A Cognitive Model for Humanoid Robot Navigation and Mapping using Alderbaran NAO

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Abstract The aim of this work is to build a cognitive model for the humanoid robot, especially, we are interested in the navigation and mapping on the humanoid robot. The agents used are the Alderbaran NAO robot. The framework is effectively applied to the integration of AL computer vision, and signal processing problems. Our model can be divided into two parts, cognitive mapping and perception. Cognitive mapping is assumed as three parts, whose representations were proposed – a network of ASRs, an MFIS, and a hierarchy of Place Representations. On the other hand, perception is the traditional computer vision problem, which is the image sensing, feature extraction and interested objects tracking. The points of our project can be concluded as the following. Firstly, the robotics should realize where it is. Second, we would like to test the theory that this is how humans map their environment. The humanoid robot inspires the human vision searching by integrating the visual mechanism and computer vision techniques.

Keywords Humanoid Robot; Absolute Space Representations; Memory for one’s Immediate Surroundings

I. Introduction

As we are ushered into a new era, humanoid robots are seen to have many applications in many fields, such as blind people guiding, automatic driving and geological exploration and so on. A key aspect to the success of these robots is the ability to autonomously navigate through the environment. To do this, the robot must have the ability to map the environment using its sensors and reason about it to perform optimal functions, such as path planning and task planning. There are many approaches a robot might use to implement this functionality, broadly, they categories into cognitive (biologically grounded) model and non-cognitive models. Our experimental robotics platform is the Alderbaran NAO robot, which is an autonomous, programmable, medium-sized humanoid robot, developed by Aldebaran Robotics. These humanoid robots see the world as a series of connected spaces. These spaces are initially mapped as an occupancy grid in a room by room fashion. Briefly speaking, occupancy grid maps are a popular approach to represent the environment of a mobile robot given known poses. In addition, humanoid robots typically move in a non-linear mode, unlike wheeled robots, which are smooth and linear. As the robot leaves a space, denoted by passing through a doorway, the grids are converted to a polygonal representation. This polygonal representation is stored as rooms and hallways as a set of Absolute Space Representations (ASRs) representing the space connections.

Using this representation makes navigation and localization easier for the robot to process. An Absolute Space Representation or abbreviated as ASR, is a cognitive mapping technique used to build models of rooms or spaces visited. Absolute space comes from the idea that the representation for each space should be independent of all other spaces. Also, humans view the world cognitively and so should our robots. This research will pursue a cognitive approach, specifically framing the problem around Absolute Space Representations, as explained in the following sections.

II. Related Work and Background

The background could be broken down into several stages. Firstly, the initial conception is “bio-mimetic models”, biomimetics is the study of biological mechanisms and processes for the purpose of synthesizing similar mechanisms and processes by artificial mechanisms. Biomimetic navigation applies biological spatial theories to mobile robots. This model can be mapped into cognitive model. Cognitive model is an approximation t-o animal cognitive process for the purposes of comprehension and prediction. Our cognitive models focus on the navigation and mapping of humanoid robots. In this idea, a computational model that requires extensive computational resources to study the behavior of a complex system by computer simulation is used to construct an engineered model. While in this model, there are a lot of notable spatial representation methods, such as RTR (reaction triggered response), SUR (survey navigation), TOP (topological navigation), NUNO (neurological model), PSYC (psychological model), TPG (topological place graph), TVG (topological view graph), SNN (self-organizing neural network), ASR (abstract space representation), FSQT (free space quad-tree), FSOC (free space occupancy grid), FSGP (free space pyramid grid), V(vision sensor), PV (panoramic vision sensor), SV (stereo vision sensor), UL (ultrasound sensor), PUL (panoramic vision sensor), RIA (robotic implementation), RS (robotic simulation), CS (computer simulation) and so on [1][2][6][7][9]. Generally, our humanoid robots rely on maps localization, path planning, activity planning and so on, and mapping involves using the given sensor data (in this project...
we give the vision sensor data to the cognitive model) to calculate the most likely map, while this procedure could be denoted as the simultaneous localization and mapping problem (SLAM) [5].

Simultaneous localization and mapping (SLAM) is a technique used by robots and autonomous vehicles to build up a map within an unknown environment (without a priori knowledge), or to update a map within a known environment (with a priori knowledge from a given map), while at the same time keeping track of their current location [10]. Alternatively speaking, concurrent mapping and localization refers that humanoid robots constructs a map in an unknown environment without knowing its current position, and self-positioning and navigating based on the map simultaneously. While SLAM problem, which can be described as, the robots start moving from an unknown position, localize itself based on the position estimation and sensor data during the moving process, and create incremental map simultaneously [11]. The latest SLAM technique [15] could be referred from a paper: Simultaneous Localization and Mapping for Pedestrians using only Foot-Mounted Inertial Sensors”, the author claimed “FootSLAM” [12] with stable relative positioning accuracy, another advanced algorithm of SLAM on detection and tracking of moving objects as we illustrated in figure 1. These latest techniques are good complements to the model construction. My conclusion is that, the SLAM would be useful by treating your home as a warehouse. To fulfill the midterm goal, the ability to interact with human is the key. Robots need to be smart, which means react quicker at least, safer, and softer. Therefore, borrow ideas from biological neural systems is the key to success, especially in vision. Beside this, computer vision can also to help sort out object recognition, handling, understand the scenes (for example, to know if a person is in normal status or in emergency so may need to call a doctor) etc, which is also the critical technique to future robots.

