

# Techniques and Approaches in Robocup@Home - A Review

Tahir Mehmood\* and Usman Hashmi  
Department of Electronics Engineering  
Iqra University, Islamabad  
Email: tahir1969@gmail.com

Arsalan Akhter\* and Ammar Ajmal  
Department of Computer Engineering  
Bahria University, Islamabad  
Email: arsalan\_akhter@ymail.com

**Abstract**—RoboCup is a platform for professionals, students and enthusiasts to demonstrate their technical skills in the domain of Artificial Intelligence for everyday life usage like in soccer, home or work. RobCup@Home is a part of RoboCup, which deals with domestic service Robots. In this paper we discuss different development approaches, components and algorithms used to design and develop Robots used in the RobCup@Home League.

**Keywords:** ROS, Robotics, Robocup@Home, Image Processing, Robot Navigation, Home Environment, Kinect, Face Recognition, Object Recognition, Speech Recognition

## I. INTRODUCTION

In the field of Artificial Intelligence and Robotics, scientific competitions are becoming very popular day by day. They provide a platform for students and professionals to exhibit and share their ideas, expertise, skill-sets and experiences. Aerial Robotics Challenge, RoboCup and Defence Advanced Research Projects Agency's (DARPA) competitions are some of the well known examples. These competitions aim to promote research and development in the fields of Artificial Intelligence (AI), Machine Learning (ML) and Robotics by challenging the participants to develop machines with capabilities of thinking and acting rationally.

RoboCup is holding international competitions since 1997 with the idea that game scenarios can be used as challenging problems to foster research in the field of Robotics and AI [1]. Initially, the objective of these events was to develop Robots capable of playing soccer with humans and ultimately winning against their counterparts. With the passage of time, RoboCup has started various events encompassing other areas of Robotics. Major examples are developing Robots for Rescue operations, for industrial environments and Robots to be used in home environments. This paper focuses on 'RobCup@Home' which is a competition to develop Robots for accomplishing a pre-defined set of tasks in a controlled, home environment using various strategies.

A Robot is a reprogrammable multi-functional device designed to move material, parts/tools, specialized devices or even itself by using variable programmed motions for a variety of pre-defined tasks. Software and hardware are two main

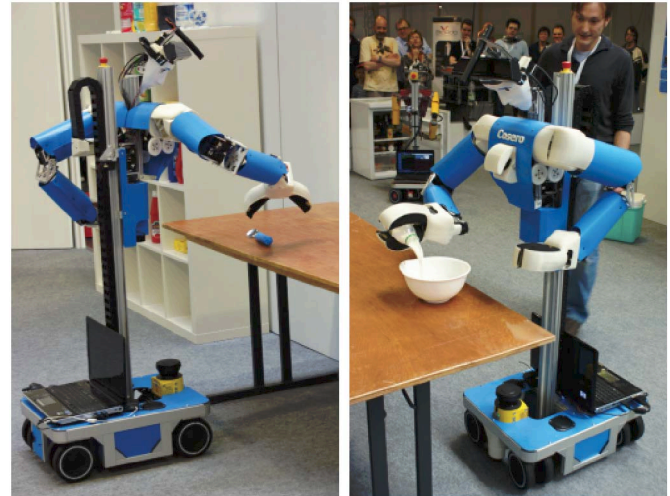


Fig. 1. A robot in a typical Robocup @Home scenario [7]

portions in developing a complete Robot. In this paper we will discuss these two aspects of a Robot development in regards to Robocup@Home competition. A robot in a typical Robocup@Home scenario is shown in Fig 1.

## II. SYSTEM OVERVIEW

To achieve a particular goal, Robots in Robocup@Home take both visual and auditory inputs from their surroundings using cameras and microphones or other sensors. This raw data is processed to generate meaningful commands for the Robot to execute and develop an understanding of the environment. This is done by generating maps or using sensors and techniques for avoiding collisions with objects in the environment. All of the data obtained is sent to the on-board main server which decides the next tasks to be executed. These include a number of tasks, such as recognizing a gesture, someone's face, following someone, picking or placing something, finding an object, moving in a cluttered environment etc. Once the main server decides which tasks to execute, it then sends commands to the actuators, mainly the motors of the base of the robot and the arm and gripper, to execute those tasks. Each of these modules has their feedback mechanisms in-place to effectively execute the given commands. Feedback data can also be used

---

Asterisk (\*) denotes authors who contributed equally to the work.

by the main server to fine tune performance and decision making.

