CZECH TECHNICAL UNIVERSITY IN PRAGUE

Faculty of Electrical Engineering

MASTER'S THESIS

Zdeněk Rozsypálek

Brick Detection for MBZIRC Competition

Department of Control Engineering

Thesis supervisor: **RNDr. Petr Štěpán Ph.D.**

Prohlášení autora práce

Prohlašuji, že jsem předloženou práci vypracoval samostatně a že jsem uvedl veškeré použité informační zdroje v souladu s Metodickým pokynem o dodržování etických principů při přípravě vysokoškolských závěrečných prací.

V Praze dne ....

podpis autora práce

Author statement for undergraduate thesis

I declare that the presented work was developed independently and that I have listed all sources of information used within it in accordance with the methodical instructions for observing the ethical principles in the preparation of university theses.

Prague, date ....

signature

ZADÁNÍ DIPLOMOVÉ PRÁCE

I. OSOBNÍ A STUDIJNÍ ÚDAJE

Příjmení: **Rozsypálek** Jméno: **Zdeněk** Osobní číslo: **457216**

Fakulta/ústav: **Fakulta elektrotechnická**

Zadávající katedra/ústav: **Katedra řídicí techniky**

Studijní program: **Kybernetika a robotika**

Studijní obor: **Kybernetika a robotika**

II. ÚDAJE K DIPLOMOVÉ PRÁCI

Název diplomové práce:

Detekce cihel pro soutěž MBZIRC

Název diplomové práce anglicky:

Brick detection for MBZIRC competition

Pokyny pro vypracování:

Seznam doporučené literatury:

[1] Himmelsbach, Michael, et al. "LIDAR-based 3D object perception." Proceedings of 1st international workshop on cognition for technical systems. Vol. 1. 2008.
[2] Dou M., Guan L., Frahm JM., Fuchs H. (2013) Exploring High-Level Plane Primitives for Indoor 3D Reconstruction with a Hand-held RGB-D Camera. In: Park JI., Kim J. (eds) Computer Vision - ACCV 2012 Workshops. ACCV 2012. Lecture Notes in Computer Science, vol 7729. Springer, Berlin, Heidelberg
[3] Ma, L., Kerl, C., Stückler, J., & Cremers, D. (2016, May). CPA-SLAM: Consistent plane-model alignment for direct RGB-D SLAM. In 2016 IEEE International Conference on Robotics and Automation (ICRA) (pp. 1285-1291). IEEE.

Jméno a pracoviště vedoucí(ho) diplomové práce:

RNDr. Petr Štěpán, Ph.D., Multirobotické systémy FEL

Jméno a pracoviště druhé(ho) vedoucí(ho) nebo konzultanta(ky) diplomové práce:

Datum zadání diplomové práce: **14.01.2020** Termín odevzdání diplomové práce: ______________

Platnost zadání diplomové práce:
do konce letního semestru 2020/2021

RNDr. Petr Štěpán, Ph.D. podpis vedoucí(ho) práce	prof. Ing. Michael Šebek, DrSc. podpis vedoucí(ho) ústavu/katedry	prof. Mgr. Petr Páta, Ph.D. podpis děkana(ky)

III. PŘEVZETÍ ZADÁNÍ

Diplomant bere na vědomí, že je povinen vypracovat diplomovou práci samostatně, bez cizí pomoci, s výjimkou poskytnutých konzultací.
Seznam použité literatury, jiných pramenů a jmen konzultantů je třeba uvést v diplomové práci.

.

Datum převzetí zadání	Podpis studenta

Acknowledgements

I would like to express my appreciation to Ing. Tomáš Petříček for his valuable and constructive suggestions during the planning and development of this thesis. I would also like to thank to the Department of Cybernetics of the Czech Technical University and to Michal Němec for the provided hardware. Finally, I wish to thank my family for support throughout my study.

