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Colloquium Paper

Motion Planning For Real World Robots

I chose to watch an online colloquium by Doctor Kris Hauser which covered the topic of motion planning. The basic concept of motion planning requires understanding of a few additional concepts. The first is the initial condition. The initial condition refers to a present state — in referring to real world robots, this could include factors such as an initial velocity, or perhaps the location and perceived states of surrounding objects. This initial condition is then used as an input into some sort of objective function or path which describes a system or motion which is being optimized. Furthermore, this function will have some sort of terminal condition which we are hoping to achieve, as well as some constraints on what we have available to us, and some derivative constraints on the motion or system. This whole function can be described using the following generic formula:

$$min_x \int_0^1 J(x(u))\,\mathrm{d}u. + \Phi(x(1)))s.t. \qquad \textit{objective}$$

$$x(0) = x_0 \qquad \textit{initial condition}$$

$$x(1) \in G \qquad \textit{terminal condition}$$

$$x(u) \in F \text{for all } u \in [0, 1] \qquad \textit{kinematic constraints}$$

$$x'(u) \in D(x(u)) \text{for all } u \in [0, 1] \qquad \textit{dynamic constraints}$$

The concept is often visualized using some sort of abstract space in which we are trying to get from point a to point b. This abstract space contains some sort forbidden region, and a feasible region as well. The feasible region is the set of all solutions which satisfies your constraints, while the set of all solutions which *fail* to satisfy those constraints falls into the forbidden region. Although this basic concept may apply to regions of study outside of motion planning, we can uniquely specify that robotic motion planning seeks to find global solutions to this problem rather than local ones, as well as being limited by more complex restraints than many other areas of study.

Today, with the advent of cheaper actuators and sensors, we are able to actually build cheap robots. This has rapidly moved the field of motion planning from theory into reality. Sensors such as the Microsoft connect allow us to discover and investigate many new real world challenges. For example, the complexity of our robots has skyrocketed in recent times. This can be seen by the Baxter robots that many labs are beginning to see. These robots have a full 12 degrees of freedom. Furthermore, we now also have to deal with the vast amounts of data that our improved sensors are bringing into the robot. This is beginning to go past visual information and move into tactile and other fields of information. In addition to the new sensor data, we have improved algorithms for analyzing our data. A great example of this is the Google Goggles program. Which allows us to send visual information about objects to the algorithm and returns all sorts of data about what it is and how we may then interact with the objects. This now moves our models beyond three dimensions to also include this semantic information. Beyond this, we have to consider motion uncertainty. This means that things will not always move and react in the real world as they might in lab. Wind can create variations in the movement of our robots as well as friction or deformations; this uncertainty could even come from inputs as mundane as carpet bunching up beneath us. All of these, and more cause a much higher degree of complication when working in the real world rather than in theory and lab.

Doctor Hauser worked on a team to develop ladder claiming humanoid robots for the DARPA Robotics Challenge. The Robotics Challenge seeks to: "develop ground robotic capabilities to execute complex tasks in dangerous, degraded, human engineered environments". This hopes to to allow for example robots which can interact with the environments at natural disaster scenarios. Doctor Hauser and his team work on a sub-capability of the Challenge's 8 overarching goals – just the ladder climbing functionality. Within the United States, the most common and readily available humanoid robot was the DRC HUBO. Because of its predominance in the US, Dr. Hauser and his team decided to utilize this robot so that many different teams could work together on the same robots without actually using the same physical robot. However Dr. Hauser and his team soon discovered that the Robot need more freedom in its arms and torso in order to complete the tasks set forth. Consequently, the team had to work with the DRC HUBO Design and engineering teams in order to create a new HUBO which had greater dexterity in its wrists, as well as longer and stronger arms and hands.

After developing the newer and more capable DRC HUBO, Dr. Hauser's team soon realized that simply modeling the movements of the robot around the equivalent human actions would not be plausible. In regards to climbing a ladder, the team quickly realized the complexity of a humans approach to this problem. Humans take advantage of spring and force coming from their toes and feet. Humans utilize complex momentum based on sensory inputs. And finally, humans move quickly to avoid what would otherwise boil down to a one legged squat for each rung. However the HUBO cannot do this. The challenges of developing human movement were to great. Instead the team approached the problem like a motion planning problem.