### III. HARDWARE DESCRIPTION

This section briefly discusses hardware components used by different teams in Robocup@Home.

An Autonomous Robot perceives information from environment using its sensors. After data analysis, a Robot takes decisions and interacts with the environment to perform the desired tasks, such as object detection, tracking, obstacle avoidance and gesture recognition etc. Depth information along with images is an integral part of the data acquired for recognition purposes, which employs various sensors like Microsoft Kinect sensor[2], ASUS XTION [3] sensor or Nintendo Wii. Kinect has an added advantage over rest of the sensors with respect to extensive device support and drivers and open source support libraries like OpenNI Library and Kinect Studio etc. It also has a motor which can be used to control its position remotely. Kinect has a low image quality and requires extra power source while comparing to ASUS XTION, which is USB powered and has a better image quality [4].

Obstacle avoidance and distance measurement from objects is basic information required by a Robot to maneuver in a cluttered environment. HUKOYU [5] and SICK [6] are the more commonly used sensors due to their availability, small size and precision. SICK LMS100 is a little expensive but has a much higher range i.e, 20 meters as compared to HUKOYU URG04-LX which has a range of 5.6 meter [8].

Controlling and managing the speed of a Robot is a critical requirement in Robot motion and maneuvering. Servo motors and DC geared motors with encoders are used to achieve this task. Servo motors are precise while DC motors are relatively cheaper. Slippage of the wheels is a common issue whose effects could be minimized by using control techniques like Proportional-Integral-Derivative controllers etc.

Layered design approach is a common approach used by Robocup@Home teams, where first layer is considered to be the bottom or the base of the Robot. This layer can either be designed indigenously using Acrylic or Aluminum sheets or can be acquired using Off-the-shelf. Laser range finders or scanners, batteries and some other external sensors could be mounted on the base of the Robot.

Some teams use commercially available robots instead of designing from scratch by themselves. Some of the commercially available Robots are NAO, Reem, Care-O-bot, DARwin-OP, PR2 and Otto bock etc. Some robots have their own operating system like NaoQi for Nao while some are programmable with OS like PR2. These Robots differ in shape, capacity, degree of freedom and cost.

Second layer is the upper body and arms of the Robot. The Robot's arms are used for manipulation of objects in the environment. Arms could be purchased or designed indigenously. Some commercially available Robotic arms are Katana [9], UR6 [10] and TurtleBot [11] arm etc. Katana has a 5-degree-of-freedom and can lift weight up to 2 Kg. This arm is widely

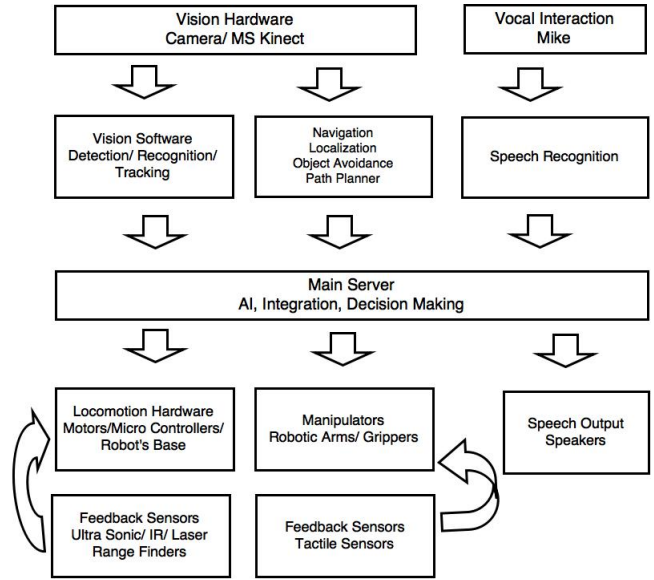


Fig. 2. System Overview of a Robot in a Robocup@Home setting.

used by Robocup@Home teams. On the other hand, Turtlebot has a main advantage of built-in library in ROS. Arm at the base (i.e., the first layer) is not useful for several tasks, like object manipulation on the table or at various heights. Arm on upper body with up and down moving capacity are more feasible as the Robot can adjust its height according to the given task.