Abstract

BLAH BLAH

Abstrakt

BLAH BLAH

Keywords: Keywords

Contents

List of Figures

1 Introduction

Multirobot, autonomous, motivation, BLAH BLAH BLAH

2 MBZIRC Contest

The contest took place in March in Abu Dhabi. Whole competition consisted of three challenges and the grand challenge which connected all challenges together. The first challenge was the only one which was focused solely on UAVs. The goal of the first challenge was to pop multiple big color balloons and to catch small ball carried by the organizer's drone. The other two challenges was designed for both UGVs and UAVs. The second challenge was about building a wall using the robots. Multiple polystyrene bricks were placed in the arena and the robots should have move these bricks to the destination area and stack them on top of each other to build the wall. Lastly the third challenge was to extinguish fire on the surface of the building model. This task was motivated by inability of firefighters to extinguish fire inside high-rise buildings in UAE. UAVs and UGVs carried tanks full of water and squirt it into the fire dummy. Every team had three rehersals in before the contest and then two competition attempts for each one of three challenges. Only the best teams from all three challenges was nominated into the grand challenge which was limited to just one attempt.

2.1 Second challenge

This thesis is focused on the second challenge and more specifically on the ground robot section of the second challenge, so that we provide more detailed description of this challenge. Each team is given thirty minutes to explore the arena (40×60 meters), localize all interest areas and build the wall. There are four types of the bricks with different colors. All bricks must be very light to enable the UAVs to pick them up. The dimension and colors of the bricks can be seen in the figure 1. Team obtains points for every placed brick. Bricks with different colors are rewarded by the different number of points. Placing bigger bricks means higher rewards. In addition the UAV bricks are rewarded by twice as many points as the UGV bricks.

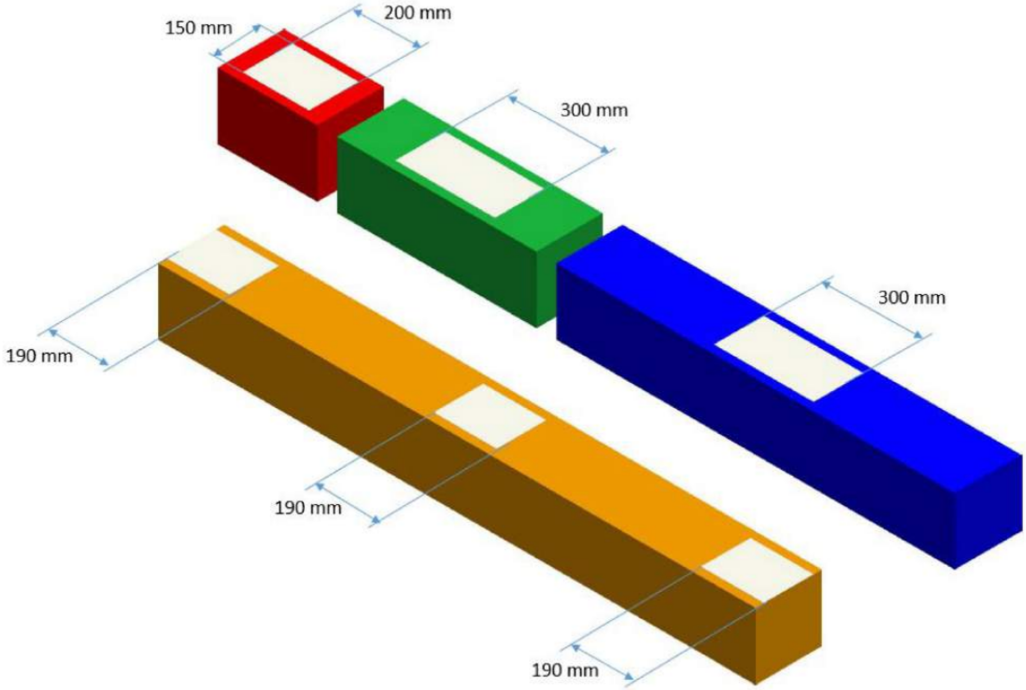


Figure 1: Colors and dimensions of the bricks provided by the organizer.

