Robotic Inspection and Safe Removal of Suspicious/Abandoned Luggage

Ray Jarvis
Intelligent Robotics Research Centre
Monash University
Melbourne Victoria
ray.jarvis@eng.monash.edu.au

***Abstract*— Concerns about terrorist acts of planting explosive and/or dangerous chemical/biological agents in public environments such as air and bus terminals have prompted preventative actions at all levels. One such possible measure is covered in this paper: detection, inspection and safe removal of suspicious/abandoned luggage. A number of specialized mobile robotic platforms take on a linked set of roles in reacting to video evidence of objects which remain stationary beyond a reasonable time interval. This paper outlines the overall strategy and the implementation details to date with respect to robotically averting the potential human risk associated with this type of terrorist threat with minimal risk to security personnel and bystanders alike.**

I. Introduction

In public transit spaces, such as air and bus terminals, travelers are usually constantly warned not to leave their luggage unattended. Thus, unattended (or potentially abandoned) luggage is 'suspicious' under such a regime. Detection of unattended luggage could be by casual bystander observation or by security personnel carrying out routine patrols. However, human vigilance is subject to fluctuation of alertness and thoroughness, subject to boredom and fatigue as well as to simultaneous coverage limitations. Video surveillance provided by iOmniscient Pty. Ltd., the industrial partner in this project, is able to provide location details of objects of specific size limitations which have not moved for a specified period of time against a stationary background (walls, floors, etc.) despite dynamic activities obscuring the view of these objects temporarily. An operator in the surveillance control centre is immediately alerted when such a suspicious event occurs and can observe the offending object or objects on a monitor. Some of those events may be immediately dismissed as harmless such as in the case of a sleeping infant or a scrap of rubbish or where stationary luggage is in fact attended. Should, however, the operator not be reassured of the objects harmlessness, a sequence of robotic interventions can be initiated as steps of escalating concern, without unnecessary risk to security personnel or bystanders and yet hopefully without causing panic or initiating false alarms. Human judgment must be exercised at all times during the escalation of robotic interventions which may follow step by step.

Some clarification concerning the style of robotic intervention called for in these operations is required. Since human supervision is regarded as mandatory in the context of human life risk decisions being required in what may develop to become a crisis situation, there is no particular requirement for full automation, even if such a capacity existed over the tasks to be completed, some being quite intricate and delicate. Thus sensor rich, intuitive and highly reliable teleoperation is much more appropriate. Whilst it makes good sense to equip the robots with the mechanical capabilities to complete tasks autonomously, in principle, supported by a rich set of sensors, it is the presentation of the sensor information to the human operator which is critical, rather than computational reasoning to interpret it. However, this being said, there is still scope for some degree of automation where this can be applied without critical outcomes or failure. An example may be the deployment of a robot towards the general vicinity of its target along optimal collision-free paths. Full teleoperation can then be applied for the critical components of the mission. Both on-board sensors and the fixed cameras of the video surveillance system can be used for the non-critical autonomous navigation phase.

II. Visual Inspection

The first robotic intervention stage to help confirm or dismiss a suspicion associated with unattended baggage (or package) detected by the video surveillance system and not immediately classed by the operator as harmless, is one of simple, close-up visual inspection using a small, friendly and

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innocuous robot which can be visually teleoperated to the baggage in question. The platform chosen for this task is a simple robot built on a base driven by wheel chair motor/gear sets [see Figure 1] and operated via radio Ethernet from a remote computer with a user–friendly graphical interface. The on-board camera can be adjusted in pan and tilt remotely.

Figure 1 Visual Inspection Robot

In pure teleoperative mode, the operator can see the view of the operational environment of the robot (as captured by an on-board video camera) on the remote screen and can drive the robot using mouse interaction on a drive/steer icon. The purpose of this robot intervention following deployment triggered by a suspicious luggage alert provided by the video surveillance system to the operator, is to confirm or reject the hypothesis of potential danger presented by this occurrence. Clearly, confirmation of risk by close-up video inspection of the article and its markings, labels, abnormal appearance or location should lead to further action which may begin by warning bystanders to move away without causing a panic. Any unnecessary warnings of this type would hardly be appreciated, yet only very minimal risks should be tolerated.

Should the suspicion be sustained after preliminary visual inspection and the bystanders moved away, the second stage of robotic intervention would be initiated.