The third layer of the Robot is the head. Kinect sensor and cameras are mounted on the head. As discussed previously[4], the depth sensors cameras are of low pixel quality hence stereo/HD cameras could be used for better processing and results.

Microphone is a basic sensor necessary for input audio information essential for Human Robot Interaction. Noise in the air is an important issue which needs to be catered for better input quality. Using Shotgun microphones having built in noise cancellers employing differential microphones topology, is one of the ways to achieve noise cancellation.

### IV. SOFTWARE ARCHITECTURE

In Robocup@Home, vocal input signals are used to give instructions to the Robots. These instructions may consist of sentences uttered by a human operator and interpreted by the Robot. These instructions have three sub categories:

a) *Questions:*

Question is a sentence through which a user enquire something from the Robot and requires a satisfactory answer.

b) *Information:*

Information is an instruction through which a human operator requires the Robot to store the specific info.

c) *Commands:*

Commands are set of instructions used by a Robot to execute and perform various tasks.

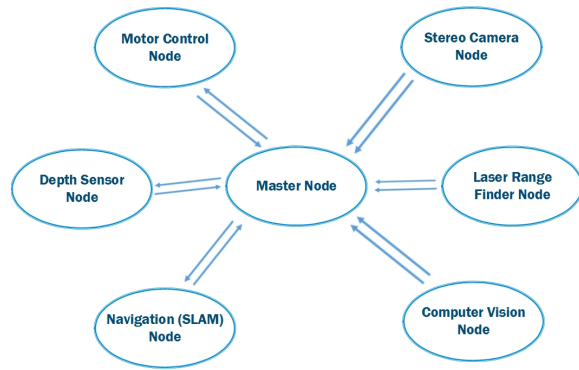


Fig. 3. A typical control system diagram of a Robot working in ROS

Processing of these instructions is divided into the following levels:

a) *Perception Level:*

This level is directly connected to the sensors which perceive information from the environment and apply specific algorithms depending upon the data perceived.

b) *Decision level:*

Decision level gets data from the perception level and makes decisions for the required tasks. This level is mainly responsible for Robot's behavior.

c) *Control level:*

This level interprets instructions from decision level and gives commands to the specific components for the manipulation of tasks precisely.

The most common approach used to develop the software architecture is to develop components or modules of the software and then connect them using either ROS [12], SitLog (Situation and logic) [13] or SmartSoft [14] etc. However, The platform most commonly used for this purpose is Robot Operating System (ROS). A typical control system diagram of a Robot working in ROS is shown in figure 3.

#### A. Face Recognition

Face Recognition is an important aspect in Human Robot Interaction, as it allows the Robot to interact with humans in a similar way as humans interact with each other. Detection and recognition is done by processing the data coming from the depth sensors and stereo cameras (if used). Detection is an essential part for recognition which is used to detect or find a human face while recognition is to recognize a face from a predefined set of facial images library.

Approaches to Face Recognition [15] include:

- i. Feature-Based Approach
- ii. Holistic Approach
- iii. Hybrid Approach

Holistic Approach is an appearance based approach [15] [16]. It uses holistic texture features that can be applied to whole or a portion of a face. Min-Eigen and Fisher Faces databases (holistic databases) have proved their efficiencies with large datasets. Earlier schemes of holistic features were only able to detect faces while recent holistic approaches with

HAAR like features can work under occlusion [17]. These techniques will go for whole face, not for some features like nose or eyes only. PCA and LDA [18] are examples of Holistic approach based algorithms.

Feature based approach[19] extracts useful features of a Human face. It works for geometric facial features (like eyes or Nose) and their relationship. As compared to Holistic approach this technique is less sensitive to image view point and its illumination. It does not depend upon localization of a face. Elastic bunch graph matching [20] and Face recognition using Gabor Wavelet Transform [21] are examples of feature based face recognition methods. Accuracy of feature based approach reduces rapidly due to any distortion or non-linearity by the image source. This issue, however, is not faced by Holistic approaches.

Hybrid approach is a combination of both Holistic and feature based approaches. Since hybrid approach combines the strengths of both Holistic and feature based approaches, it generally provides with a better performance. An example of a hybrid approach is Subspace LDA [22]. SLDA uses both PCA and LDA, where LDA is used as a classifier and dimension reduction is achieved using PCA.

