ROBOT NAVIGATION MODALITIES

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Abstract: Whilst navigation (robotic or otherwise) consists simply of traversing from a starting point to a goal, there are a plethora of conditions, states of knowledge and functional intentions which dictate how best to execute this process in a manageable, reliable, safe and efficient way. This position paper addresses the broad issues of how a continuum of choices from pure manual or teleoperation control through to fully autonomous operation can be laid out and then selected from, taking into account the variety of factors listed above and the richness of live sensory data available to describe the operational environment and the location of the robot vehicle within it.

1 INTRODUCTION

The dominance of ‘Simultaneous Localisation and Mapping’ (SLAM) (Leonard, 1991) in recent publications on robot navigation can give the false impression that this approach is always the best way of carrying out this task, largely ignoring the fact that there are very few situations where such an approach is either necessary or even feasible, given normal expectations of prior knowledge and functional/safety requirements.

As a simple counter example, why would one want to carry out complex SLAM style navigation in a building for which exact plans are available? Alternatively, if a rich database concerning the geometry and appearance of a reasonably static environment can be constructed off-line with accuracy and convenience and this need only be done once, why not just use this 3D colour rendered map data for continuing robot operations on a day to day basis ever more? In the other extreme, in highly complex and dynamic environments with high risk potentials, such as robotic bushfire fighting operations, why not navigate a robotic vehicle under human teleoperation control to allow the full judgement of human reasoning to apply throughout whilst the operator is in a safe and comfortable place?

There are many other examples between the extremes described above, each requiring its own appropriate navigation modality. In what follows the essentials of robot navigation will be described, various navigational modalities outlined and a number of case studies presented for illustration purposes. Discussion and conclusions then follow.

2 ROBOT NAVIGATION ESSENTIALS

Six sub-system requirements govern the task of robot navigation:

(a) Localisation (Jarvis, 1993) concerns the fixing of the position and pose of the robot vehicle within its working environment, whether by following the pre-laid lines on the floor, detecting beacons or interpreting natural landmarks (or general environmental metrics and/or appearances). The less preparation required the better but not at the expense of overall efficiency, accuracy and safety. The recent tendency is to try and use on-board acquired sensory data of the operational environment with minimal purposeful marking up of it by way of specific signs.

(b) Environmental mapping concerns the provision or acquisition of data specifying the occupancy, geometry, topology or essential nature of the physical operational environment and sometimes also the identification of relevant objects within it. Such a map may assist localization but must also provide the basis for obstacle avoidance and path planning.

(c) Path planning (Jarvis, 1994) concerns the determination of efficient collision-free and safe

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paths from start to goal locations or, in some cases, a coverage pattern of the accessible environment. In many cases paths can only be constructed incrementally as environment mapping data is acquired from on-board sensors (possibly indicating the location of previously unknown obstacles), if not provided beforehand.

(d) Motion Control involves the mechanistic operation of wheels, legs, propellers etc. to drive the robot along the planned path.

(e) Communication amongst sensors, operator, computational resources and mechanism components is also essential. The distribution (and redundancy) of these provisions on-board and off (where there might be a remote base station) are critical to efficiency, timeliness, safety and reliability.

(f) Function refers to the intended operation, whether it be directing water at a fire, picking up suspicious baggage or apprehending a terrorist, or some other requirement. This aspect is often neglected or regarded as a “do last” task in the system design process but should actually be considered first, not only because the type of vehicle, its sensory capabilities and its reliability are dependent on its function but also because the navigation modality may be less critical than the manipulation (or some other task required) when the goal is reached. For example, if the task requires the close supervision by a remote operator (e.g. in defusing a bomb) then a sophisticated autonomous navigation strategy may not be justifiable, even if possible.

Just how the above six aspects are sensibly integrated is critically dependent on the functional requirements, the available prior knowledge of the environment, the dynamics of the situation and, not least, on human risk related considerations.

3 NAVIGATION MODALITIES

For the sake of structure, three dimensions of the robot navigation modality choice process can be identified (See Figure 1):

The first is that of degree of availability of prior knowledge (e.g. maps, views, 3D geometry) or the ease with which this can be acquired off-line (e.g. via laser scanners, stereo views, appearance mapping, etc.). When environmental knowledge suitable for supporting robot navigation (localisation, obstacle avoidance/path planning and function) is readily available, it makes good sense to use it as it is likely that such an approach would lead to better accuracy, reliability and efficiency than learning such knowledge using on-board sensors alone.

The second dimension is that of the complexity of the defined function and whether human agencies would be required to handle them, whether or not the pure navigational aspects could be automated to some degree. For example, if the complex operation of defusing a bomb via delicate teleoperated manipulation with rich sensory feedback needs the application of expert human skill, the necessary attendance of the expert suggests that the navigation may as well be by teleoperation also, unless this part of the overall task is particularly tedious or time consuming.