Each brick has thin metal plate on top of it, so that the robots are able to pick them up using electromagnets. In the beginning of challenge are all bricks placed at beforehand unknown position. Initial position of bricks is unknown but there is predefined pattern in which are the bricks put together. There are different patterns for the UGV piles of bricks and the UAV piles. The UGV bricks are stacked into the multiple height levels whereas the UAV bricks are stacked into the width and all are put on the ground. Due to the low weight of the bricks it is necessary to put UAV bricks into the rails, otherwise the bricks can be easily blown away by the propellers of the drones. Since the UAV bricks are all on the ground level (in purely horizontal pattern), it is much easier to detect them with the UAV bottom camera than using the lidar. That is why we are further concerned only about UGV bricks. These bricks are stacked in the positions displayed in the figure 2.

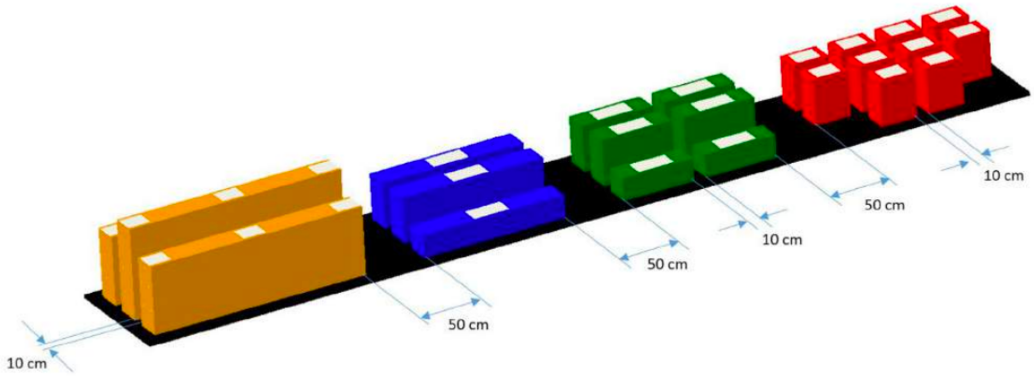
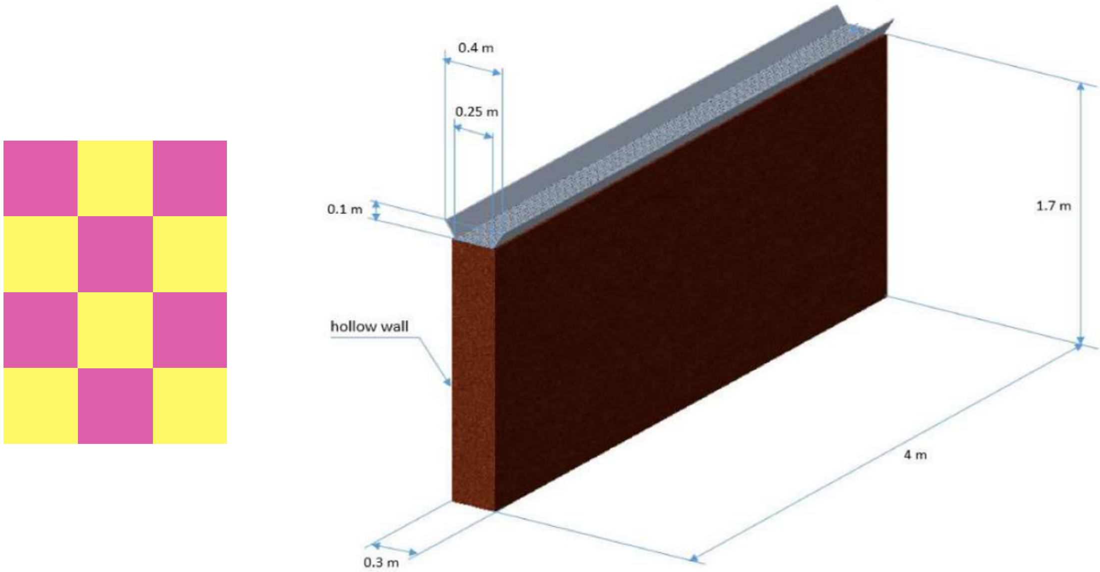


Figure 2: The positions of the bricks at the beginning of the second challenge.

