Tele-Autonomous Watercraft Navigation

Ray Jarvis
Intelligent Robotics Research Centre
Monash University
PO Box 35
VICTORIA 3800
Australia
Ray.Jarvis@eng.monash.edu.au

Abstract: This paper concerns the instrumenting of a small watercraft to support a hybrid navigation strategy which combines remote human supervisory guidance with reaction based obstacle avoidance. This style of control is called 'tele-autonomous'. Potential applications include search and rescue operations, coastal surveillance, water pollution source tracing and surface support for a submersible. Details are provided, the concept promoted and future plans sketched.

1. Introduction

It is now relatively easy to develop fully autonomous mobile robots for operations in well-structured factory environments [1, 2]. Tasks such as delivering components between workstations or carrying out surveillance duties can be accomplished autonomously and reliably in such domains.

In less structured environments such as in a home or in rugged outdoor situations [3, 4] a greater degree of intelligence based on sensor data acquisition and interpretation is required. The provision of autonomous system support becomes more expensive and, generally, reliability is poor.

Where the motivation has less to do with the reduction of human resources and more to do with safety and convenience, teleoperation, particularly in sensor-rich modes, has a lot to offer. Permitting humans to control complex navigation and manipulative tasks at a remote, hazardous site (as in mining, space exploration, undersea operations, in mine fields and nuclear plants) whilst, they, themselves, are in a safe and comfortable control centre offers many practical advantages.

Furthermore, such solutions can be delivered with reduced levels of artificial intelligence, since human judgement can be as fully engaged as the sensor feedback quality permits. With appropriate sensor feedback and sensitive and responsive feed-forward control, it is possible to extend 'teleoperation' into 'tele-existence' where the operator has the sensation of being at the remote site but without the danger or discomfort. Some forms of virtual reality can extend this type of activity towards creating computer-fabricated worlds within which people and machines interact to ultimately complete physical tasks with human intelligence and machine capabilities nicely matched.

This paper is concerned with capturing the essence of both autonomous functionality and sensor-rich teleoperation in a hybrid structure which flexibly provides a variable mix of automation and human intervention, in this case, with respect to watercraft navigation. The term 'tele-autonomous' has been invented to represent this hybrid approach. This mode is a type of supervisory control but where the degree of human involvement can range from peripheral to intense, depending on the mission goals and the time-varying environmental circumstances.

Possible applications include tracking the sources of pollution, search and rescue operations, surface support for submersibles and recreational activities.

We have chosen a recreational craft, a 'water-bike', as the platform for tele-autonomous experiments (See Figure 1). This craft is small (2 metres in length) and yet is capable of carrying a payload sufficient for appropriate instrumentation and power sources. The 'control centre' for tele-autonomous operations can be shore based (See Figure 2) or on-board another vessel.

Figure 1. Instrumented 'Water Bike'

2. Essential Requirements

The essential requirements for safe watercraft navigation are as follows:

1. The location of the craft should be known. This can be accomplished using Global Positioning Systems (GPS). The recent turning off of the 'selective availability' clock error by U.S.A. defence forces makes even stand-alone systems sufficiently accurate for these purposes, though both differential and phase modes can improve this considerably.

2. A naval map of the area, particularly in electronic form, allows path planing to be carried out.

3. Knowledge of surrounding vessels or hazards not shown in the naval maps

Figure 2. Shore Based Remote Control Centre (Home Base)

is important. This information can be provided by radar but only within accuracies of ± 25 metres up to tens of kilometres. Being able to relate the radar data to the map details is very important.

4. Steering and speed controls are needed. A number of steering servos systems which allow set bearings (supported by a flux gate compass) to be followed are readily available on the market. Accelerator control is not usually provided but can easily be achieved.

3. Auxiliary Instrumentation

The following extra instrumentation is used for our experiments:

1. A laser time-of-flight scanning rangefinder capable of measuring a one dimensional sweep of range data at 0.5 degree intervals over 180 degrees up to 50 metres with ± 3cm accuracy.

2. An optical gyroscope with relatively low drift to help with steering control.

3. Night vision video camera for low light operations.

4. Stereo colour cameras for stereo viewing by the operator.

5. A video cross bar switch to select various video sources for viewing from the control station.

6. Video transmitter(s).

7. Pitch/roll/bearing sensor.

8. Radio ethernet communications.

4. Implementation Details

Figure 3 shows the block schematic for the whole system. Two distinct communications subsystems are shown, one based on video transmitters, the other on radio ethernet, the latter with a return path from the control centre to the watercraft for steering and speed control.