There are numerous constraints that then come into play when looking at the ladder as a motion problem. The team had to consider whether or not the robot would be able to handle the high levels of torque required to bring the robot up each step. They had to also consider collision avoidance. Finally, they had to consider which motions keep it balanced, and how that is effected by where its contact points are. The team was able to input all of these constraints and develop a motion planning problem around them for a given step. This is a full body coordination problem. Meaning they had to coordinate and plan the motions of all 30 joints in the robot as well as additional points of rotation not considered a joint. In approaching this problem, the team had to test all sorts of limits on the robot as well. They were able to test for points of friction which help to keep the robot grounded. They were able to test the torque limits in order to evaluate the maximum levels of stress that each joint can sustain, as well as testing the torque capabilities of each joint in order to ascertain the amount of torque that these joints can output. Because of all the constraints and inputs. Rather than looking at the introductory two dimensional representation of a motion planning problem. The team was working within a subspace of a 36-dimension space dictated by the limitations and characteristics of all the joints and other robotic factors.

Because of this approach, the team was able to apply some traditional sampling based approaches to motion planning problem solving in order to get them started. They were able to apply either the probabilistic roadmap approach or the rapidly expanding random trees algorithm in order to "plan from point a to point b". By repeating this process over and over again, the motions will eventually converge to something that is feasible, but for lack of a better description, the robot eventually looks like a drunk college student rather than a highly tuned and balanced robot. This was not the teams goal. So, instead they applied a strategy that Dr. Hauser had utilized in previous projects. They applied a "motion primitive adaptation". This meant that rather than developing the whole system at once with the aforementioned techniques, they developed each individual motion in a manner that appeared more natural and intuitive to the designers. These motions include things such as shifting the center of mass over different feet, releasing and grabbing new handholds, moving one foot up one step, etc. Each of these then can become a basis for how a new problem can be sampled and modeled. A variation of the system could be differing rung spacing or frictional coefficients for example. To do this, we can take the motion primitive, map it to the new problem, and then detect the points of inefficiency or failure, and then patch these specific points.

Applying this to multiple steps rather than one, once again increases the complexity of the problem. Often, with multiple steps, the robot is forced to back-step or undo previous steps during planning due to various functional dead ends. In other words, the choices made during one step, effect the robots ability to perform subsequent steps. Without proper planning, this would mean that the robot would have to climb all the way down the ladder and start over again. In order to avoid this problem, the team actually plans and models the path all the way to the top of the ladder prior to executing steps using this backtracking search method. Interestingly, the robot utilizes very minimal feedback control currently. Instead, it relies heavily on its planning abilities to set itself up for success rather than attempting to adapt to unforeseen obstacles.

By using one set of generic motion primitives, the robot was able to climb a variety of stairs and ladders. Unfortunately, because the nature of the set up and planning, the team was not able to physically test all of the various ladders discussed. Instead they were able to physically test on a primitive stair case system, and then were able to adapt a simulation to the other ladder systems. Thus the team can still conclude the robots capability without expending the needless time in order to set up each new scenario.

Finally, the team was able to compete in the DARPA Robotics Challenge. Dr. Hauser's team was the only American Ladder climbing team able to climb more than 1 rung of the ladder. Furthermore, they were the only team originally registered which was able to climb without specific modifications to the ladder. Unfortunately, Dr. Hauser's team (the other development teams approaching the 7 other tasks) was not able to preform as well on the other 7 tasks, and thus they did not move to the next round of the competition.

I personally am an Electrical and Computers student emphasizing in robotics. Thus this presentation was quite interesting for me. I found it to be incredibly interesting how the team was able to develop a technique which looked so much more fluid than they would have been able to develop by modeling off of humans. Even more interesting about their approach is that it required the robot to approach the ladder "rear end first". This is really quite cool because it is something really requires some creative thinking and experimentation. Not only does the backwards approach lend to a more successful climb, but it also shows the expanded capabilities of robots. This worked because the robot had the proper dexterity as well as the ability to rotate its head a full 360^{o}, thus allowing it to simply look over its shoulder.

The difficult aspect of the robotics industry is how easy humans make these tasks seem. For example, in this ladder climbing problem, it took a team of world class engineers and researchers months of time to develop just the software needed to climb 8 rungs of ladder. A human can complete this task with little to no training in seconds. Even with the team of geniuses at its side, the HUBO robot took a full 30 minutes to climb the given 8 rungs of ladder. As much as this seems like a point of frustration though, I also see it as an opportunity for expansion in the robotics field. If we can get just a few more things working with new methods and techniques, it seems as though the field of robotics is primed to conquer new functions.