Another objects of interest are destinations where the bricks should be placed. The robots must during the exploration look for them too. UGV bricks destination is marked by checker pattern. Detecting pattern was very challenging because exact shape was not know till second rehersal. The final form of the pattern is shown in the figure 3a. Although we are not concerned about the UAV bricks, the destination of the UAV bricks is a vertical object, so it is much easier to detect it from the ground using the lidar. The UAV brick destination is basically a wall as can be seen in the picture 3b. Bricks should be placed on top of this wall. The metal plates on top of each brick shift the center of mass to the top and make the brick very susceptible to rolling. That is why are on the top of UAV destination auxiliary handles to help place the bricks properly. At the beginning of the challenge is each team given the instructions which describe how the wall should look like at the end. When the built wall does not fit the instructions, the team gets penalty and gains less points for inaccurately placed bricks.



(a) UGV destination pattern.

(b) UAV destination

Figure 3: Description of target places for UAVs and UGVs. Each square in the UGV pattern has 10cm. Pattern consists of two 4×0.4 meter segments which are connected into the L shape. Whole UAV destination consists of five similar segments arranged into the M shape with right angles.

3 Equipment

For the sake of completeness is necessary to describe what exact equipment was available. We used **Clearpath Husky A200** which is wheeled robot designed for outside robotics. The robot is equipped with many additional devices. As a computer running all code controlling the robot is used **Intel NUC**. To manipulate the bricks we mounted **Kinova robotic arm** on top of the Husky robot. Two **12V electromagnets** are attached to the end-effector to enable the arm to grip the bricks. It would be very hard to grip the bricks without any feedback loop to the hand. For visual servoing and proper gripping we placed **Intel Realsense** camera close to the end of the arm. It is also possible to obtain feedback from electromagnets thanks to hall effect sensors and decide whether the brick is gripped correctly. For the localization, collision avoidance and detection is used **Velodyne VLP-16** lidar sensor. Lastly for the moving the bricks around the arena we created a handmade cargo area which can contain up to six bricks and attached it to the rear bumber. Whole setup is captured in the figure 4.

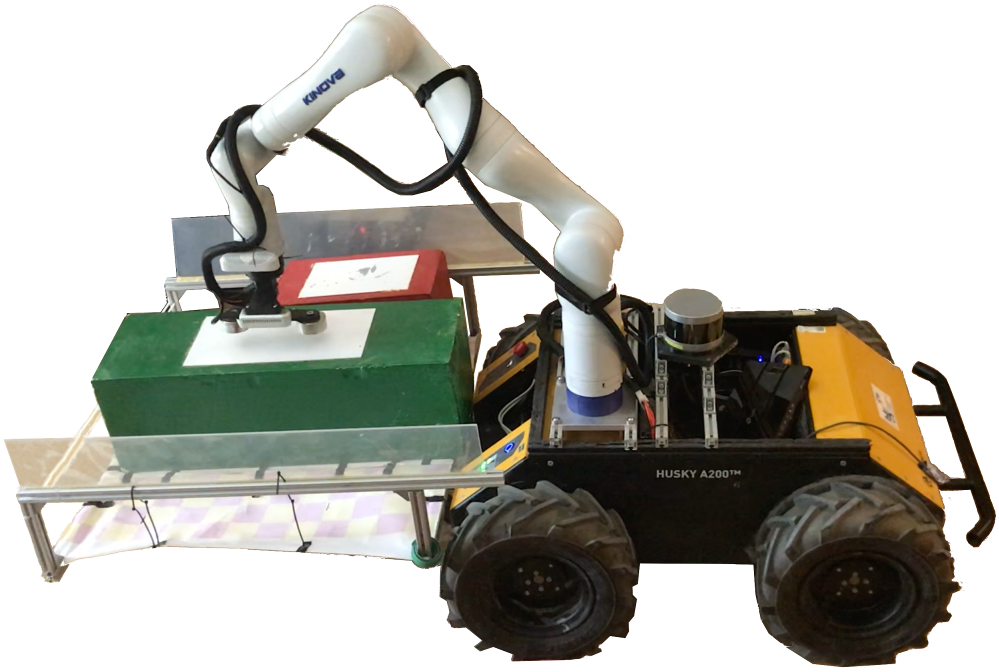


Figure 4: Clearpath Husky A200 adjusted for the second challenge.