HOG [23], SURF [24], SIFT [25] and Min Eigen Features [26] are mostly used by RoboCup@Home participants. HOG features are easy to use and are one of the basic approaches used for feature extraction. However, there efficiency might decrease in cases where there are a large number of images. SURF features are used by most of the teams in RoboCup@Home. Viola Jones [27] face detection is also one of the highly employed methods for face recognition. It uses min Eigen features for face detection and employs adaboost [28] which can fairly work in real time with some occlusion. With this method, human face, nose, upper body and eyes can be detected, if specified. If the above parameters are not specified, the algorithm will go for face detection by default, but one disadvantage of this algorithm is that the Eigen face differences in images are susceptible to variability and do not always provide a cent per cent accurate result.

To improve efficiency of the system, we can use different other methods with facial recognition techniques like Skin texture analysis [29]. Unique lines, patterns and spots are expressed as mathematical model. Different experiments have shown that this increase accuracy up to 20-25%[30].

For tasks in Robocup like 'follow me' or 'bring something', the tracking of detected and recognized faces is necessary. Cascade object detector based approaches such as Viola Jones [27] is used by most of the teams to track faces with varying thresholds. Cascade object tracker takes the geometric transform of the image from MS Kinect or a stereo camera. After transformation there are some outliers in the transform so one needs to remove these outliers because they act as noise. For this RANSAC [30] algorithm, Least Median Square method or MASC algorithm can be used to remove outliers. RANSAC [31] is used by most of the teams to remove outliers. One can adjust removal of points according to ones need. Finally faces are tracked based on these points (inliers). Kalman Filters [32]

are extensively used to predict the position of the face or any object that is not detected in the image for a small period of time.

### B. Object Recognition

MS Kinect is a depth sensor designed basically for gaming purposes but also used for various object recognition tasks. It gives a mirror and deep image as its output which are difficult to process or to apply algorithms directly and some pre-processing is required. One needs to convert these images to 2D or 3D images for processing. 3D point cloud [33] or ICR algorithm [34] are used to extract the planes. Object recognition can be divided into 2 categories.

#### i. Detection

Object detection module can be designed using SURF [24], SIFT [25], SVM Classifier [35], MOPED framework [36] or other methods, which have already been discussed in section 4a.

#### ii. Classification

Classification of an object is usually achieved by matching the shape of the object with existing data present with the host machine. This can be accomplished in various ways. For dynamic objects, occupancy grid map [37] is used. Opencv [38], LIBSVM [39], openNI [40], object Recognition Kitchen [41] are some libraries used for object tracking. For 3D object recognition Hough-transform voting scheme [42] is used by some after the extraction of point cloud data from Kinects output. The data then is clustered which can be done using DBSCAN [43] based approaches or Euclidean distance based clustering [44]. Neural networks based approaches also provide with promising results. Growing neural gas [45] approach can recognize unknown objects which were not used in training. It recognizes depending upon the maximum similarities of the unknown object with trained database.

Once the features are extracted and the objects have been classified, they are identified based on the measure of similarity with the objects in the existing databases. The system then identifies it with the object with the highest probability.

### C. Object Manipulation

Object manipulation is an important aspect in Robocup @Home which is used in tasks like lostnfound or fetchncarry etc. For manipulation of the environment, the robot uses its arm and gripper. The input of this module is coordinates of the place where the object is placed. To ensure that no collision occurs between the robot arm and its environment, path planning algorithms such as RRT [46] and PRM [47] as well as pre-built libraries are used. Commonly used obstacle avoidance libraries used for a robotic arm manipulation include MoveIt [48], object recognition stack in ROS [49] and OPML [50]. After picking the object the object is taken to its desired destination for placement. To identify whether an object has been placed, one solution would be to use the camera to check whether the object has touched the surface or not, which is

an expensive and difficult task to accomplish. This issue is resolved by using a force torque sensor attached to the gripper and looking for the force sensor to cross a predetermined threshold. Similarly to ensure that a gripper has effectively taken hold of the object before picking it up, ultraviolet sensors can be used. This minimizes or even removes the need for the use of a visual feedback.