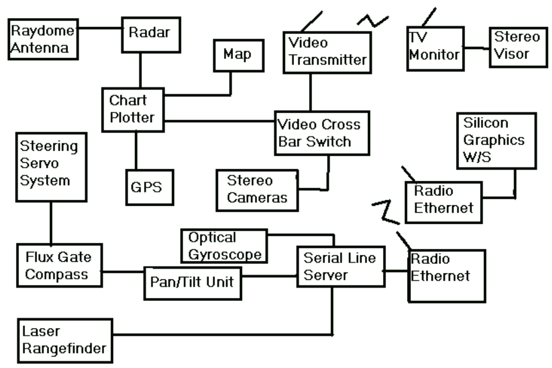

Figure 3. Tele-Autonomous System Block Schematic

A Raytheon RL 70CRC chart plotter system displays both GPS (Global Positioning System) derived position fixes on an electronic chart and radar scan data from a Raytheon system. In split screen mode both the mapping and radar data can be viewed simultaneously to scale and 'synchronised' in central location and orientation. A single colour video camera can provide both sets of data in a single image via a quality video radio transmitter to a remote (shore or boat based) home station.

A pair of stereo colour cameras (See 4) are genlocked so as to provide field sequential video through multiplexing electronics. A single video stream is radio transmitted from the camera pairs to a home base head mounted stereo visor which. demultiplexes the signals to the left and right screens. Alternatively, electronically switched glasses can be used to view the camera screen in stereo imagery on a standard TV receiver screen. It is planned to provide a night vision (0 lux) camera with its own infra-red illuminator for night operations. Switching video streams between the mapping/radar camera, the stereo camera pair and the night vision camera can be achieved using a video cross-bar switch is controlled via standard RS232 serial line to the serial line server (shown in Figure 3). Up to 8 input video channels can be handled so a number of other cameras in strategically useful positions can be easily added - including cameras which may be on a tethered submersible, for which the 'up top' vessel is the surface support base.

An Erwin Sick scanning rangefinder is used to detect relatively close obstacles floating in the water in front of the vessel. The rangefinder shown in Figure 4 is fitted with a mask to block out specular reflections from the water, which can frustrate the instrument. This rangefinder can provide $\pm$3cm accuracy range up to 50 metres away at 1/2 degree intervals over a horizontal

Figure 4. Stereo Cameras

sweep of 180 degrees. The range data is channelled at 9600 baud via a RS232 serial link to the line server.

Figure 5. Erwin Sick rangefinder with Anti-specular Reflection 'Mask'

An optical gyroscope and a pitch/tilt sensor are also linked to the serial line server. The optical gyroscope can be used to aid steering control whilst the pitch/tilt sensor can indicate the altitude and rocking movements of the vessel to complement the interpretations made via the stereo cameras.

All of the instrumentation data scan provided via the serial line server (range, pitch/tilt, optical gyroscope) are transmitted via radio ethernet to a remote Silicon Graphics workstation at the home base in graphic from, allowing for easy interpretation by the operator. Control signals from the home base to the vessel are also transmitted via radio ethernet to the serial line server and from there to where they are acted upon via RS232 serial links, the serial line server being a multiple full duplex device.

An Raytheon sportspilot steering servo system directly operates the steering wheel, which in turn swivels the rear outboard petrol engine via cables.

The steering servo systems is designed to hold a set bearing by adjusting the steering wheel to maintain bearing data provided by a flux gate compass. The normal operation with a human pilot on board, is to point the vessel in the intended direction and then to engage the autopilot to maintain that bearing. If the pilot were to override this operation by taking hold of the steering wheel, the servo system simply takes over again to keep the new bearing once the wheel is released by the human pilot. Minor bearing adjustments can be made by pressing small buttons on the unit.

The way we have chosen to steer the craft involves a small amount of lateral thinking. Once the autopilot is engaged, steering bearing changes can be smoothly implemented by rotating the steering flux gate compass about a vertical axis in the opposite direction by an amount equal to the intended bearing change. The autopilot is 'tricked' into taking up a new bearing by trying to maintain what it takes to be original setting. A Directed Perception Inc. pan/tilt head is used for this purpose; it too is controlled via the serial line server by the operator at the home station. The pan axis is used to rotate the flux gate compass and the tilt axis to adjust the outboard motor accelerator via a light cable. Thus both steering and speed are controlled via this single pan/tilt head.

