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Collective mapping and movement
in a swarm of highly unreliable
individuals in unknown
environments



FAKULTÄT FÜR
INFORMATIK

Intelligent Cooperative Systems

Master's Thesis

Collective mapping and movement in a swarm of highly unreliable individuals in unknown environments

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Winter term 2017

Stephan Dörfler: *Collective mapping and movement in a swarm
of highly unreliable individuals in unknown environments*
Otto-von-Guericke-Universität
Magdeburg, 2017.

Abstract

Foo Bar Baz

this will be
written at
the very
end of the
project

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1 Introduction

- Importance of robotics
- Importance of swarm-robotics
- We can't measure *true/exact* values \rightarrow probabilistic approach
- Combination of "swarm" and "probabilistic" to find good solutions despite of the problems

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low

Robots and automation are topics that more then ever take place in the average everyday life. Not only are robots well-established in industrial surroundings but also personal appliances are getting common, like autonomous vacuum-robotos or self-driving cars. It's obvious that robots can assist humans on their tasks or even replace the need for humans, sometimes even surpassing human performance or accuracy.

In the recent years robots became so common that due tue improvements in their manufacturing and pricing it is now possible to get elaborated robots as toys for personal usage. This again opened up new posibilities in regards of swarm-robotics.

The field of swarm-intelligence traditionally was inspired by nature itself, seeing large numbers of individual animals like fish or birds behave in such a manner that the combined actions of all the single individuals result in an action none of the individuals could have accomplished on it's own. Many of the theories on swarm-behavior are well known for years. Now with the emerging possibilities introduced by cheap, simple robots these theories can be put to test by experimenting in real-world setups with adjustable individuals. The first results of this research can lately be observed in the form of .

One persisting problem in the field of real-world robotics is the inherent inaccuracy of the robot's actions, it's sensorics and even their surrounding. The models used to define the behavior of the robots often times assumed exact values and for most simple scenarios the observed real-world results were close

find some
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enough or the deviation could be explained and accounted for. But with increasing complexity of the use-cases the robots are applied in, this inaccuracy becomes a bigger problem.

As a solution for this, the models defining the behaviour of the robots tried not to calculate with exact values, as these were known to be unrealistic. Instead a probabilistic approach was chosen. In that, the varying confidence in the perceived values is accounted for and all the possible results of the possible values are computed each with a probability. This results not in a single value which might or might not be fitting, but instead in a distribution of possible values and their respective probability to be true. Future iterations of usage or perception of that value then are used to improve and adjust that distribution of probability.

Any usage of these probabilistic data is subject to uncertainty. As a result it is a key factor to improve the probabilistic data to their maximum possible quality. The iterative approach of constantly improving the data indicates a correlation between the number of samples used and the overall quality of the estimate. Here is where Swarm-robotics enters the stage. One of swarm-robotic's key features is a high number of individuals. These individuals are able to cross-check each other's perception and when feeding into a shared estimation can easily outperform a greater number of autarkic individuals, each only acting on its own.

wording

1.1 Motivation

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the list below

- simple individuals
 - cheap
 - robust
 - easy to use/initialize
 - very limited capabilities
 - highly inaccurate
- try to overcome the weaknesses
 - additional external sensors (camera tracking)
 - additional external computing (by commands via bluetooth)

- probabilistically learn the inaccuracy and compensate accordingly
- combine multiple individuals in a swarm for better results
 - higher quality & quantity probabilistic data for learning
 - get the differences between multiple individuals
 - get a better/faster impression of the environment's effects
 - in most use-cases: single individual's minor inaccuracies are compensated for by the swarm

1.2 Goal

-
- Find an effective way to measure and quantify the error/inaccuracy
 - From a single measurement differentiate the own error from the environment's error
 - Publicly share the information about the measured inaccuracy
 - As a swarm: continuously & collectively improve the knowledge about inaccuracy
 - Find a way to use the knowledge of the inaccuracy to take countermeasures

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1.3 Structured approach

-
- Figure out the required knowledge and technologies
 - Draft the (measurable/verifiable) measure for success
 - Related work: which similar problems are already (partly) solved?
 - Design a concept
 - Evaluate the concept theoretically
 - Exemplary show the realization of the concept to confirm the theoretical evaluation

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To archive the beforementioned goal a structured approach was chosen in such a way to be comprehensible and verifiable. This chapter will give an outline of that approach.

In the first step research was done to identify the required knowledge and technologies. This especially includes a current state of the art regarding the research on topics like robotic exploration, swarm coordination, probabilistic robotics, measurement filtering and more. Also, the robots used in the given setup were closely examined for their capabilities and limits, as well as the way to control them and extract data. A special focus was set on swarm capabilities during that process.

In the next step the goal of this work was defined. Within the scope of that a research question and hypothesis was defined along with the measure for the hypothesis to be true or false. This took into account existing works in the field and the questions already answered or asked by them.

These existing works were also regarded for steps in this work to re-use and build upon. Out of that a concept was developed to address the previously defined goal. That included comparing different approaches for aspects like movement, measurement and processing of combined swarm-data.

Firstly, this concept then got evaluated theretically in comparing it to alternatives .

which?