### D. Navigation

Service robots should be able to navigate in both dynamic and static environments especially through narrow and cluttered paths. Localization is a fundamental need of an autonomous robot. For localization, an autonomous robot needs map of its surrounding, which is not known a-priori. Simultaneous Localization and Mapping (SLAM) is a common technique used to generate the map of the environment in which the robot intends to move. There are a lot of techniques for implementation of SLAM, such as Iterative Closest Points [51], probabilistic SLAM [52] [53] and Adaptive Monte Carlo Algorithm based approaches. Also many variations of Kalman filters such as EKF (Extended Kalman filter [54]), UKF (Unscented Kalman Filter [55] [56]) are employed in SLAM related problems to increase the efficiency and robustness of the algorithm. Adaptive Monte Carlo algorithms [56] are widely used for SLAM due to their robustness to measurements and accuracy.

Map development is achieved by merging the odometry data with the data of laser range finders. ROS navigation stack is also used for the development of the occupancy map. Adaptive Monte Carlo Localization (AMCL) [57], which is a probabilistic localization technique for a robot in 2D, is provided by the navigation stack, which is used for localization. Mobile Robot Programming Toolkit (MRPT) [58] is also a toolkit used by some for localization of a robot. Advanced Robotics Navigation and Localization System (ARNL) [59] is also used for path planning and localization. For developing a 2-D occupancy grid-map using laser scans, gmapping [60] [61], (whose wrapper for ROS is available) is used. To develop a 3D-occupancy grid-map using laser-scans, octomap [62] [63] (whose wrapper for ROS is available) is used. Zelinsky [64] path transform based approaches can be used to merge the changes dynamically happening in the environment in the existing occupancy map.

### E. Speech Recognition and Synthesis

Speech recognition is an important module in Robocup@Home as audio commands are given to the robot to instruct it to do certain tasks. In Robocup @Home, teams from different regions of the world sometimes use language processing tools built for their own respective languages. Several modules and software are available for different languages for example Julius [65] is used for Japanese language processing. Microsoft SDK [66], Vocon by Naunce [67], Pocket Sphinx by Carnegie Mellon University (CMU Sphinx) [68] [69], Loquendo [70] (Grammar based speaker independent) are some of the software used by

different teams for speech recognition, with CMU Sphinx being the most commonly used system due to the availability of its ROS package. Another approach by a team [8] was to use an android app employing Android Speech Synthesis and Recognition API, which then communicated with ROS packages on the robot. Festival [71] is used by almost all the teams of RoboCup@Home for speech synthesis, so that the robot could talk back to the person for an interactive human Robot experience.

## V. CONCLUSION

RoboCup@Home is an excellent initiative having a purpose to advance the state-of-the-art in the field of domestic service Robots. Every year the field advances with the complexity of the Robots increasing day by day. This paper briefly explains how such a domestic service Robot can be designed and discusses different techniques and approaches used by different teams in Robocup@Home. The purpose of the paper is to discuss the current trends in the development of such robots in Robocup@Home and to get a birds eye view of the assembly techniques as well software modules used in such a system. This is supposed to be helpful for other teams as well who intend to enter in the field of domestic service robots in general and the robots in Robocup@Home in particular.