However, the pan axis does not permit a full ±180 degree rotation, there being a dead zone of ±30 degrees. If the vessel is required to make a round trip in straight line segments in a single loop, or complete several loops this could be a problem. A simple solution was found. It takes advantage of the possibility of 'taking over' the wheel to change the intended bearing. In our strategy the vessel is trying to maintain a pseudo single bearing but is being 'tricked' by rotating the compass. Stopping the wheel from turning whilst rotating the compass is like resetting the bearing. Very simply, a braking a solenoid is actuated when the pan angle is nearing the limit and the intention would be to move beyond this except for this limit. The solenoid activation is implemented using the tilt control in a position beyond the idling speed point of motor accelerator control to trip a microswitch. The solenoid pushes a brake pad against the steering wheel to hold it fixed, at which time the panning position of the pan/tilt head is moved back to where maximum rotation in either direction is possible. Then the wheel is released and the vessel is accelerated again in its original direction. Now, however, maximum steering range is re-established. Thus the maximum steering change potential can be reinstated when a limit is being approached and an effectively continuous bearing change accumulating beyond 360 degrees can be achieved. Absolute bearing data is provided on the chart display which uses a separate flux gate compass as a reference and the optical gyroscope can also be used to assist in making steering changes, although this should not be necessary with a bit of practice. Since the response to a bearing change command would be subject to the speed of the vessel, the gain of the servo system and other factors such as wind and currents, the optical gyroscope can indicate actual bearing changes over short terms, without the gyroscope drift being of significance. Whilst the map plus radar data can give a large scale view of navigational activity, the stereo camera view and the laser range finder scans provide localised range sensing which may prove valuable for manoeuvres close to obstacles.

An automatic obstacle avoidance mechanism can take over when the operator is perhaps occupied with other matters. Only this reactive autonomy has been considered so far; other aspects may be added later, depending on the task at hand. The Sick rangefinder can detect potential collisions with obstacle closer than 50 metres surrounding the vessel in the forward 180 degrees. The appropriate action is to slow the vessel, steer around obstacles and then to resume the original track. This strategy is currently being implemented. It is hoped that its success can be demonstrated when the paper is presented. Some aspects of the strategy relate to work with a semi-automatic wheelchair [5].

As indicated above, the tele-autonomous mode to be experimented with first is that of human intervention for global path planning with the support of mapping/GPS/radar data but to provide local obstacle avoidance autonomously by linking rangefinder data analysis with the steering and speed control once the overall plan is specified by the operator. The operator can intervene at will at any time. Thus, once a navigation mission has been planned and commenced, local obstacle avoidance can be carried out automatically and the operator will be alerted only when some situation too complex to handle autonomously arises.

At a later stage in our experiments it is intended that aspects such as route planning using map/GPS/radar data be automated once the operator has set the parameters of the overall mission. Once again, the operator will be free to take over at any time. Thus, parts of a mission may be almost completely carried out autonomously but other, more critical, stages can be under the direct and detailed control of the operator. Mixtures of automatic and human operator control can be used to suit particular missions and circumstances.

5. Conclusions

This paper has described preliminary work on a semi-autonomous watercraft, arguing the case for a mode of control called 'tele-autonomous', in which human high level supervision and low level activation modes are mixed according to the needs of the mission. Further work has yet to be done to demonstrate the full capability of such an approach and to properly gauge the best way in which human guidance and autonomous capabilities might be combined for various defined tasks, including search and rescue, submersible surface support and tracing water pollution sources.

References

[1] R. A. Jarvis and A. J. Lipton. GO-2 :- an autonomous mobile robot for a science museum. In *Proc. 4th International Conference on Control, Automation, Robotics and Vision, Westin Stamford, Singapore*, pages 260–266, 3-6 December, 1996.

[2] B. Hendry, R. A. Jarvis, and I. Bridger. An automated guided vehicle for industrial environments. In *Proc. ARA Conference on Robots for Australian Industries, Melbourne*, pages 121–131, 5-7 July, 1995.

[3] R. A. Jarvis. An autonomous heavy duty outdoor robotic tracked vehicle. In *Proc.*

International Conference on Intelligent Robots and Systems, Grenoble, France, pages 352–359, Sept. 8-12, 1997.

[4] C. Thorpe. Mixed traffic and automated highways. In *Proc. International Conference on Intelligent Robots and Systems, Grenoble, France*, pages 352–359, Sept. 8-12, 1997.

[5] R. A. Jarvis. A user adaptive semi-autonomous all-terrain robotic wheelchair. In *submitted to the 6^{th} International Conference on Intelligent Autonomous Systems, Venice, Italy*, July 25-27, 2000.