III. Motivation and Research Problems

As we mentioned in the background, the most imperative motivation is to implement a cognitive model on a humanoid robot. For example, humans have the capacity to receive and process enormous amounts of sensory information from the environment, integrating complex sensory. Most goal-oriented robots currently perform only those or similar tasks they were programmed for and very little adaptability in behavior selection are exhibited. What is needed is an alternative paradigm for task learning and execution. Specifically, we see cognitive flexibility and adaptability in decision-making in our brain as a desirable design goal for the next generation of intelligent robots. For example, human decision-making is strongly influenced by our internal states such as emotions. A change in internal states results in changes in which we perceive which goals are more important. One of the goals of our humanoid research is to enhance the potential robustness of the grounds. And we would like to test the theory that this is how humans map their environments. Additionally, it presents an effective way to dealing with the non-linear motion of a humanoid robot. There are a lot of non-linear motion ways, such as cognitive robot mapping with poly-lines and so on. Last but not least, due to the increasing size of environments, ASR starts to approach maximum constraints. Overcoming these constraints remains a challenge even today in computer science. The above listed points comprise our motivation. Still, there existed some research questions as depicted below.

The previous research of humanoid robots is usually armed with sonar and odometry. But in our project, the main problem that we are pursuing is that “can the ASR cognitive theory modeled to work with vision sensors and implemented on a humanoid robot?” If this works, we need to further evaluate the robustness of this model, for instance, it is size scalable, with a non-increasing computational time required to map and a linearly increasing computational time required to reconstruct the ASRs after completion of mapping. But when the humanoid robot goes into a complex and complicated situation, does this assumption still work?

Such problems could also be raised as the following, for example, can the model recognize locations when it approached and viewed from different directions? Sometimes we need manually adjust rotation error among the ASRs but it is not the ideal cases. Or sometimes the robots will drop into an endless cycle, our cognitive model on a humanoid robot could walk out of this circle and recognize the locations and landmarks when it goes into another directions. Or can we use vision as the principle sensor or we might need to include other internal sensors, because usually input is an inclusive of olfactory, tactile, vision sensor data and so on, if we use vision sensor only, would the humanoid robots still work so efficiently as usual? Can the model robustly handle a variety of static environments due to the data overflow? Can the model robustly handle a variety of dynamic environments, this situation is quite similar to the mean-shift algorithm, sometimes we could not track the object because of fast-moving objects, can the model have low computational complexity since this is the problem haunted us for many years, and can the model run in real-time so it can be used in practical application? Such problems could be looked after in this project and we could raise other questions depending on the different models. In order to circumvent these potential problems, we should set up a proposed framework and modify it during this project.

IV. Methodology and Proposed Framework

As displayed in figure 1, the prerequisite of a cognitive model is the perception parts, which indicate vision sensor input. Then, our cognitive mapping process will generate a local space which can be formally called ASR. These ASRs could be represented as a network. Simultaneously, MFIS (memory for one’s immediate surrounding) is another representation of the existing model. The MFIS maintains a global co-ordinate system centered upon the current ASR to describe the positions of some ASRs adjacent to its current ASR. In addition, ASR is dynamic, the initial condition is to generate the ASR using a vision sensor, then our algorithm will track them when they are moving, if the object walks out of the boundary, a new ASR is formed and the interior link will be established between the new and the previous ASR [8].
Figure 1. Assumed model of cognitive mapping: Three key representations were proposed — a network of ASRs, an MFIS, and a hierarchy of Place Representations.