III. TRACE DETECTION

Relatively new on the scene are portable devices which employ Ion Mobility Spectrometry (IMS) technology to detect drugs, explosives and chemical agents with vapour or particle (using a swab) samples. Such a device can be used as an intermediate inspection tool between visual and x-ray inspection. A Sabre 4000 from Smiths Detection was used in our project. This device can detect 10 narcotic, 9 explosive, 8 chemical warfare and 9 toxic industrial chemical substances in very small quantities. It is designed to be hand held and is battery operated and is thus ideal for deploying on a robot. For vaporous substances a nozzle tube can collect the sample. Otherwise a small paper swab must be wiped on the surface of the object suspected to carry traces of the substances being tested for. A small robotic arm has been designed (to be operated under teleoperation) to wipe the swab on the suspect baggage, perhaps near the handle or openings and to deposit the swab in the slot provided on the Sabre 4000. Both the arm and the Sabre 4000 can clearly be seen in Figure 1., it having been decided to include the chemical inspection on the same robot carrying out a visual inspection. The robot arm can also carry an extension of the vapour input nozzle to an appropriate location to sample a substance trace. The result of the analysis can be conveyed to the remote operator via a camera observing the display screen on the saber 4000. If drugs but not explosives are detected this way, clearly no risk to personnel undertaking further inspection would exist. Just where the existence of chemical agents would fit in the risk determination between narcotics and explosives would need to be further investigated by referring to experienced security personnel. If explosives were detected, the area would be entirely cleared before the next inspection stage.

IV. X-RAY INSPECTION

The robot used for this stage of intervention is purpose built using wheelchair motor/gear sets for locomotion [see Figure 2]. It is fitted with an x-ray baggage inspection unit which is moved out to the side of the robot to permit the suspected baggage to be positioned between the x-ray source and the electronic imaging sensor by driving the robot along side it. The unit can be triggered and the x-ray image retrieved remotely via radio Ethernet. The inspection x-ray source/imager can be moved up and down to cover the vertical extent of the baggage and the robot can be moved forward to backward to accommodate its length with multiple images transmitted to the human operator. The x-ray system uses lead sheets to limit the leakage of x-rays to a safe level two feet away. Since remote operation is envisaged with bystanders at a distance, this is an ultra-safe arrangement. On-board cameras can be used to position the x-ray system for full x-ray inspection of the baggage which can be of a variety of sizes.

Figure 2(a) X-Ray Inspection Robot

Figure 2 (b) X-ray Inspection Robot in Position to Inspect Luggage

V. Safe Removal

Should x-ray inspection confirm the danger of explosives or chemical/biological agents or fail to dismiss these threats to a sufficient extent, safe removal for destruction may then be carried out. Two cooperative robots can now be deployed to complete this final task. One is capable of handling and carrying small bags or suitcases by the straps using a robotic manipulator arm and can negotiate stairs if need be [see Figure 3]. However, if very delicate treatment is considered necessary, carrying such a load up stairs is not advised despite care to minimize jolts. For larger pieces of baggage, a fork lift robot can be used [See Figure 4]. The baggage can be gently pulled on to the forks by a loop swung over the baggage and slowly retracted. The robot with the manipulator arm can also help in loading the baggage. It could also cover the baggage with blast proof material to further limit explosive dangers, once it is loaded. This last mentioned strategy has not yet been tested. However, it has been discovered that commercial blast proof cover systems are available but are quite expensive.

Figure 3 Track Vehicle with Manipulator Arm

Figure 4 Forklift robot for baggage carrying

VI. Instrumentation and Control

The main robot sensors for navigation, inspection and manipulation tasks are visual, as provided by one or more video cameras, some connected by a radio Ethernet link to the home station, others with a separate video link to provide higher bandwidth for critical operations. The most delicate tasks are those of picking up small suspicious objects/packages or grasping a carrying strap/handle of a larger piece of baggage. Stereo vision to provide 3D viewing of the fine manipulation processes involved is provided to the operator via a regular TV monitor and switching glasses or a stereo head-mounted display, depending on preference. A user-friendly (highly intuitive) graphic interface on a remote computer (perhaps the same computer being used as the video surveillance machine) drives an on-board serial line server attached to the remote end of a radio Ethernet link. The server can have a number of channels if needed but only one is required to feed a 32 channel servo motor controller. Two servo motors control steering and forward/reverse movement of any of the robots described (identical logical set up on each machine) above and others the various actuators for robot arm or X-ray arm movements. Each graphic interface is customized for an individual robot but all are generated by a set of specification tables which include details of position, size and type of control sliders, mouse/joysticks and switches and the gains, offsets and directional requirements for each servo. Reconfiguring the interface for a specific purpose is a trivial exercise. Of course the x-ray and the Sabre 4000 units also amongst the sensor elements for this project.