## REFERENCES

- [1] Hiroaki Kitano, Minoru Asada, Yasuo Kuniyoshi, Itsuki Noda, Eiichi Osawai and Hitoshi Matsubara. RoboCup: A challenge problem for AI and robotics. *AI Magazine*, Vol18, No. 1. 1998.
- [2] Microsoft Developer Network, MS Kinect for Windows. Section 1.5, 1.6, 1.7, 1.8: Kinect for Windows Programming Guide. *Online Available: <https://msdn.microsoft.com/en-us/library/hh855348.aspx>* [Accessed: July 28, 2015]
- [3] ASUSTeK Computer Inc. Technical Staff, Quick Start Guide for ASUS Xtion PRO LIVE, ASUSTeK Computer Inc, 2011.
- [4] Vicky Gray-Clark, Ambient Public Relations, Depth Sensors Comparison, ipisoft.com, May. 13, 2013. *Online Available: [http://wiki.ipisoft.com/Depth\\_Sensors\\_Comparison](http://wiki.ipisoft.com/Depth_Sensors_Comparison)*. [Accessed July 28, 2015]
- [5] HUKOYU AUTOMATIC CO., LTD Technical Staff, Scanning Laser Range Finder, HUKOYU AUTOMATIC CO., LTD, 2009.
- [6] SICK Sensor Intelligence Technical Staff, My Sick Laser Range Finder, SICK Sensor Intelligence.
- [7] Max Schwarz and Sven Bhenke. "Nimbro@Home Team Description for the RoboCup 2015 Competition", 2015.
- [8] Viktor Seib et. al. Robocup 2015 Team Description Paper homer@Unikoblenz (Germany)
- [9] Yaskawa Electric Corporation Technical Staff, Katana-Automation made easy, Yaskawa Electric Corporation,
- [10] UNIVERSAL ROBOTS Technical Staff, UR6 Robotic Arm, UNIVERSAL ROBOTS, 2005.
- [11] Trossen Robotics Technical Staff, TurtleBot Robotic Arm, Trossen Robotics.
- [12] Quigley, Morgan, et al. "ROS: an open-source Robot Operating System." ICRA workshop on open source software. Vol. 3. No. 3.2. 2009.
- [13] Pineda, Luis A., et al. "SitLog: A Programming Language for Service Robot Tasks." *International Journal of Advanced Robotic Systems* 10 (2013): 538.
- [14] Christian Schlegel and Robert Worz. The Software Framework SmartSoft for implementing Sensorimeter Sytems. In the Proceedings of IEEE/RSJ International Conference on Intelligent Robots and Systems, 1999.
- [15] G. M. Zafarruddin, H.S.Fadewar, Face Recognition: A Holistic Approach Review, *Contemporary Computing and Informatics (IC3I)*, 2014 International Conference on, vol.,no.,pp.175,178, 27-29 Nov, 2014.
- [16] K.M. Lam and H. Yan An Analytic-to-Holistic Approach for Face Recognition Based on a Single Frontal View. In *IEEE Transactions on Pattern Analysis and Machine Intelligence*, vol. 20, no. 7, July 1998.
- [17] Nasrollahi, K. and Moeslund, T.B., Haar-like Features for Robust Real-time Face Recognition, 20th IEEE International Conference on Image Processing (ICIP). VIC Melbourne, Sept 2013.
- [18] Sudarshan, D.S.; Pooja, D.S.; Sachin, S.S., "Pose Variant Based Comparative Analysis of PCA and LDA," *Emerging Trends in Engineering and Technology (ICETET)*, 2009 2nd International Conference on, vol., no., pp.188,191, 16-18 Dec. 2009.
- [19] Manjunath, B.S.; Chellappa, R.; von der Malsburg, C., "A feature based approach to face recognition," *Computer Vision and Pattern Recognition*, 1992. Proceedings CVPR '92., 1992 IEEE Computer Society Conference on, vol., no., pp.373,378, 15-18 Jun 1992.
- [20] Wiskott, L.; Fellous, J.-M.; Kuiger, N.; von der Malsburg, C., "Face recognition by elastic bunch graph matching," *Pattern Analysis and Machine Intelligence*, *IEEE Transactions on*, vol.19, no.7, pp.775,779, Jul 1997