3.1 Velodyne VLP-16

This thesis deals mainly with lidar data so following subsection will provide more detailed description of lidar sensor. Inside the VLP-16 puck is rotating class one infrared laser which measures the distance using the time of flight principle. Lidar provides 16 layers of laser scans with vertical field of view ±20°. That gives vertical resolution of 2°. Horizontal field of view is 360° with maximal resolution of 0.1° and 5Hz frequency. Sensor has for our purposes sufficient precision of ±3cm. Lidar is powered by 12V power supply and the data are transferred via UDP packets over the ethernet.

4 STH ABOUT ROS???

5 Lidar data processing

To detect individual bricks would be handy to extract straight lines from lidar data. Several methods can be used to achieve this goal. One of the most popular algorithms for lines extraction is currently split and merge algorithm. Initially was this algorithm proposed for image segmentation by Horowitz and Pavlidis [1]. Simple version of this algorithm for pointcloud processing is described in algorthm 1. There are many implementations of this algorithm which differs mainly in a way how they compute some particular steps of the algorithm. For example just the method of fitting a line to cluster can vary a lot. Very often is used the least squares method, but as simple method as connecting endpoints of cluster could be used. When the latter method is applied - algorithm is usually refered as Iterative End Point Fit (IEPF) [2]. For the cluster creation are the points iterated in each layer one by one. When the distance of subsequent points is too high we split the cluster. Every cluster is then further recursively split based on the most distant point from the fitted line. In a comparison of many line extraction algorithms was the split and merge algorithm one of the best performing in terms of precision and computational complexity [3].

```
Data: pointcloud
Result: line_segments
initialize constants C, S;
clusters = find_clusters(pointcloud, C);
while clusters is not empty do
    cluster = clusters.pop();
    line = fit_line(cluster);
    point = most_distant_point(cluster, line);
    if distance(point, line) > S then
        c1, c2 = split_cluster(cluster, point);
        clusters.push_back(c1, c2);
    else
        line_segments.push_back(cluster[start], cluster[end]);
    end
end
merge_colinear(line_segments);
```

Algorithm 1: Lidar data segmentation using split and merge algorithm. C is clustering distance and S is splitting distance.

6 EM algorithm

7 RANSAC

7.1 Correspondences

8 Lidar to camera registration

9 Global model and transformations

10 Experiment

BLAH BLAH BLAH

11 Conclusion

BLAH BLAH

11.1 Future work

BLAH BLAH

References

[1] Theodosios Pavlidis Steven L. Horowitz. Picture segmentation by a tree traversal algorithm. 1974.

[2] Axel Kaske Ali Syadat. An optimized segmentation method for a 2d laser-scanner applied to mobile robot navigation. 1997.

[3] Stefan Gachter Viet Nguyen. A comparison of line extraction algorithms using 2d range data for indoor mobile robotics. 2006.

Appendix A CD Content

In Table 1 are listed names of all root directories on CD.

Directory name	**Description**
thesis	the thesis in pdf format
ctu_thesis	latex source codes
lidar-gym	OpenAI gym environment

Table 1: CD Content

Appendix B List of abbreviations

In Table 2 are listed abbreviations used in this thesis.

Abbreviation	**Meaning**
CNN	Convolutional neural network
DDPG	Deep deterministic policy gradients
DQN	Deep Q-learning
MDP	Markov decision process
RL	Reinforcement learning
ReLu	Rectified linear unit
TD	Temporal difference

Table 2: Lists of abbreviations