# INSTITUTO TECNOLÓGICO DE AERONÁUTICA

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# MULTI-AGENT GRAPH EXPLORATION WITHOUT COMMUNICATION

Bachelor's Thesis
2023

# Computer Engineering

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São José dos Campos
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Bachelor's Thesis approved in its non-final version by the signatories below:

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Aos amigos da Graduaï¿½ï¿½o e Pï¿½s-Graduaï¿½ï¿½o do ITA por motivarem tanto a criaï¿½ï¿½o deste template pelo Fï¿½bio Fagundes Silveira quanto por motivarem a mim e outras pessoas a atualizarem e aprimorarem este excelente trabalho.

# Acknowledgments

Primeiramente, gostaria de agradecer ao Dr. Donald E. Knuth, por ter desenvolvido o TeX.

Ao Dr. Leslie Lamport, por ter criado o LaTeX, facilitando muito a utilização do TeX, e assim, eu não ter que usar o Word.

Ao Prof. Dr. Meu Orientador, pela orientação e confiança depositada na realização deste trabalho.

Ao Dr. Nelson D'Ávilla, por emprestar seu nome a essa importante via de trânsito na cidade de São José dos Campos.

Ah, já estava esquecendo... agradeço também, mais uma vez ao TeX, por ele não possuir vírus de macro :-)

*"If I have seen farther than others,
it is because I stood on the shoulders of giants."*
— Sir Isaac Newton

# Resumo

Aqui começa o resumo do referido trabalho. Não tenho a menor idéia do que colocar aqui. Sendo assim, vou inventar. Lá vai: Este trabalho apresenta uma metodologia de controle de posição das juntas passivas de um manipulador subatuado de uma maneira subótima. O termo subatuado se refere ao fato de que nem todas as juntas ou graus de liberdade do sistema são equipados com atuadores, o que ocorre na prática devido a falhas ou como resultado de projeto. As juntas passivas de manipuladores desse tipo são indiretamente controladas pelo movimento das juntas ativas usando as características de acoplamento da dinâmica de manipuladores. A utilização de redundância de atuação das juntas ativas permite a minimização de alguns critérios, como consumo de energia, por exemplo. Apesar da estrutura cinemática de manipuladores subatuados ser idêntica a do totalmente atuado, em geral suas caraterísticas dinâmicas diferem devido a presença de juntas passivas. Assim, apresentamos a modelagem dinâmica de um manipulador subatuado e o conceito de índice de acoplamento. Este índice é utilizado na sequência de controle ótimo do manipulador. A hipótese de que o número de juntas ativas seja maior que o número de passivas ($n_a > n_p$) permite o controle ótimo das juntas passivas, uma vez que na etapa de controle destas há mais entradas (torques nos atuadores das juntas ativas), que elementos a controlar (posição das juntas passivas).

# Abstract

Well, the book is on the table. This work presents a control methodologie for the position of the passive joints of an underactuated manipulator in a suboptimal way. The term underactuated refers to the fact that not all the joints or degrees of freedom of the system are equipped with actuators, which occurs in practice due to failures or as design result. The passive joints of manipulators like this are indirectly controlled by the motion of the active joints using the dynamic coupling characteristics. The utilization of actuation redundancy of the active joints allows the minimization of some criteria, like energy consumption, for example. Although the kinematic structure of an underactuated manipulator is identical to that of a similar fully actuated one, in general their dynamic characteristics are different due to the presence of passive joints. Thus, we present the dynamic modelling of an underactuated manipulator and the concept of coupling index. This index is used in the sequence of the optimal control of the manipulator.