- [21] Kepenekci B (2001) Face recognition using Gabor wavelet transform. Technical Report, Department of electrical and electronic engineering, The Middle East Technical University.
- [22] Jian Huang; Yuen, P.C.; Wen-Sheng Chen, "A novel subspace LDA algorithm for recognition of face images with illumination and pose variations," *Machine Learning and Cybernetics*, 2004. Proceedings of 2004 International Conference on, vol.6, no., pp.3589,3594 vol.6, 26-29 Aug. 2004.
- [23] Dalal, N.; Triggs, B., "Histograms of oriented gradients for human detection," *Computer Vision and Pattern Recognition*, 2005. CVPR 2005. IEEE Computer Society Conference on, vol.1, no., pp.886,893 vol. 1, 25-25 June 2005.
- [24] Bay, H.; Ess, A.; Tuytelaars, T. & Gool, L. V. (2008), 'SURF: Speeded Up Robust Features', *Computer Vision and Image Understanding (CVIU)* 110, 346-359.
- [25] David G. Lowe, "Distinctive image features from scale-invariant keypoints," *International Journal of Computer Vision*, 60, 2 (2004), pp. 91-110
- [26] Swets, Daniel L., and John Juyang Weng. "Using discriminant eigenfeatures for image retrieval." *IEEE Transactions on Pattern Analysis & Machine Intelligence* 8 (1996): 831-836.
- [27] Viola, Paul, and Michael Jones. "Rapid object detection using a boosted cascade of simple features." *Computer Vision and Pattern Recognition*, 2001. CVPR 2001. Proceedings of the 2001 IEEE Computer Society Conference on. Vol. 1. IEEE, 2001.
- [28] Viola, Paul, and Michael Jones. "Fast and robust classification using asymmetric adaboost and a detector cascade." *Advances in Neural Information Processing System* 14 (2001).
- [29] Drimborean, Alexandru F., et al. "Image processing techniques to detect and filter objectionable images based on skin tone and shape recognition." *Consumer Electronics*, 2001. ICCE. International Conference on. IEEE, 2001.
- [30] M.-H. Yang, D.J. Kriegman, N. Ahuja, "Detecting Faces in Images: A Survey" *IEEE Transactions on Pattern Analysis and Machine Intelligence*, Vol. 24, No. 1, January 2002, pp. 34-58
- [31] Chen, Chu-Song, Yi-Ping Hung, and Jen-Bo Cheng. "RANSAC-based DARCES: A new approach to fast automatic registration of partially overlapping range images." *Pattern Analysis and Machine Intelligence*, *IEEE Transactions on* 21.11 (1999): 1229-1234.
- [32] Sorenson, Harold Wayne, ed. *Kalman filtering: theory and application*. IEEE, 1960.
- [33] Rusu, Radu Bogdan, and Steve Cousins. "3d is here: Point cloud library (pcl)." *Robotics and Automation (ICRA)*, 2011 IEEE International Conference on. IEEE, 2011.
- [34] Ko, Jaepil, Eunju Kim, and Hyeran Byun. "A simple illumination normalization algorithm for face recognition." *PRICAI 2002: Trends in Artificial Intelligence*. Springer Berlin Heidelberg, 2002. 532-541.
- [35] Chapelle, Olivier, Patrick Haffner, and Vladimir N. Vapnik. "Support vector machines for histogram-based image classification." *Neural Networks*, *IEEE Transactions on* 10.5 (1999): 1055-1064.
- [36] Collet, Alvaro, Manuel Martinez, and Siddhartha S. Srinivasa. "The MOPED framework: Object recognition and pose estimation for manipulation." *The International Journal of Robotics Research* (2011): 0278364911401765.
- [37] Thrun, Sebastian. "Learning occupancy grid maps with forward sensor models." *Autonomous robots* 15.2 (2003): 111-127.

