centre of the body will be noted.
The time it requires to complete a manoeuvre should not vary more than 25% between smooth and rough surfaces.	A variation of less than 25% in time can still be considered to be a similar time. This proves that the robot can move over different surfaces with similar difficulty.	The robot will be instructed to complete a specific set of movements on a flat smooth surface and the time to completion will be recorded. Various obstacles will be placed in the way of the robot (small blocks, sand, etc.), and the robot will be instructed to repeat the specific set of instructions and the time difference will be noted.
The robot should be able to walk at a speed of at least 100mm/s.	100mm/s is a reasonable speed for the scale of the robot. This proves that all of the subsystems function together well.	The robot will be instructed to walk at maximum speed in a straight line for one meter. The time to completion will be measured.

The robot should be able to walk on a surface with a 10% incline without falling over.	An incline of 10% proves that the robot platform is stable while not putting too much strain on the servo motors.	The robot will be placed on a slanted surface and instructed to translate and rotate. It should not fall over while performing these manoeuvres.

Table 1. Mission-critical system specification

2. Field conditions

REQUIREMENT	**SPECIFICATION (IN MEASURABLE TERMS)**
The robot should be in range of the wireless smartphone controller.	For wireless communication to work reliably, the user with the smartphone should be less than 10m from the robot.
To prevent falling over, the robot should walk on surfaces close to horizontal.	The robot should not be operated on surfaces with an incline of more than 10%
The robot should stay dry to protect electronics.	The robot should never be operated near water or wet surfaces.
The robot should work in normal temperature conditions for South Africa.	The robot should be operated in the temperature range 10^{o}C to 40^{o}C.

Table 2. Field conditions

3. Functional unit specifications

SPECIFICATION	**ORIGIN OR MOTIVATION**

FU1. The smartphone application should communicate commands from the user interface to the robot at a frequency of at least 10 Hz.	The robot should be in constant communication with the smartphone application to update the trajectory vectors. An update frequency of 10 Hz will update the robot fast enough to make the robot feel responsive.
FU2. The inverse kinematics calculator of the robot should be able to calculate the joint positions correctly to move each leg to the desired location.	The joints should all be calculated correctly in order for the robot to make the correct set of movements to walk.
FU3. The servo motor angles should all be within 5 degrees from the calculated values.	The servo angles have to be accurate in order to make the robot walk predictably. A tolerance of 5 degrees can still be considered accurate for hobbyist servo motors.

Table 3. Functional unit specifications

5 Deliverables

1. Technical deliverables

DELIVERABLE	DESIGNED AND IMPLEMENTED BY STUDENT	OFF-THE-SHELF
Microcontroller for control of the robot.		X
Control code for inverse kinematics and servo control.	X	
Android application with a user interface for control of the robot.	X	
Wireless module for communication between the smartphone interface and the robot		X
Circuits implemented on PCB for interfacing all hardware with the microcontroller.	X	
Servo motors for movement of the joints.		X
Robot body and legs.	X	
Simulations on all implemented software and analogue design	X	

Table 4. Deliverables

2. Demonstration at the examination

1. The robot will be placed on a grid on the floor and the examiners will be shown that the robot is capable of holonomic movement.

2. The centre of the robot will be noted on the grid and the examiners will see that the robot is capable of rotating around its centre without translating.

3. The robot will execute a specific set of movements while the time to completion is being recorded.

4. Small obstacles will be placed in the way of the robot to make movement more challenging. This includes small blocks to step over as well as a change in surface such as sand.
5. The robot will repeat the set of movements over the obstacles while the time to completion is measured again.
6. The examiners will see that the robot is capable of moving with similar effort over various surfaces.

Part 4. Main report

3. Literature study

4. Approach

4.1 Design alternatives

4.2 Preferred solution

5. Design and implementation

5.1 Theoretical Analysis

5.2 Modelling

5.3 Simulation

5.4 Optimisation

5.5 Hardware design

5.6 Hardware implementation

5.7 Software design

5.8 Software implementation

5.9 Design summary

6. Results

6.1 Summary of results achieved

Description of requirement or specification (intended outcome)	**Actual outcome**	**Location in report**
Mission requirements of the product		
1	2	3
Field conditions		
1	2	3
Specifications		
1	2	3
Deliverables		
1	2	3

6.2 Qualification tests

[1]

References

[1] A. Hidayat, A. N. Jati, and R. E. Saputra, "Autonomous quadruped robot locomotion control using inverse kinematics and sine pattern method," *IEEE*, 2017.