Stockholm May 2006

2D1426 Robotics and Autonomous Systems

Name: ______________________________

Person number: ______________________________

The written exam carries a credit of 50 points corresponding to 50% of the final grade for the course. Questions 1-4 carry 9 points credit each and question 5 carries a credit of 14 point. The total time to complete the exam is at most 3 hours. Please read the entire exam before preparing the answers to make sure that you have a good view of the questions to be answered. Enjoy!

1. The control of a robot is at least for simple motion controlled using a kinematic model. Each robot model has its own kinematic structure. The most common model is the differential drive robot. a) describe/derive the basic kinematic model for a differential drive robot, b) why is the model expressed in velocity and not in pose coordinates?

a) The kinematic model for a vehicle describes the relation between the velocity of the vehicle and control of the actuators. I.e., for a two-wheel differential drive system with wheel motion ω_r and ω_l respectively the kinematic model is a mapping to

$$f : \begin{bmatrix} \omega_l \\ \omega_r \end{bmatrix} \rightarrow \begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{\theta} \end{bmatrix}$$

The coordinates $[x,y,\theta]^T$ are termed the pose coordinates. The mapping can be derived from basic geometry as done in lecture 3 of the course. The motion of each wheel is equal to $\omega_x * r$ and with a center of rotation about the other wheel contact point the motion forward of the local coordinate frame is $\omega_x*r / 2$ and the rotation is $\omega_x*r / 2l$. The resulting mapping is then

$$\dot{\xi}_R = \frac{r}{2} \begin{bmatrix} \omega_l + \omega_r \\ 0 \\ \frac{\omega_l - \omega_r}{l} \end{bmatrix}$$

where r is the radius of the wheels and l is the inter-wheel separation.

b) The standard differential drive system has a non-holonomic constraint. It cannot move sideways. This implies that it has non-integrable constraints and as such the motion-> pose transformation is sequence dependent. Consequently the transformation is not unique. By using a velocity model the transformation is unique.

2. Walking robots can be designed to be statically or dynamically stable. a) What is the difference between the two types of stability? b) How many legs are need for a robot to be statically stable? c) How many legs are needed for a dynamically stable platform? d) what is a gait pattern? e) describe two typical gaits

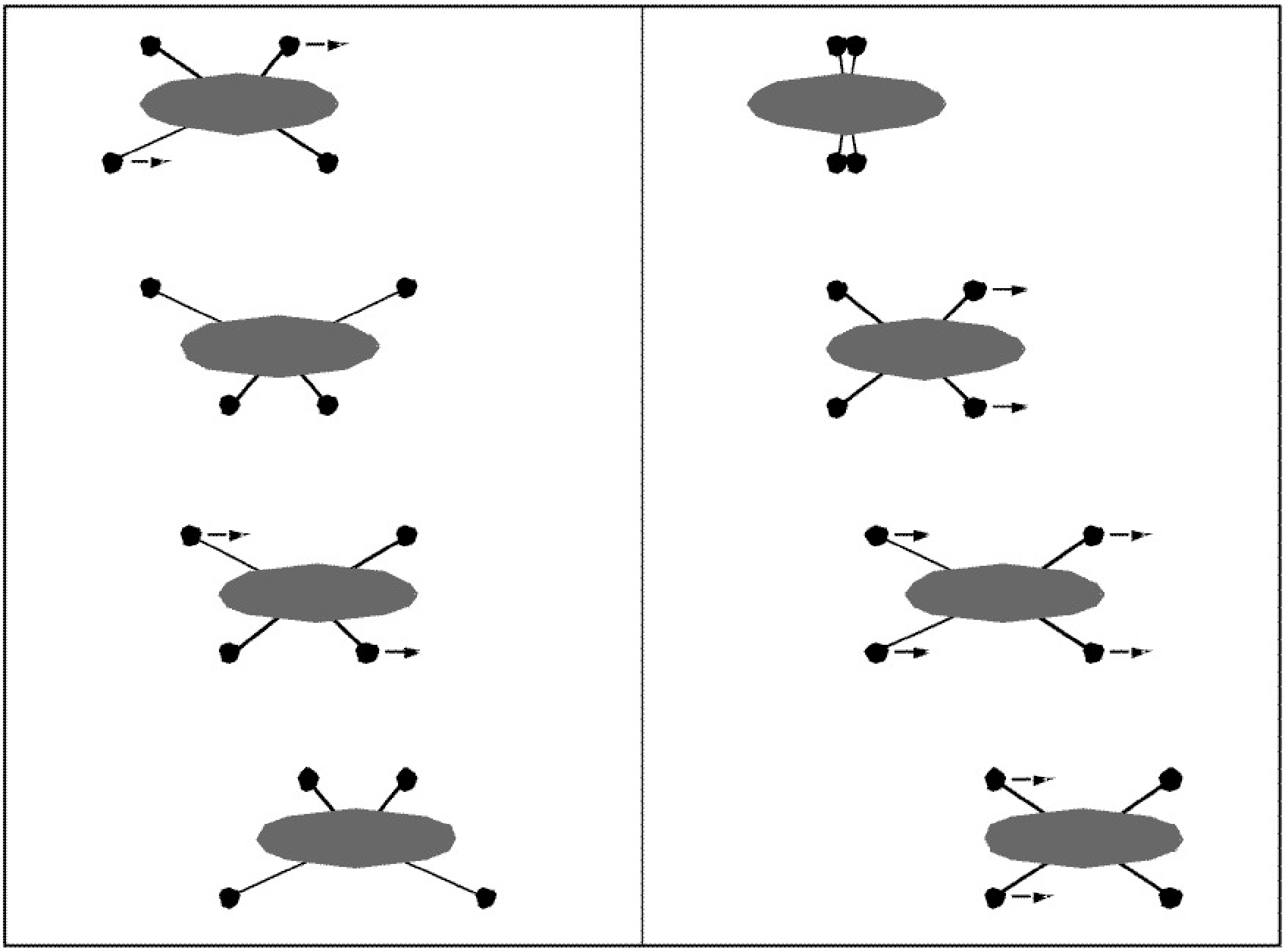
a) A statically stable platform is stable without any active control, whereas a dynamically stable platform requires active control to remain stable. The prototypical statically stable platform is a quadruped system where one leg can be moved at a time with out loss of stability (given a center of mass at the local reference frame and light legs). A extreme dynamically stable platform is a one-legged hopper such as the Raibert Hopper from MIT (shown in the lectures). A one legged system can only remain upright through active control of the leg.