Next, the concept also was evaluated in an exemplary implementation and conducted experiments. The results from that were compared to the theory and finally assessed in regards of the initial goal and it's measure for success.

2 Background/Basics

- Basics to mobile robotics
- Basics to probabilistic robotics
- Basics to swarm behavior
- Basics to distributed mapping
- Basics to ROS as development framework

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2.1 Spherical Robot: Orbotix Sphero

- Definition: spherical robot
- Sphero: specifics and limitations
 - Movement: differential drive
 - Sensors: accelerometer
 - sources of inaccuracy (slip, orientation through odometry)

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In this work a special kind of mobile robot is used. As stated in the previous chapter one of the principles in swarm robotics is to be able to achieve a relatively complex task with each individual being as simple as possible. In regards to this principle the kind of robot used in this work is one of the simplest forms a robot can take: a spherical robot.

state in the
prev. chap.

A spherical robot is a robot which outer hull is spherical and all the elements are contained within this spherical hull. Thus, collisions can be handled extremely well and a lot of issues emerging from the direction the robot is currently facing are avoided. Also, for most use-cases the internal workings of the robot can be disregarded/abstracted to just a sphere rolling in it's

state some
issues

wording

environment.

To be able to reproduce and verify the findings in this work, real-world robots were used. The robot best matching the properties stated above was found to be the "Sphero" made by the Company "Obortix".

state more
(beneficial)
properties

footnotes &
links

image

2.1.1 Orbotix Sphero: Specifics and Limitations

The Sphero (img.) is based on a spherical acrylic hull which contains the internal sensors and actors. It is originally sold as a toy to be remotely controlled via bluetooth from a smartphone. Based on the communities use-cases and suggestions more and more features regarding remote programming and automated controlling were officially added to the Sphero's capabilities.

Movement

The movement is realized with a differential drive, two wheels running against the acrylic hull from the inside. This special design has implication on the possible movements of the Sphero. In regards of the nautical/Cardan angles this renders the Sphero impossible to turn in a *roll* axis (bank-axis). Spinning around the *pitch* axis will result in movement and steering the direction of the movement relative to a two-dimensional world-frame is done by controlling the individuals wheels with different speeds and thus spinning around the *yaw* axis (bearing).

explain &
references

Sensors

Inaccuracy

2.2 Probabilistic robot movement and perception

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- uncertainty is inevitable in real-world use-cases
- instead of unrealistic simplifications use best-effort with probabilities
- approaches to minimize uncertainty

2.3 Requirements

-
- There is an error model to evaluate the error/inaccuracy by quantity and quality
 - Each individual's movement is subject to a smaller error when it has *knowledge* vs. when it hasn't
 - Each individual is able to use data from locations *any* individual has visited
 - Statistically: increase in accuracy after a small amount of time/iterations

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2.4 Related work

Topics:

-
- distributed mapping
 - error-correction

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3 Concept

- Error-data are collected
- Error-data get evaluated (statistically)
- Error-data are shared throughout the swarm
- Error-data are used to improve quality of movement
- New movements feed back into measurement-loop

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3.1 Measurement of error

- Error is measured by error in position and error in movement
- Error is measured for each individual
- Error-data are scored by quality
- Error-data about environment and it's quality is fed into a centralized map
- Existing error-data are used to improve each individual's movement

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3.2 Separation of environmental influences from inherent inaccuracy

- Error-data get separated by error from environment and error from individual

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- Constant/linear error *probably* originates from individual
- Dynamic error *probably* originates from environment
- Comparison with existing measurements to statistically improve separation
- Environmental influences are shared with every other individual
- Individual error is kept and continually improved

3.3 Continuous improvement

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- Respect existing data
 - per individual
 - from environment
- generate new data from movement
- feed back new data into the map
- improve data (accuracy/quality) using *Kalman Filter*

3.4 Data-Distribution

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- Error-data about the individual are not shared
- Error-data about the environment are shared
 - A single centralized map with error-data for each coordinate
 - Each update is used to statistically improve a single coordinate's quality of data (*Kalman-Filter*)

4 Exemplary implementation

-
- plan, goals, restrictions of implementation
 - outline general structure of implementation
 - used environment and tools

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4.1 Ros Nodes

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- existing ROS libs
 - camera tracking
 - bluetooth-control
 - ros-sphero-driver
 - simones error-correction
 - newly developed nodes
 - centralized map
 - error-distinction (self vs. env)

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5 Evaluation

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- evaluation-approach
- formally evaluate math/statistics
 - probabilistic data increase in accuracy
 - time/effort needed single vs. swarm
- evaluate via real-world tests
 - explain setting/arena
 - raw data from multiple runs
 - processing of recorded data
 - insights obtained from experiment
- evaluate via simulation
 - diff. simulation vs. real-world
 - raw data from multiple runs
 - processing of recorded data
 - insights obtained from experiment
- explain results rl vs. sim

6 Future works

-
- unanswered questions \rightarrow unexplained experimental data?
 - overcome simplifications used in this work
 - static vs. dynamic environments
 - transfer this approach to different levels of reliability
 - map to imaginable use-cases (firefighter...)

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