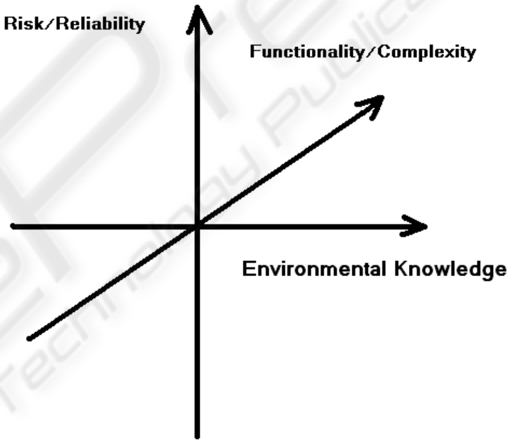

Figure 1: Robot Navigation Modality Choice Factors.

The third dimension is that of risk and reliability requirement factors. For example, having a robot clean a carpet or mow a lawn fully autonomously to obviate human tedium makes good sense, since degrees of unreliability and inefficiency can be tolerated and very little human risk is involved. On the other hand, using the bomb defusing example again, the remoteness of the operator for risk minimisation is the essential factor and the question of modality of navigation may be considered relatively irrelevant, so a flexible mixture of automation and direct teleoperation may be suitable for this application. Guiding a fire tanker to a fire fighting location too hazardous for humans to attend should perhaps be handled entirely by rich sensor feedback supported teleoperation, since the safety of other personnel operating in the vicinity may be more severely jeopardised if a fully autonomous system were used, especially as the situation is likely to be subject to severe dynamic variation with a moving fire front, changing wind conditions and the extent of other fire fighting vehicle and personnel deployment.

4 FLEXIBLE APPROACH TO ROBOT NAVIGATION

Rather than accepting one rigidly defined robot navigation modality along the spectrum from pure teleoperation to fully autonomous operation, it makes sense to devise ways in which these extremes can be moved between gracefully with smooth variation of the degree of human intervention applied in a hybrid strategy where levels of autonomy can be adjusted for particular tasks and adapt to changing conditions over time. A good example of this approach is where a disabled person is using a wheelchair in complex environments with the aid of robotically inspired sensory and control mechanisms (Jarvis, 2001). The disabled occupant may be permitted a user-adaptive degree of control of the wheelchair within an envelope of safety provided by the robotic instrumentation which adjusts the degree of intervention to the capability of the user to handle the situation over variations of physical reflex, poor vision, degrees of fatigue etc.

Using a three level control strategy (see Figure 2) nicely complements the notion of flexible navigation modality selection. The lowest level can be purely reaction based collision avoidance through stopping or minor trajectory adjustments using close range obstacle sensing as a trigger. The second level can be thought of as “local guidance” which indicates a safe passage over a limited range of movement, generally in the intended direction. The top level is global and includes complete path planning and control transition strategies. In the robotic wheelchair example, the human occupant provides the top level strategy, the second level provides the user with steering advice and the lowest level simply avoids collisions.

In the more general robot navigation situation, the top level could drift between fully human control via teleoperation and fully autonomous operation, with the lower two levels playing their roles in supporting the global strategy. For example, a teleoperator, like the wheelchair user, can direct the activities of the robot using the advice of the second level and accepting the collision avoidance reaction level as a safety precaution should his attention stray.

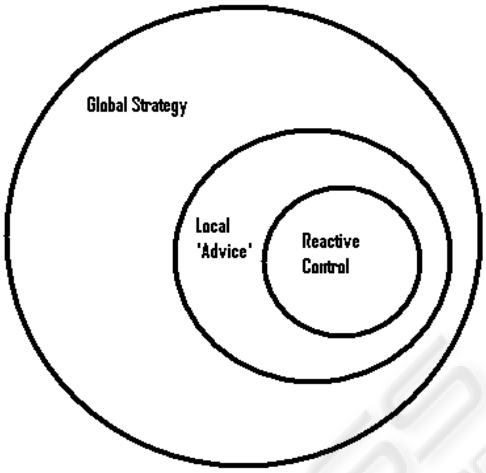

Figure 2: Multi-level Control Heirarchy.

5 CASE STUDIES

The user adaptive robotic wheelchair (Jarvis, 2001) described above is shown in Figure 3. The user can indicate navigation intention using human gaze detection but near collisions impose increasing degrees of instrument driven navigation intervention, with control being handed back to the user gradually as near collision statistics improve. The main environment sensor is a Erwin Sick laser range finder. GPS is also provided for guidance as a non-essential convenience.

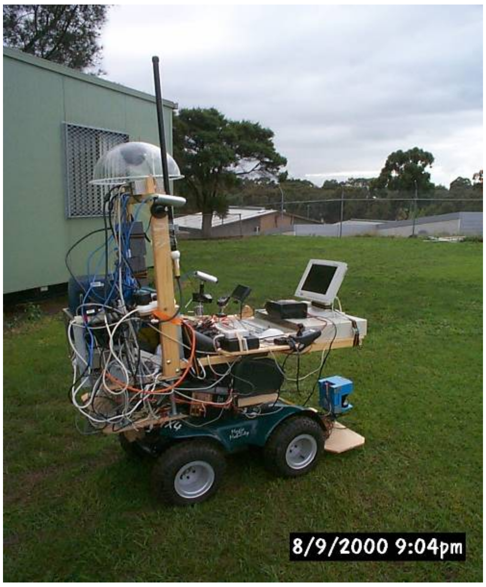

Figure 3: User-Adaptive Robotic Wheel Chair.

