Birmingham Autonomous Robot Club (BARC)

Motto: *Learning by doing*

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***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 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.

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

I. Introduction

Birmingham Autonomous Robot 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 BARC structure was changed in order to incorporate the lessons learned and to allow the team to take part in robotics competitions. We participated in Sick Days 2014 [**?**] and RoCKIn@Home 2014. This year, we would like to participate in RoCKIn@Home as well, as we have still many things to learn and improve. Hence, this paper overviews our system from last year and analyses drawbacks of our approaches. Moreover, it discuss extensions what we are currently working on.

The team has the support of the Intelligent Robotics Lab [**?**] 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.

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 **??**. 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 [**?**] running on Ubuntu Trusty Tahr. Additionally, our system this year uses some of the publicly released packages from the STRANDS project [**?**]. 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

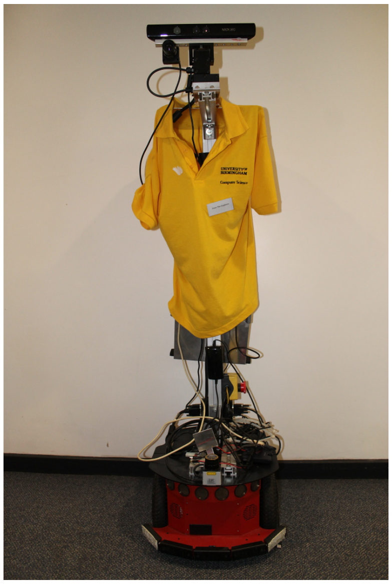

Fig. 2. Dora is an extended Pioneer 3D-X robot with sensors such as a laser range finder, depth camera and a laptop mounted on top.

the competition. Our system architecture contains six modules which are explained below.

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" [**?**]. 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.

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 [**?**] 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 [**?**] 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 [**?**] 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) [**?**] 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 [**?**]. 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 [**?**], is responsible for following the global path and reactively avoiding obstacles.

G. Object detection and recognition

H. 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.

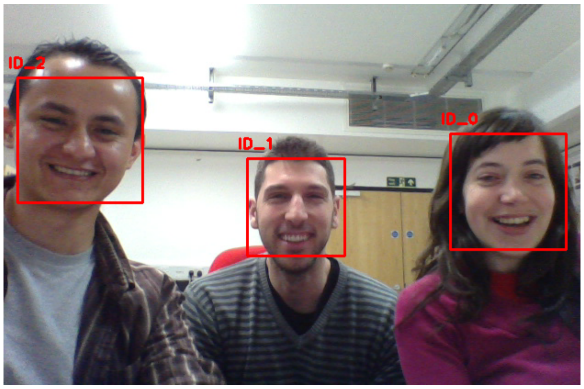

Fig. 3. An example of the face detection and face recognition algorithms. The red bounding boxes surround the successfully detected faces, while each of them is given a corresponding identification code.

1) Indirect Face detection and recognition: Face detection, see Fig. 3, is performed using the *Viola-Jones* algorithm [**?**]. 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 [**?**]. 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.

3) Direct person detection:

I. Human interaction

J. Semantic mapping

IV. Our focus and plan

This section summarises our intentions for our system this year. We would like to aim for high reusability of the 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

B. Welcoming visitors

Last year, we completed this task. Hence, the main structure is built. We are improving the uniform detection to increase robustness. Moreover, we are improving our human detection system, for example, we are making tests with an IR camera.

C. Getting to know my home

We proved last year, that our system is able to robustly detect doors using laser rangefinder. Moreover, we were able to detect changes in 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, which is able to detect dynamic clusters from 3D point clouds and recognise to which object they belong. Moreover, we would like to detect objects as well.

D. Timetable

Our plan is to perform complete *Welcoming visitor*(referred as MW) task during competition. Moreover, we will work on *Getting to know my home*(referred as MG) task, where we assume to be able to recognise state of doors. In order to achieve these goals, we set up our milestones:

- MW1 - training of a face, recognising a known person based on the face, mapping, localisation, robust navigation in a known map. Deadline: 7.5.2014
- MW2 - Increase robustness of face recognition, detection if a person is following the robot, speech recognition. Deadline: 27.7.2014
- MW3 - Integration and test, producing new video. Deadline: 31.7.2014
- MW4 - Cloth recognition, robot behaviour to restrict person to follow it. Deadline 31.8.2014
- MW5 - Integration and test. Deadline: 5.9.2014
- MW6 - **Perform complete *Welcoming visitor* task during British science festival 6.9.-11.9.2014**
- MW7 - Perform more test. Deadline 30.9.2014
- MG1 - Work on autonomous recognition of state of doors, cooperation with human in detection of other changes. Deadline 31.10.2014
- Test of overall system. Deadline 23.11.2014

The expected timetable of our milestones can be seen in Fig. **??**.

V. Evaluation and benchmarking

VI. Team members

Currently, the team has eight active members - three bachelor's, two masters 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. The overview of team members follows along with a description of their background and research interests. The final team line-up is likely to change before the competition as more members will contribute.

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 [**?**]. "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 [**?**]. 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 constrains 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. Therefore, we decided to focus only on a part of the RoCKIn@Home challenge this year. We expect that our robot Dora will be able to perform completely the *Welcoming visitors* task and recognise the doors' state in the *Getting to know my home* 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.

Moreover, 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.