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# List of Tables

# List of Abbreviations and Acronyms

| | |
|---|---|
| CTq | computed torque |
| DC | direct current |
| EAR | Equação Algébrica de Riccati |
| GDL | graus de liberdade |
| ISR | interrupção de serviço e rotina |
| LMI | linear matrices inequalities |
| MIMO | multiple input multiple output |
| PD | proporcional derivativo |
| PID | proporcional integrativo derivativo |
| PTP | point to point |
| UARMII | Underactuated Robot Manipulator II |
| VSC | variable structure control |

# List of Symbols

$a$        Distância

$\mathbf{a}$        Vetor de distâncias

$\mathbf{e}_j$        Vetor unitário de dimensão $n$ e com o $j$-ésimo componente igual a 1

$\mathbf{K}$        Matriz de rigidez

$m_1$        Massa do cumpim

$\delta_{k-k_f}$        Delta de Kronecker no instante $k_f$

# Contents

# 1 Introduction

This graduation work aims to discuss the main maze exploration algorithms and then propose a method where multi-agents must find the maze solution without any type of communication, only working with probability distributions to guide their behaviors. The main challenge of this research is to find a distributed exploration approach with total communication restriction since an agent's partial knowledge cannot be shared with another agent and, at the same time, a single agent must avoid repeating a branch of another agent. The proposed maze structure abstraction is a traditional regular grid that can be generalized into graphs.

This report is the initial part of the bachelor's thesis, and this chapter intends to introduce the general concept of the related thesis and present the motivation (Section 1.1), the related work (Section 1.2), and the main definitions about maze-solving algorithms (Section 1.3).

## 1.1  Motivation

Graph exploration has been the target of studies since Leonhard Euler proved that Seven Bridges of Königsberg (SHIELDS, 2012) has no solution. It has been researched not only in academia but also in the industry due to several practical applications, like airline scheduling, planning path on maps, search engine algorithms, social media marketing, Internet routing protocols, and robotics.

Specifically in robotics, graph exploration can be used to explore a maze with a single agent through a bunch of traditional algorithms: random mouse, wall follower, Trémaux, etc (SADIK et al., 2010). And it can be useful to guide many real-life problems such as search in nuclear plant disasters, burning buildings, and extraterrestrial environments. In these previous examples, the multi-agent exploration is more interesting than the single-agent approach since it can speed up the exploration. Recent studies have explored multi-agent maze-solving algorithms as seen in the Multi-Agent Maze Exploration paper (KIVELEVITCH; COHEN, 2010), where authors proposed a Tarry's algorithm generalization. It is important to emphasize that maze-solving algorithms consider that the structure is

unknown, and then traditional search algorithms, such as Dijkstra and A*, cannot be used to solve the maze.

Traditional multi-agent maze exploration approaches is based on internal communication between agents, where each agent knows about visited cells by another agent. It avoids a second exploration in a useless path and thus it decreases computational costs. However, there are some real situations where communication is limited or impossible, such as deep sea exploration, search in large wall structures, or search with low energy-based autonomous agents.

However, the incommunicable approach between agents have not been concretely found in the literature despite it may have real applications and may guide search plans in real-world problems. In order to explore it, this work presents some ways to achieve the solution of a maze based on agents without communication, that might be generalized to graph exploration algorithms.

## 1.2   Related work

Multi-agent cooperative system approaches are common in literature, especially when it comes from robotics researches. In the context of communicable agents, mainly in robotics, this chapter presents some related works.

Matarić (1995) established common properties across different scenarios of mobile multi-agent interactions, such as dispersion - "the ability of a group of agents to spread out in order to establish and maintain some minimum interagent distance" -, aggregation - "the ability of a group of agents to gather in order to establish and maintain some maximum interagent distance" -, homing - "the ability of an agent to find a particular region or location" -, etc. The author proposes a synthetic structure in order to abstract different types of interagent basis behaviors.

Sadik et al. (2010) presents, as seen in the title of the paper, a comprehensive and comparative study of maze-solving algorithms techniques by implementing graph theory. The research is delimited in the "Micromouse competition" context, which is a famous maze competition that has been performed worldwide since late 1970s. The authors compared maze-solving methods based on graph theory algorithms, such as DFS (Depth First Search) and BFS (Breath First Search) flood-fill, to common algorithms in the "Micromouse" context, such as Wall Follower. They concluded that, despite graph theory algorithms demands higher computational complexity, they are more proficient compared to non-graph theory methods.

