

# Birmingham Autonomous Robotic Club (BARC)

## Motto: *Learning by doing*

Members: Lenka Mudrova, Manolis Chiou, Marco Becerra,

Sean Bastable, Joshua Smith, Edoardo Bacci, Tanya Daskova and Anya Hristova

Email: robot-club@cs.bham.ac.uk

Affiliation: School of Computer Science, University of Birmingham, UK

Website: <http://lenka-robotics.eu/index.php/robotic-club>

**Abstract**—Birmingham Autonomous Robot Club (BARC) connects students from the University of Birmingham, with a strong interest in robotic applications and competitions. This paper is part of our qualification for the RoCKIn@Home 2015 competition. Therefore, it overviews our robot Dora and the developed software structure based on ROS middleware.

It overviews how this challenge relates to our interests and experiences and how we can achieve high reusability of our system by integrating different subsystems from other projects. Moreover, team members, their experiences and research interests are described in detail.

Finally, the conclusion summarises our motivation and relevance for this competition.

## I. INTRODUCTION

Birmingham Autonomous Robotic Club (BARC) was established in 2011 in the School of Computer Science at the University of Birmingham. The main purpose was to provide an extra opportunity for students to gain additional knowledge about robotics and to work on real robotic platforms and projects. Several students involved in the team contributed to projects which were mainly used to promote robotics during the school's open days. For example a robotic waitress which accepted orders for drinks and deliver them.

In 2014, the structure of BARC was changed in order to incorporate the lessons learned and to allow the team to take part in robotics competitions. We participated successfully in Sick Days 2014 [1] and RoCKIn@Home 2014. In the latter we won two of the competition challenges. This year, we would like to participate again in RoCKIn@Home as we have still many things to learn, improve and most importantly contribute.

The team has the support of the Intelligent Robotics Lab [2] in the School of Computer Science. The lab conducts research and has expertise in a variety of fields including but not limited to computer vision, manipulation, planning, architectures, reasoning and mobile robots. Furthermore, the lab has strong links with the industry. We are also starting to cooperate with other departments within our university, such as electrical and mechanical engineering. We hope to create more interdisciplinary team than we had last year.

This paper overviews our system from last year and analyses the drawbacks of our solutions. Moreover, it extensively discusses what we are currently working on.



Fig. 1. Our logo represents our university campus with famous clock tower Old Joe.

## II. HARDWARE

Our robot Dora is created using the differential platform Pioneer 3D-X and central supporting construction for sensors and a laptop, see Fig 2. In last year, Dora was equipped with 2 laser rangefinders and 1 depth camera, which were used to ensure safe navigation and people detection. This year, we are going to significantly improve Dora's hardware in order to provide more support for:

- *human robot interaction* - Dora's speech understanding and speech reproduction were strongly limited to the used laptop last year. We are going to extend Dora by mounting a microphone and a speaker on her. Additionally, we are going to improve her appearance to be more user-friendly.
- *safe and robust navigation* - We are investigating usage of Pioneer's sonar to detect small objects. Moreover, Pioneer's bumpers will be used to stop the robot when an object is hit.
- *object recognition* - another depth camera with short range is added to allow detection of small household objects.

## III. SOFTWARE ARCHITECTURE

As our goal is to achieve high re-usability, modularity and openness, we built our software architecture on the Robot Operating System (ROS) middleware, using version Indigo [3] running on Ubuntu Trusty Tahr. Additionally, our system this year uses some of the publicly released packages from



Fig. 2. Dora is an extended Pioneer 3D-X robot with sensors such as a laser range finder, depth camera and a laptop mounted on top.

the STRANDS project [4]. This allows us not only integrate the cutting edge research to our robot, but also contribute to the evaluation of this research. Moreover, we integrate our own research where our interest overlaps with the focus of the competition. Our system architecture contains following modules.

#### A. State machine

Even though AI planning is in our expertise, we use *finite state machines* to control and monitor robot's states and actions. We have two main reasons for this decision. First, the competition defines all *task benchmarks* as short scripts, so a robot does not have too much freedom in decisions how to fulfil a task. Second, a state machine provides us with *repeatability* during testing.

For each of the benchmarks, we develop the state machine using ROS's SMACH package, that is “a task-level architecture for rapidly creating complex robot behaviour” [5]. All of the task's state machines are linked with the central state machine which communicates with the referee box and based on the accepted benchmarking test triggers specific state machines.

#### B. Database for robot knowledge

Robot's knowledge is managed in a database, which allows us not only record all data as rosbags, but also extract and separate data offline in order to evaluate our system in different scenarios. We are using Robomongo [6].