- [38] Bradski, Gary. "The opencv library." *Doctor Dobbs Journal* 25.11 (2000): 120-126.
- [39] Chang, Chih-Chung, and Chih-Jen Lin. "LIBSVM: A library for support vector machines." *ACM Transactions on Intelligent Systems and Technology (TIST)* 2.3 (2011): 27.
- [40] Villaroman, Norman, Dale Rowe, and Bret Swan. "Teaching natural user interaction using OpenNI and the Microsoft Kinect sensor." *Proceedings of the 2011 conference on Information technology education*. ACM, 2011.
- [41] Willow Garage Inc. *Object Recognition Kitchen Online Available: [http://wg-perception.github.io/object\\_recognition\\_core/](http://wg-perception.github.io/object_recognition_core/)* [Accessed July 29, 2015]
- [42] Fernandes, Leandro AF, and Manuel M. Oliveira. "Real-time line detection through an improved Hough transform voting scheme." *Pattern Recognition* 41.1 (2008): 299-314.
- [43] Birant, Derya, and Alp Kut. "ST-DBSCAN: An algorithm for clustering spatialtemporal data." *Data & Knowledge Engineering* 60.1 (2007): 208-221.
- [44] Jain, Anil K., M. Narasimha Murty, and Patrick J. Flynn. "Data clustering: a review." *ACM computing surveys (CSUR)* 31.3 (1999): 264-323.
- [45] Fritzsche, Bernd. "A growing neural gas network learns topologies." *Advances in neural information processing systems* 7 (1995): pp 625-632.
- [46] Kuffner, James J., and Steven M. LaValle. "RRT-connect: An efficient approach to single-query path planning." *Robotics and Automation, 2000. Proceedings. ICRA'00. IEEE International Conference on*. Vol. 2. IEEE, 2000.
- [47] Kavraki, Lydia E., et al. "Probabilistic roadmaps for path planning in high-dimensional configuration spaces." *Robotics and Automation, IEEE Transactions on* 12.4 (1996): 566-580.
- [48] Sucan, Ioan A., and Sachin Chitta. "Moveit!." *Online Available: <http://moveit.ros.org>* (2013).
- [49] Viktor Seib, "Object\_recognition" *Online Available: [http://wiki.ros.org/object\\_recognition](http://wiki.ros.org/object_recognition)* [Accessed July 29, 2015].
- [50] Sucan, Ioan, Maciej Moll, and Lydia E. Kavraki. "The open motion planning library." *Robotics & Automation Magazine, IEEE* 19.4 (2012): 72-82.
- [51] Nehter, Andreas, et al. "6D SLAM 3D mapping outdoor environments." *Journal of Field Robotics* 24.89 (2007): 699-722.
- [52] Brunskill, Emma, and Nicholas Roy. "SLAM using incremental probabilistic PCA and dimensionality reduction." *Robotics and Automation, 2005. ICRA 2005. Proceedings of the 2005 IEEE International Conference on*. IEEE, 2005.
- [53] Durrant-Whyte, Hugh, and Tim Bailey. "Simultaneous localization and mapping: part I." *Robotics & Automation Magazine, IEEE* 13.2 (2006): 99-110.
- [54] Huang, Shoudong, and Gamini Dissanayake. "Convergence and consistency analysis for extended Kalman filter based SLAM." *Robotics, IEEE Transactions on* 23.5 (2007): 1036-1049.
- [55] Martinez-Cantin, Ruben, and Jose Castellanos. "Unscented SLAM for large-scale outdoor environments." *Intelligent Robots and Systems, 2005.(IROS 2005). 2005 IEEE/RSJ International Conference on*. IEEE, 2005.
- [56] Chen, S. Y. "Kalman filter for robot vision: a survey." *Industrial Electronics, IEEE Transactions on* 59.11 (2012): 4409-4420.
- [57] Adaptive MONTE Carlo Localization *Online Available: <http://wiki.ros.org/amcl>* [Accessed July 29, 2015]
- [58] The Mapir Group, *Mobile Robot Programming Toolkit [Online] Available: <http://mrpt.org>* (2013) [Accessed July 29, 2015]
- [59] ADEPT MOBILEROBOTS LLC, *Advanced Robotics Navigation and localization System (ARNL), Online Available: <http://www.ing.unibs.it/~arl/docs/documentation>* [Accessed July 29, 2015]
- [60] Dedre Gentner, *Gmapping, Online Available: <http://wiki.ros.org/gmapping>* [Accessed July 29, 2015]
- [61] Stachniss, C., and G. Grisetti. "GMMapping project at OpenSLAM. org." (2007).
- [62] Octomap 3D occupancy Grid Mapping Approach *Online Available: <http://wiki.ros.org/octomap>* [Accessed July 29, 2015]
- [63] Wurm, Kai M., et al. "OctoMap: A probabilistic, flexible, and compact 3D map representation for robotic systems." *Proc. of the ICRA 2010 workshop on best practice in 3D perception and modeling for mobile manipulation*. Vol. 2. 2010.
- [64] Zelinsky, Alexander. "Environment exploration and path planning algorithms for mobile robot navigation using sonar." (1991).
- [65] Lee, Akinobu, Tatsuya Kawahara, and Kiyohiro Shikano. "Julius—an open source real-time large vocabulary recognition engine." (2001).
- [66] Norberto Pires, J. "Robot-by-voice: Experiments on commanding an industrial robot using the human voice." *Industrial Robot: An International Journal* 32.6 (2005): 505-511.
- [67] Nuance Communication, Inc. *Speech Recognition Solutions, Online Available: <http://www.nuance.com/for-individuals/by-solution/speech-recognition/index.htm>* Nuance Communication, Inc. [Accessed July 29, 2015]
- [68] Lamere, Paul, et al. "Design of the CMU sphinx-4 decoder." *INTER-SPEECH*. 2003.
- [69] Carnegie Mellon University. "PocketSphinx". *Online Available: <http://wiki.ros.org/pocketsphinx>* [Accessed July 29, 2015]
- [70] Dalmaso, Emanuele, et al. "Loquendo-Politecnico di Torino's 2008 NIST speaker recognition evaluation system." *Acoustics, Speech and Signal Processing, 2009. ICASSP 2009. IEEE International Conference on*. IEEE, 2009.
- [71] Taylor, Paul, Alan W. Black, and Richard Caley. "The architecture of the Festival speech synthesis system." (1998).