Based around maze-solving algorithms, Kivelevitch & Cohen (2010) proposed a gen-

eralization of Tarry's algorithm, but the new approach is that all visited cells of the maze are known by each agent, since each agent shares its knowledge with all the others. In that sense, each one holds an dynamic map of the maze excluding redundant information, allowing information sharing. The authors presents in the article the performance of the proposed solution, where a group of virtual coordinate agents is required to find the goal without an a-priori knowledge of the maze, so-called "maze exploration".

Beisel (2014) *Distributed Maze Solving By Cooperative Robotic Platforms*

Mainly considering these previous references, the next section intends to define common terms about maze-solving algorithms and graph theory. Furthermore, the next section also intends to clarify the approach domain of this work.

## 1.3 Definitions

DEFINITIONS

# 2 Models

MODELS

# 3   Results

RESULTS

# 4 Next steps

NEXT STEPS

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Beisel, B. W. (2014). **Distributed Maze Solving By Cooperative Robotic Platforms.** University of Maryland, Department of Electrical and Computer Engineering.

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# FOLHA DE REGISTRO DO DOCUMENTO

| [1.] CLASSIFICAÇÃO/TIPO TC | [2.] DATA 25 de marï¿½o de 2015 | [3.] DOCUMENTO Nº DCTA/ITA/DM-018/2015 | [4.] Nº DE PÁGINAS 20 |
|---|---|---|---|

[5.] TÍTULO E SUBTÍTULO:

Multi-agent graph exploration without communication

[6.] AUTOR(ES):

**Arthur José de Sousa Rodrigues**

[7.] INSTITUIÇÃO(ÕES)/ÓRGÃO(S) INTERNO(S)/DIVISÃO(ÕES):

Instituto Tecnolï¿½gico de Aeronï¿½utica – ITA

[8.] PALAVRAS-CHAVE SUGERIDAS PELO AUTOR:

Cupim; Cimento; Estruturas

[9.] PALAVRAS-CHAVE RESULTANTES DE INDEXAÇÃO:

Cupim; Dilema; Construï¿½ï¿½o

[10.] APRESENTAÇÃO: (**X**) **Nacional** ( ) **Internacional**

ITA, Sï¿½o Josï¿½ dos Campos. Curso de Mestrado. Programa de Pï¿½s-Graduaï¿½ï¿½o em Engenharia Aeronï¿½utica e Mecï¿½nica. ï¿½rea de Sistemas Aeroespaciais e Mecatrï¿½nica. Orientador: Prof. Dr. Adalberto Santos Dupont. Coorientadora: Profª. Drª. Doralice Serra. Defesa em 05/03/2015. Publicada em 25/03/2015.

[11.] RESUMO:

Aqui começa o resumo do referido trabalho. Não tenho a menor idéia do que colocar aqui. Sendo assim, vou inventar. Lá vai: Este trabalho apresenta uma metodologia de controle de posição das juntas passivas de um manipulador subatuado de uma maneira subótima. O termo subatuado se refere ao fato de que nem todas as juntas ou graus de liberdade do sistema são equipados com atuadores, o que ocorre na prática devido a falhas ou como resultado de projeto. As juntas passivas de manipuladores desse tipo são indiretamente controladas pelo movimento das juntas ativas usando as características de acoplamento da dinâmica de manipuladores. A utilização de redundância de atuação das juntas ativas permite a minimização de alguns critérios, como consumo de energia, por exemplo. Apesar da estrutura cinemática de manipuladores subatuados ser idêntica a do totalmente atuado, em geral suas caraterísticas dinâmicas diferem devido a presença de juntas passivas. Assim, apresentamos a modelagem dinâmica de um manipulador subatuado e o conceito de índice de acoplamento. Este índice é utilizado na sequência de controle ótimo do manipulador. A hipótese de que o número de juntas ativas seja maior que o número de passivas ($n_a > n_p$) permite o controle ótimo das juntas passivas, uma vez que na etapa de controle destas há mais entradas (torques nos atuadores das juntas ativas), que elementos a controlar (posição das juntas passivas).

[12.] GRAU DE SIGILO:

(**X**) **OSTENSIVO**     ( ) **RESERVADO**     ( ) **SECRETO**