#### C. Navigation

We use standard ROS packages for localisation, mapping and low-level navigation (move-base), e.g. navigation planning path from an initial coordinates to the goal's ones. This systems has proved great robustness in last year competition

and we reuse it this year. However, we observed that at some cases, such as passing narrow doors and overcoming a doorstep, a special robot behaviour would be better. Therefore, we extend our system by high-level topological navigation [7] and we can strongly benefit from three main features:

- Waypoints and edges are managed in a database which allows even online modification.
- A special robot behaviour can be specified on the edges overriding standard move-base.
- A navigation policy [8] provides paths on the top of the topological map containing waypoints. Thus, the robot must pass the surrounding area of the waypoint on the path. This can be mainly used to demand certain robot movements and keep the robot from obstacles in an environment.

Moreover, this year system is extended by an extra monitoring level, which overrides the standard move-base behaviour when the robot needs to recover from being stuck, etc.

#### D. Mapping

is done by *OpenSlam's GMapping* algorithm [9] through the ROS wrapper package called *slam\_gmapping*. This approach uses a Rao-Blackwellized particle filter in which each particle carries an individual map of the environment. The particles are updated by taking into account both odometry and the latest observations from a laser range finder.

#### E. Localisation

in a known map uses an *Adaptive Monte Carlo Localisation* (AMCL) [10] algorithm. This node is part of the ROS navigation stack package. It uses laser range finder readings to update a particle filter. Every particle represents a specific discrete state and stores the uncertainty of the robot being in that state/position within the known map. Also, every time the robot moves it uses the motor information to shift the particles to the corresponding direction.

#### F. Low-level navigation using move-base

was used last year as the only navigation system. It is a proven robust solution for domestic environments [11]. More specifically this node reads the odometry, the current pose estimate and the laser range finder scans and 3-D points clouds from a depth camera and safely drives the robot in the environment to a predefined goal. In order to navigate smoothly, it uses a combination of a global and a local planner. The global planner creates an optimal global path based on the robot's pose and a global cost-map. Then the local planner, which uses the *Dynamic Window Approach* algorithm [12], is responsible for following the global path and reactively avoiding obstacles.

#### G. Human detection and recognition

Human detection can be split to indirect, when a robot must use only an RGB camera of the flat, and direct, when a robot can use any sensors.

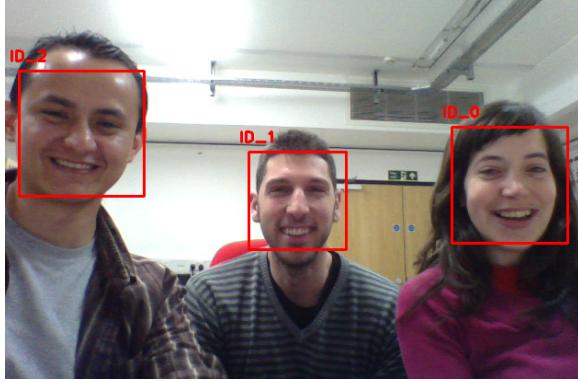


Fig. 3. An example of the face detection and face recognition algorithms. The red bounding boxes surround the successfully detected faces, while each of them is given a corresponding identification code.

1) *Indirect Face detection and recognition:* Face detection, see Fig. 3, is performed using the *Viola-Jones* algorithm [13]. The algorithm looks for faces by applying incrementally many simple Haar classifiers. The composition is performed by a cascade function, which needs to be trained *a priori* with many positive and negative images. The resulting classifier can find faces efficiently with independence of the size of the faces and light conditions.

Face recognition is performed by applying a *Local Binary Pattern Histogram* (LBPH) algorithm [14]. The principle of the algorithm is to build local binary patterns (LBP) for each pixel depending on a variable neighbourhood scheme. Then, it divides the formed LBP image into  $m$  local regions and computes the LBP distribution histogram from each region. Finally, classification is performed by comparison between the LBP histograms of a new face with the ones from the dataset.

2) *Indirect uniform recognition:* Our uniform recognition was based on a simple segmentation of an input image to two regions. A positive region was corresponding to a colour within previously hand calibrated lower and upper bounds. In contrast, a negative region correlated to the colours outside of these limits. Based on the size of the positive region, the person was clarified as a Postman, Deliman or other. However, this detection is infeasible for robust performance due to high sensitivity on hand calibration and no knowledge about a detected area (for example any significantly big object in a background can create fall positive). Therefore, we are currently working on an extension using an upper body detector. The colour of the uniform will be then recognise only on this limited area, minimising the fall positives.