b) 3 legs are needed to provide stable support and to be able to walk an addition leg is needed. So the minimum stable platform must have 4 legs (given the assumption of small feet).

c) As outlined above the minimum number of legs needed for a dynamically stable platform is 1 leg

d) A gait pattern defines the sequence of leg motions. I.e. when is each leg moved in a given control cycle.

e) Most obvious 4 legged gaits



3. Sensing is a crucial aspect of mobile robotics. a) why is sensing needed? Typically we discriminate between two different classes of sensors, b) what are the two classes and what is the difference between the classes? c) describe 2 different sensors and characterize them in terms of measurement principle and objective.

a) In mobile robotics the world is typically non-deterministic and there is a considerable risk of slippage due to motion of the platform. There is thus a need to deploy sensors to make sure that the robot does not get lost and for detection of obstacles / structures in the environment.

b) Typically sensors are classified according to interoception (internal state) and exteroception (external world state) but sometimes sensors are also classified as active / passive. Both answers are acceptable.

c) Typical sensors for a mobile platform are ultra-sonic sonar and laser scanner. The ultra-sonic sonar typically operates in the 50-70 kHz range. They send out a sound chirp and measure the time-of-flight until the sound is reflected and returned to the sensor. The dispersion of sound is such as the typical opening angle of a sonar is in the range 10-30 degrees. The sound energy tapers off inversely proportional to the cubic distance which poses a challenge. The sensors have typically been designed for detection of objects over relatively big spatial areas at closer range. A typical application is obstacle detection.

Another typical sensor is the laser scanner. A laser sends out a light pulse or modulated light. For the light pulse the measurement principle is similar to the ultra-sonic sonar. For the modulated light the phase difference between emitted and reflected light is measured. Given the wavelength of the modulation signal and the transmission speed of light it is simple to measure the distance from the phase difference. Lasers beams have a small foot print and the accuracy can be down to < 1 mm. These sensors are well suited for detection of structures in the environment for localisation and for obstacle handling

4. For mobile platforms there is a need to generate a model of the environment for handling of obstacles and to achieve localization. a) Mentioned 3 different representations? b) exemplify updating/estimation for each of the 3 mentioned models? c) what are advantages / disadvantages for each of them?

a) Typical representations for mobile robotics include

1) Appearance based models
2) Grid representations
3) Feature based representations
4) Topological graph representations

b) Updating of the appearance based representation is typically performed by scan matching i.e. LSQ fitting of new data to an existing representation. For grid based models the simplest is to have a probability model for the sensor p(Object|Reading) and perform grid updating using Bayes rule. Feature maps are typically updated using for example a Kalman filter, i.e. a recursive least square estimator. The topological map is updated by adding / remove nodes and links to the graph based on detection of structures in the environment.

c) Appearance based models are simple to acquire and reaccess the model have no implies semantics and as such scale poorly. Grid based models in the homogenous tesselation case have a complexity that is O(NMR), where N and M is the size of the environment and R is the rotational resolution of the map. Even for simple environment the grid maps can become excessive. The grid map is simple to update. The feature map is a compact representation that can be designed to the task / objectives of the robot. The updating is typically $O(N^2)$, where N is the number of features. A major challenge in many applications is reliable data-association. The topological map model is a very compact data structure but it provides only a coarse estimate of location

5. The Urban Grand Challenge has just been advertised for launch of vehicles that have to navigate autonomously for 100 km in an urban environment (with houses, ...) at a maximum speed of 40 km/h. The robot has to detect and avoid other vehicles in the environment. a) What sensors would you put on a robot to handle localisation and detection of objects? please motivate your choice? b) what representation would you adopt? why? and c) finally for navigation in a city what planning method would you adopt? why?

a) There is no universal answer to this question. The typical considerations would suggest

GPS - provides absolute localisation but is challenges in part by houses etc
Odometry - Basic short-term estimation of motion

Inertial sensors -- Estimation of motion (6DOF) for the vehicle in the presence of GPS challenges
Radar - provides a method for medium range detection of other vehicles
Laser Scanner - Local estimation of structures, detection of obstacles and closely cars
Camera - Lane, road and sign detection

b) The separation of objects is on most cases such as the feature representation makes the most sense. At the same time way point are typically represented in a topological representation so a graph based overall strategy might also make sense. In general a mixture of representations will be required to handle varying spatio-temporal requirements (i.e. short-range fast reaction to long-range strategic handling)

c) if the waypoints are known in advance then in principle a variation of the traveling sales man can be used for mission planning. If only start and goal positions plus environmental layout is known the best strategy for mission planning would be a standard graph search such as A*/D*. For local handling of obstacles a potential field approach might be a good first guess.