VII. Path Planning Methodologies

Whilst, as was indicated in the introduction, there is no critical need for autonomous robot operation since there is always an operator to take over navigation procedures for the various robots involved, using both the on-board video cameras and the fixed cameras (which are part of the video surveillance structure which detects suspicious/abandoned luggage in the first instance) some navigation assistance can nevertheless be easily provided. Since the plan of the airport, bus transit station, or whatever public space is the subject of this security system is known and most of the fittings within that space are known, Distance Transform (DT) [Jarvis, 1984,1994]] path plans can be pre-calculated for all of the navigated space.

Distance can be propagated out throughout all connected free space from the fixed initial locations of the robots (presumable close at hand to the video surveillance system operator). All minimal paths from any point in free space to this initial location is defined by steepest descent trajectories in the DT space. The reverse path can take the robot to the location of the suspicious/abandoned luggage. Variations in the placement of obstacles can be accommodated either by periodically regenerating the DT using the surveillance cameras to locate the changes or simply by taking local collision avoidance action when necessary. The fixed cameras in the environment can provide localization support and a laser range finder added for reactive obstacle avoidance.

Furthermore, safe paths (as distinct from optimal paths) can be found by first applying the DT out from all obstacles and using the inverse of these values as cell traversal costs in generating the path planning DT. Then all paths will give good clearance from obstacles and thus provide navigation tolerance.Examples of these procedures are illustrated in Figure 6. Varying navigatibility difficulty (such as stair negotiation) can be also reflected in the cell traversal cost structure as can requirements of overt or cover navigation [Marzouqi, 2006]]. Some examples are shown in Figure 7.

Using the procedures outlined above, the operator could delegate the approach navigation operation of the robots and take over teleoperational control for the more delicate manoeuvres and manipulation.

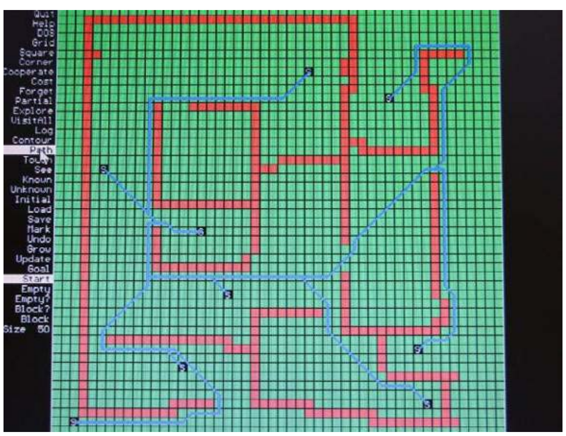

Figure 6 Multiple path planning

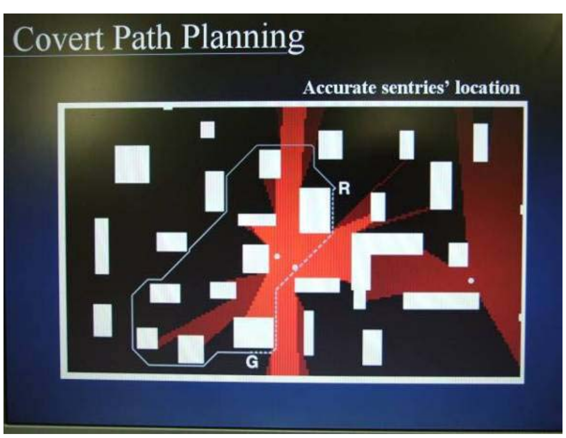

Figure 7 Covert path planning

However, although the algorithms described above have been developed and tested they have not been applied to these robots but could be if considered useful.

VIII. Discussion

There is little justification to push for full automation of the robotic intervention aspects of this project, since the events which require responding to are very infrequent and require a delicate touch due to their critical nature. Furthermore, an operator provided for the video surveillance operation is always available to direct the proceedings by teleoperation. Nevertheless some semi-autonomous assistance can be easily provided in the initial development stages of navigation to be potentially offending items using Distance Transform path planning methodology and utilizing the fixed cameras of the video surveillance system for localization and trajectory following confirmation, as well as obstacle mapping. The overall aim of this project was to minimize risk to humans in public places where the threats are related to the planting of substances that could maim or kill them. Linking the robotic intervention with the video detection of suspicious/abandoned luggage is of considerable value in making this approach practical and cost effective and deliberately keeps humans in the loop for providing judgment beyond the capabilities of a robot system.

IX. Conclusions

This paper has outlined strategic details of a project on robotic inspection and removal of suspect/abandoned baggage at air and bus terminals, and provided implementation details of the robots, instrumentation, and methodologies used. The approach taken is quite generic and would allow quite a variety of robotic mobility and robot arm actuation systems to be constructed with minimum effort now that the structure of the design has been formulated and tested.

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