#### IV. OUR FOCUS AND PLAN

This section summarises our intentions for our system this year. We would like to aim for high re-usability of code in our robotic system and to demonstrate that the current state of the art in AI algorithms mixed with our extensions can be successfully used to produce a robust, effective and complete robotic system with domestic applications.

#### A. Catering for Granny Annie's Comfort

A robot will receive commands from Granny Annie by natural speech. These commands may contain interaction with an intelligent flat or bringing to her a specific object. We have not participated in this task last year because we had not a robust speech recognition as neither of us is an expert in the field. However, we have started a cooperation with research group in this field and we hope to be able to recognise speech more robustly than using CMU Sphinx last year, see Sec. IV-F.

We would like to prepare our robot so that it can perform the first part - cooperation/interaction with an intelligent flat. This subtask still contains interesting challenges, such as robust speech recognition and robot navigation in a way, which is comfortable and natural for a human.

#### B. Welcoming visitors

In this task, a robot should welcome visitors, recognise them and accompany them to a specific location in Granny's flat. Several components are needed in this task: computer vision for face recognition and for uniform detection. Moreover, machine learning techniques are needed to be able to learn these two patterns in order to recognise them. A robot can also benefit from speech recognition if face/uniform recognition does not provide a certain decision. Additionally, a robot must have robust navigation in an environment in order to accompany a person to a specific place. Finally, human-robot interaction is needed while accompanying a person.

Last year, we successfully completed this task. Our system was built on several components which are mentioned in Sec. III. Here, we would like to discuss their properties, advantages and disadvantages and their future extensions. Our core state machine is built for this task calling several components. We do not plan changes in our face recognition system as neither of us is an expert in this field. However, we will create bigger database of faces in order to support machine learning algorithm.

Uniform recognition needs to be improved due to following reasons. First, recognition was based on manual sensitive calibration of colours last year, which slowed down preparation and the calibration was sometimes impossible. Second, uniform detection was based only on segmentation of all the picture. This means, if there is significantly big object of certain colour belonging to an uniform (white/yellow) in the background, this object will be classified as the person. Both issue were limitations last year and we are improving them.

The last issue of our system last year was not sufficient detection of a human. Thus, our human-robot interaction was strongly limited. We were using only a leg detector based on the readings from the laser scanner. This system was not robust enough. Hence we are testing how to combine this system with an upper-body detector based on a depth camera or an IR camera.

#### C. Getting to know my home

In this task, a robot should recognise changes in a flat, such as open/closed doors, furniture has been moved to another

room or everyday objects were moved. The robot can detect these changes autonomously or by cooperation with a human who used speech or gestures. After detection, the robot is asked to use this new knowledge to execute some commands, such as to bring a mug on the dining table which is now in living room.

The state machine for this task from last year is in Fig. 4. Our system was built on two parts - autonomous detection of doors using the laser rangefinder and cooperation with human in order to detect where is furniture. However, the robot was unable to detect exact position of the furniture which is important to be able to use the knowledge later. Therefore, we would like to integrate one of the STRANDS packages this year, which is able to detect dynamic clusters from 3D point clouds and recognise to which object they belong. Additionally, we would like to detect objects as well.

Finally, we used CMU Sphinx last year for speech recognition. However, this system is not proper for this usage due to limited dictionary and usage. Therefore, we are going to change our speech recognition system, see Sec. IV-F.

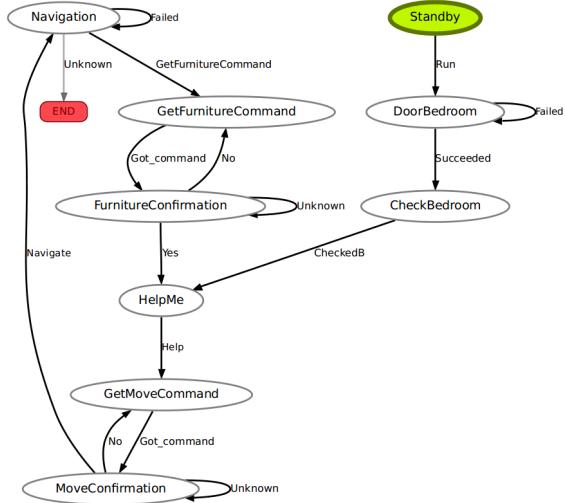


Fig. 4. The state machine for task Getting to know my home

#### D. Object perception

We are currently comparing two different approaches for object detection and recognition. The first approach uses manually created point-cloud models with rgb information. The advantage is that this algorithm detects the exact objects which were used for training. However, if the object is occluded then the detection is significantly worse. Additionally, this approach is possible for a small set of object because each object needs manually created model.