The dominant input is the vision sensors which are embedded on the humanoid robots. Then the problems convert to the object detection. Broadly speaking, the first step for image preprocessing is the histogram equalization. The goal is to eliminate the influence of different light conditions. Different light conditions will cause the intensity histogram of image to be concentrated in some different ranges. The histogram equalization is used to spread out the intensity and make the image easier for analysis. The second step is to convert the gray scale image into binary image by using the Sobel edge operator and other similar functional operators because the detection model relies on the binary image (only black and white). The third step is to convert pixel-based binary image into an object-oriented binary image. In this step, all the 8-connectivity pixels are grouped into one object, and marked by using the same number. After the preprocessing, a binary image with the marked objects is obtained. Image taken from a moving humanoid robot is gray-scale and pixel-based, i.e. the pixels in the image are represented by the intensity values between 0 and 1. In the detection model, a preprocessing step should be taken before three criteria are employed to select potential objects. After image preprocessing, according to the features of the object, or specifically the vehicle, three criteria will be employed to select potential objects from the entire image. Finally, the potential object is marked by using a bounding box and the equalized intensity image of the object is sent to the recognition model. After we target the object, the second process is to extract the features and track it until a new ASR is generated. Generally, there are lots of techniques to extract an object, such as shape-based methods, edge detection, motion detection, scale-invariant feature transform and so on. And video tracking is the process of locating a moving object over time using our vision sensor. The objective of video tracking is to associate target objects in consecutive video frames. The association can be especially difficult when the objects are moving fast relative to the frame rate. These difficulties will also be considered into our project. Based on the previous research, the successful target representation and localization algorithms could be concluded as following methods. Blob tracking is segmentation of object interior. Kernel-based tracking which can be also named as mean-shift tracking, is an iterative localization procedure based on the maximization of a similarity measure. And Contour tracking is detection of object boundary. Probably contour tracking algorithm would be imported into our project because sometimes the humanoid robot might be walk out of our virtual space. This is related to the construction of ASR as we depicted in the following parts.

Essentially, the cognitive model as we illustrated in the figure can be summarized as these features [3].

1. At the perceptual level, the vision sensor delivers its output as input to the cognitive mapping process. Outputs from other sensors might be added to it whenever they become available. Image processing and feature extraction and video tracking will surely be implemented in the perception parts.

2. The cognitive mapping process takes each spatial view as input and constructs a description of a local space into which the cognitive agent resides. This local space is referred to as an absolute space representation (ASR).

3. Using the ASRs computed, two representations are maintained in parallel. One is known as a Memory for one’s Immediate Surroundings (MFIS) and the other, a network of ASRs visited.

4. The MFIS maintains a global co-ordinate system centered upon the current ASR to describe the positions of some ASRs adjacent to its current ASR. When the individual moves out of the current ASR into another ASR, the MFIS will be refreshed to show a new display of ASRs centering on the ASR just entered. It is expected that the actual number of ASRs displayed will be affected by factors such as individual’s memory capacity, processing capacity, complexity of individual ASR computed, and others.

5. Together with the MFIS, a network of ASRs is also being computed. The network shows how ASRs visited are connected locally. In other words, the network is not described using a global co-ordinate system. Each ASR has its own local co-ordinate system and ASRs are connected usually via the exits the agent used to move between them. Consequently, some of the ASRs re-visited might not be recognized and perceptual induced errors could result in not knowing the correct locations of most ASRs that are not adjacent.

6. An abstraction process will group ASRs in the network to form a conceptual description of a place. Such place representations are then organized as a hierarchy of places to indicate different levels of abstractions. Note that the nodes in the hierarchy do not need to be restricted to spatial ones alone.
V. Experimental Results

This section presents a robot path simulation in the indoor environment. We found the proposed system works well guided by visual cues based on the MFIS and ASR modules. The navigation and map paths as indicated in figure 2. A quantitative comparison is given in figure 3.

![Figure 3](image1)

Figure 3. The trajectory for the path performed by Alderbaran NAO robot, the blue path shows 12% error compared with the red curve, while its the ground-truth data obtained by manual labeling, where the starting point is the bottom-right corner.

![Figure 4](image2)

Figure 4. Average absolute error with time in seconds by Alderbaran NAO robot, the green one is traditional SLAM while the blue one adopts the MFIS and ASR modules, which performs a better accuracy than SLAM.

VI. Conclusion and Future Work

The primary goal of the current research is to explore what insights can be gained by combining cognitive modeling and robotics. The need of a cognitive model for humanoid robot navigation and mapping is of great importance to humanoid robots research. Until now, even this project has been researched for many years. There still existed a lot of problems and we are facing up with many bottlenecks. Our work tried to set up a cognitive model under an unknown environment. Firstly, the robotics should realize where it is. Also visual feature will replace the noise feature when it used sonar to detect the object. Feature matching is a key technique in this project [13]. The robustness of our cognitive model by using vision sensor is the research emphasis. Moreover, we would like to test the theory that this is how humans map their environment. While using vision sensor, it can present an effective way to dealing with the non-linear motion of a humanoid robot. And the suggested questions will be solved in the prospective research. Our working scheme was illustrated in the proposed framework. Inevitably, there might be a little change due to the real case, but the substance of the working flowchart will instruct the cognitive model of humanoid robots navigation and mapping. In short, combining a cognitive model and a humanoid robot is a challenging task, because there is a strong relationship between higher and lower levels of cognition. Also, if there is one thing the current project has shown, it is that cognitive models are a long way from moving around in the real world as humans do. However, there is no reason to become pessimistic, as it certainly seems possible. A lot of future research has to be done, but it is certain that the work of combining cognitive models and robotics will be very rewarding.

References