Figure 4 shows a fully autonomous rough terrain tracked vehicle (Jarvis, 997) which uses GPS localisation, laser range finder obstacle mapping, and Distance Transform (Jarvis, 1994) path planning. Only the goal location is indicated on an environmental map which is populated with obstacles as they are discovered by on-board sensors. Collision-free optimal paths to the goal are recomputed on a fairly continuous basis.

Figure 4: Autonomous Rough Terrain Tracked Robotic Vehicle.

Figure 5 shows an indoor fully autonomous robot (Jarvis, 1997) which can map its obstacle strewn environment and continuously replan its paths to a nominated goal. Localisation is achieved using a Denning laser bar code reading localiser with bar code beacons placed at known locations in the floor plan.

Figure 5: Autonomous Indoor Beacon Localised Robot.

Figure 6(a) shows a teleoperated boom lift(Jarvis,2006) and Figure 6(b) a teleoperated fire tanker(Jarvis,2008). Teleoperation is supported by video cameras, GPS, laser range finders and pitch/tilt sensors. Figure 7(a and b) shows some of the types of environmental mapping data available to the teleoperator.

Figure 6(a): Teleoperated Boom Truck.

Figure 6(b): Teleoperated Fire Tanker.

Figure 8 illustrates a very recent experiment where detailed off-line environmental mapping (Jarvis, 2007) was carried out using a Riegl LMS-Z420i laser scanner provided with registered colour imaging capabilities. Navigation tasks in the "cyberspace" created by this environmental data could be replicated in the real physical space from which the model data was acquired using a physical robot. The robot could localise itself using panoramic images which were matched against images extracted from the pre-scanned "cyberspace" data. This approach does rely on the prior collection of detailed environmental data but this process need only be done once. The generality of this approach and the ease of extension into 3D highly recommends it for situations where prior data collection can be justified e.g. in public spaces, malls, air terminals etc.

Figure 7(a): Colour Rendered 3D Environmental Data.

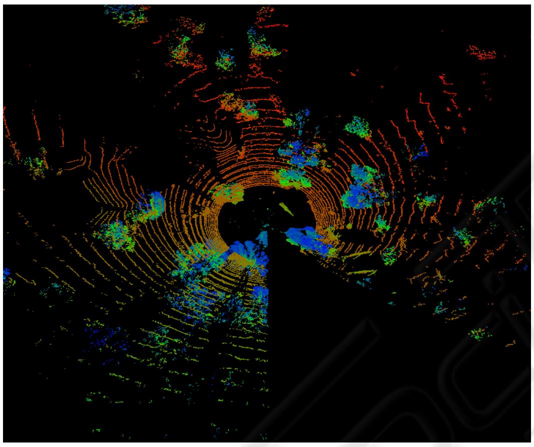

Figure 7(b): Plan View of 3D Laser Range Scan.

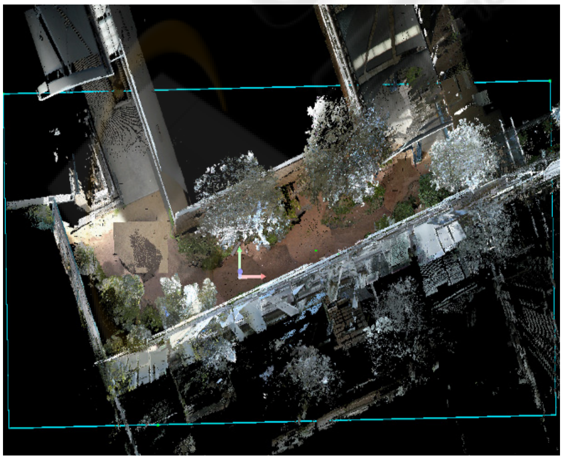

Figure 8: Dense Laser/ Colour Vision Environmental Data Collected Off-Line.

6 DISCUSSION AND CONCLUSIONS

The idea that robot navigation solutions should be flexible to span pure teleoperation to fully autonomous operations with a three level control strategy and smooth variations of human intervention is a very practical one, since it can be adapted to individual situations and changes of circumstances at will. Also, as new methods, improved sensor instrumentation and increased affordable computation come to hand various aspects of this approach can be tuned so that the balance of control may shift but the continuum maintained.

As the quality of SLAM solutions improve, human/machine interfaces evolve, swarms replace individual robots on distributed tasks, questions of risk and responsibilities resolved and co-operative interplays with human agencies developed, maintaining the type of flexibility promoted by this paper becomes even more reasonable and practical, particularly as the inclusion of this kind of flexibility does not impose any great additional cost and provides a graceful degradation path.

In conclusion, this paper has advocated a flexible approach to the selection of robot navigation modalities to suit particular circumstances relating to knowledge, risk, complexity, efficiency and reliability factors so that working solutions to important robot application domains can be applied now and improved in the future without the stagnation which may result from a more rigid approach.

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