In contrast, the second approach uses a database of 3D models of objects. These object do not represent any specific object, they rare created in software for 3D visualisation to represent a general object. Hence, the second approach uses such database to train knowledge how general chair, mug, banana, etc. looks like.

#### E. Navigation

We had robust configuration of navigation stack from ROS last year, which combined benefits from laser rangefinder and a depth camera. Additionally, we have added monitored navigation to recover from failure and topological navigation in order to control behaviour of the robot in different rooms. Details are explained in Sec. III.

#### F. Speech understanding

Last year, we used CMU Sphinx for speech recognition with no added microphone. CMU Sphinx is not good enough for this benchmark. Therefore, we have started to cooperate with research group of speech recognition in our faculty in order to deploy more sophisticated algorithm on our robot. Unfortunately, no details are known yet, as the work on this benchmark will start in September.

#### G. Timetable

We are doing our best in order to participate in all tests. However, our priorities are following. First, we will perform complete *Welcoming visitor* task. Moreover, we will detect not only doors changes, but also precise locations of furniture in *Getting to know my home* task. We will participate in *Navigation* benchmark. We hope to participate in the rest of tasks, but it is depend if we will be able to recruit new team members.

## V. EVALUATION AND BENCHMARKING

In order to develop robust system, we have decided to focus on intensive testing and evaluation. Therefore, we tried to find possibilities how to built a test arena and equipped it by real objects. However, this is impossible for us due to strongly limited budget and no space. Although, we came up with a better idea - we have decided to use flat of one of us, see Fig. 5. Hence, our robot is deployed permanently in this flat now and we record datasets during regular testing which we plan publish later.

We have found such environment really close to the arena with all tricky situations such as narrow corridors, door steps, a large mirror, etc. Therefore, we are able to test our algorithms in a realistic environment and improve their robustness. We created a video from our testing, which can be found on our websites [15]. More detailed description of our evaluation will be publish there before the competition in November.

## VI. TEAM MEMBERS

Currently, the team has eight active members - three bachelor's, one master and three PhD students in the second year of their studies. All team members are students in the School of Computer Science, University of Birmingham. Bachelor students are getting familiar with ROS and robot applications. Hence, they do not have any specific background and position in the team yet. Therefore, the overview and details are given only for the master student and PhD students. Description of their background and research interests are highlighted here. The final team line-up is likely to change before the competition as more members will contribute.



Fig. 5. Long-term deployment of Dora in a flat

#### A. Lenka Mudrova

She is a PhD student with research interests in AI planning and scheduling. In the team, she has two roles. First, she is the team leader, which mainly includes representation of the team when formal communication outside of the team is necessary. Also, she makes sure that every member of the team knows what is happening, how their modules will be used within the system and what is required from them. The second role is that she is working also on the robot's subsystem. Her research interest in Artificial Intelligence (AI) planning will be useful for creating the robot's overall behaviour next year. Moreover, she is interested in computer vision and speech recognition.

*Scientific background:* She did her bachelor's and master's studies at the Czech Technical University in Prague with a focus on Robotics. This study branch gave her a wide range of knowledge in the fields of mechatronics and artificial intelligence. She was involved as a team leader of the student robotics team FELaaCZech that took part in the international competition Eurobot for four years.

Currently, she is a PhD student with a focus on AI planning and scheduling, which are important techniques for a robot to make decisions on when, how and what needs to be performed. Such decisions are necessary in service robotics when a robot needs to complete tasks assigned by a human. The robot needs to have a control framework that makes decisions concerning which particular task should be executed. The quality of the decisions influence the overall performance of the robot and of course, the robot's goal must satisfy as many of the requirements assigned by the humans as possible. Requirements for the robot's control framework are deadline awareness, handling uncertainty about task duration and resources, creating plans on how to complete general tasks and awareness of changes in the environment where the robot operates.

Her research is part of the EU STRANDS project [4]. "STRANDS aims to enable a robot to achieve robust and intelligent behaviour in human environments through adaptation to, and the exploitation of, long-term experience (at least 120 days by the end of the project)". Therefore, the robot's control framework will exploit long-term experiences and observations

of the robot's world.

#### B. Marco Antonio Becerra Pedraza

He is a PhD student in the School of Computer Science, University of Birmingham. His research interests are 3D perception, human sensing, knowledge representation and reasoning. Inside the team he has worked with the human sensing capabilities of the robot.

*Scientific background:* He obtained his bachelor degree in Mechatronics Engineering from the Instituto Politécnico Nacional in Mexico and a master degree in Computer Science from the Universidad Nacional Autónoma de México. He is a former member of the PUMAS RoboCup@Home team.

During his PhD, he will be doing research about semantic mapping of human events. The topic has two main components:

Semantic mapping can be conceived as an extension of the mapping problem [16]. Traditionally maps were used in robotics mostly for navigation purposes. But the environment has additional spatial information that needs to be handled. Semantic maps extend the concept of maps to handle more features from the environment (e.g. structure, functionalities, events). The goal is to reason about the scene (e.g. planning, prediction, explanation, interpretation).

Activity recognition is about using observations from the world to build representations of the ongoing actions. Later, these representations can be used to find associated structures.

#### C. Manolis Chiou

He is a PhD student with a multidisciplinary background in control engineering, robotics and AI. His work on BARC involves but is not limited to control, navigation, localisation and in the future Human-Robot-Interaction (HRI).

*Scientific background:* His first degree is in Control Engineering from the Technological Institute of Piraeus, in which he got involved in a variety of robotic projects including demonstrating these projects to the public and exhibitions. His undergraduate thesis was on implementing control algorithms to robots (e.g. Model Predictive Control for stability/balance). He has an MSc in Computational Intelligence with his master thesis on formation control and transportation of objects with a swarm of robots.

The working title of his PhD thesis is "Flexible robotic control via co-operation between an Operator and an AI based control system". It addresses the problem of variable autonomy in teleoperated mobile robots. Variable autonomy refers to the different levels of autonomous capabilities that are implemented on a robot.

Robots used on demanding and safety critical tasks (e.g. search and rescue, hazardous environments inspection, bomb disposal), which are currently teleoperated, could soon start to benefit from autonomous capabilities. Such capabilities include algorithms for automatic robot navigation, algorithms for Simultaneous Localisation And Mapping (SLAM) and etc. Robots could usefully use AI control algorithms to autonomously take control of certain functions when the human

operator is suffering a high workload, high cognitive load, anxiety, or other distractions and stresses. In contrast, some circumstances may still necessitate direct human control of the robot. The research will tackle the problem by designing control algorithms for switching between the different autonomy levels in an optimal way.

#### D. Sean Bastable

He is a Computer Science bachelor's student in his final year. It is expected that he will continue to further his studies with a master's degree in Robotics. As the oldest BARC member, he has solid experience with ROS and different robotic platforms. He is also one of the team members who attended RoCKIn camp 2014 in Rome.

*Scientific background:* His final year project was about investigating and implementing a visual localisation system for a mobile robot. This allowed the robot to continue localising in environments where laser based localisation cannot be used. A good example of this is in domestic environments where the presence of people moving around the robot may obstruct the laser scan and provide false readings.

The project used a ceiling facing omnidirectional camera on the top of a robot in order to take pictures of its surroundings. The robot was trained by taking many pictures of the environment, along with location data provided through laser based localisation under ideal conditions. When localising, it can take additional pictures and compare them to the training images in order to find an estimate of its location. Principal Component Analysis (PCA) was used to match images in the localisation phase to those in the test phase.

Another potential use of this project is to provide an initial location estimate to a laser based localisation system in order to allow the robot to quickly localise from any position without any human input.

This project follows on his previous summer project of a drinks serving robot used in a launch event for the 2014 British Science Festival. As the robot was moving in a crowd, one of the key failure points was that it could become de-localised. The robot had the need to know exactly where it is in order to effectively navigate through gaps in-between crowds. Visual localisation was considered as a potential solution but due to time constraints was not implemented.

## VII. CONCLUSION

Our team has strong relevance to the domestic service robotics, as Lenka's, Marco's and Manolis's research interests involved cooperation with humans. We would like to use our expertises to combine the state of the art in AI techniques with our own contributions. As a result, a robotic system will be created with high reusability, as we use ROS middleware.

We would like to achieve high robustness of our robotic system that it can perform tasks repeatedly. In order of this our goal, we would like to put attention to verification and evaluation of our system. We expect that our robot Dora will be able to perform completely the *Welcoming visitors* task, *Getting to know my home* task and *Navigation* task. In order

of fulfil these tasks, we plan to merge techniques for face and an uniform detection, speech recognition and synthesis, navigation, people detection, HRI behaviour that will ensure that a person is following the robot, door detection, following a person and gesture recognition.

We would like to perform other tasks as well, but it depends on our human resources. We plan to cooperate more with first year bachelor's students in order to introduce them to robotics and provide them with some interesting challenges, which can be used during competition. We believe that participating in the RoCKIn@Home challenge will bring a lot of experience not only to the young students, but also to us. As a result, we are expecting to obtain more knowledge in the ongoing research in many fields of robotics.

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