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A SENSOR FUSION USER INTERFACE FOR MOBILE ROBOTS TELEOPERATION

Ctin NEGRESCU[1]

Fuziunea senzorială este aplicată tradițional pentru reducerea incertitudinii în detecția obstacolelor, îin modelarea mediului şi în localizare. Acest concept poate fi deasemenea utilizat pentru ameliorarea teleoperării. Practic putem utiliza fuziunea senzorială în crearea interfețelor utilizator cu dirijarea informației într-un mod mai eficient, facilizarea perceperii corecte a mediului situat la distanță şi rafinarea avertizărilor legate de situații de excepție sau avarie. Aceasta este posibil prin selectarea de senzori complementari, a combinării adecvate a informației şi a proiectării reprezentărilor mediului. În acest articol este prezentată fuziunea senzorială pentru teleoperarea roboților mobili.

Sensor fusion is traditionally used to reduce uncertainty in obstacle detection, word modeling and localisation. This concept and technologie can also be used to improve remote control. In fact we can use sensor fusion to create user interfaces which efficiently convey information, facilitate understanding of remote environment and improve situational awareness. This is posible by selecting complementary sensors, combining information appropriately, and designing effective representations. In this paper is presented sensor fusion for mobile robots teleoperation.

Keyword : human robot interaction, mobile robots, sensor fusion display

1. Introduction

Mobile robots teleoperation consist of three basic problems: 1- figuring out where the robot is, 2 - determining where it should go, and 3 - getting it there.

This problems can be difficult to solve, if the vehicle operates in an unknown environment. Humans in continous control may limit vehicle teleoperation.Thus to improve robot remote control is necessary to make it easier for the user to understand the remote environment, to asses the situation and to make decisions. In fact, we need to design the human-machine interface so that it maximizes information transfer while minimizing cognitive load. Numerous methods have been proposed, including supervisory control [1] teleassintance [2] and virtual reality [3].

[1] Eng., PhD Student, Dept.of Control Engineering Industrial Informatics, University “Politehnica” of Bucharest, e-mail:negrescu55@yahoo.com

2. Sensors fusion displays (SFD)

Sensors fusion displays combine information from multiple and different sensors or data sources to present a single, integrated view. sensor fusion displays are important for applications in which the operator must rapidly process large amounts of multi-spectral or dynamically changing heterogeneous data. More recent SFD have been used as control interface for telerobots. VEVI – the virtual Environment Vehicle Interface combine data from a variety of sensors (stereo video, ladar, GPS, inclinometers, etc.) to create an interactive, graphical 3D representation of the robot and its environment.[4]

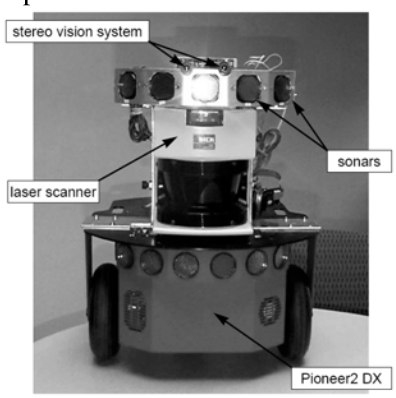


Fig. 1-Multisensor system

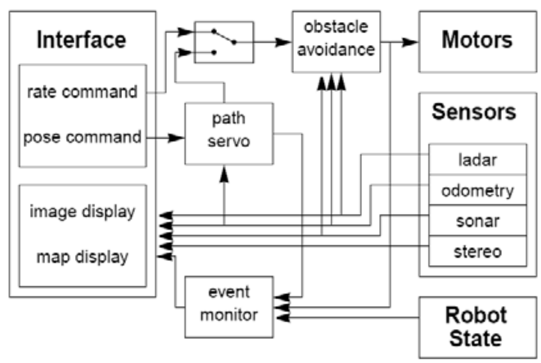


Fig. 2- System architecture

2.1 Sensors

Fig. 1 shows an multisensor system:

- The *ultrasonic sonar* ring uses polaroid 600 series electrostatic transducers and provides time-of-flight range at 25Hz.
- The *stereo vision* system is a Small Vision Module [5] and produces 2D intensity (monocrome) images and 3D range (disparity) images at 5Hz.
- Odometry is obtained from wheel-mounted optical encoders.
- The “Proximity Laser Scanner”(PLS) ladar [6] provide precise range measurement with very high angular resolution, but are usually limited to a narow horizontal band (i.e. a halfplane). This forms a good complement to the sonar and stereo sensors, which are less accurate but have a broader feld-of –view. The PLS ladar has 5 cm accuracy over a wide range (20 cm to 50 cm), a 180 degree horizontal field-of-view (360 discrete measurements) and greater than 5 Hz rate.

Table 1

Characteristics of stereo vision and sonar

Criteria	Stereo Vision	Sonar
ranging	stereo correlation	time of flight
measurement	passive	active
range	0.6 to 6 m	0.2 to 10m
angular resolution	high	low
depth resolution	non-linear	linear
data rate	$5x10^5$ bps	250 bps
update	5 Hz	25 Hz
field of view	40^0 horizontal / 35^0 vertical	30^0 beam cone
failure modes	low texture, low/high intensity low bandwidth	scross-talk specular reflection noise

3.System architecture

This is illustrated in fig. 2 and represent the modules and data flow. The robot is driven by *rate command* or *position command* generated by the ***user interface***. Pose commands are processed by a ***path servo*** which generates a smooth trajectory from the curent to the target position. All motions commands are constrained by the ***obstacle avoidance*** module.All ***sensors*** are continously read on-board the robot and the data transmitted to the interface.The sensor readings are used to update the ***image and map displays***.

Fusion algorithms for both displays are describad in the next sections. An ***event monitor*** watches for critical system events and mode changes (e.g. obstacle avoidance in progress) and also monitors robot health and generates appropriate status messages to be displayed to the user.

User interface must be a remote driving interface which contains sensor displays and a variety of command generation tools. The interface is designed to:

- improved situational awareness
- facilitate depth judgement
- support decision making, and speed command generation.

Fig. 3 show the main window of an senzor fusion based user interface. The interface contains three primary tools:

a. the Image display,
b. the Motion pad and
c. the Map display.

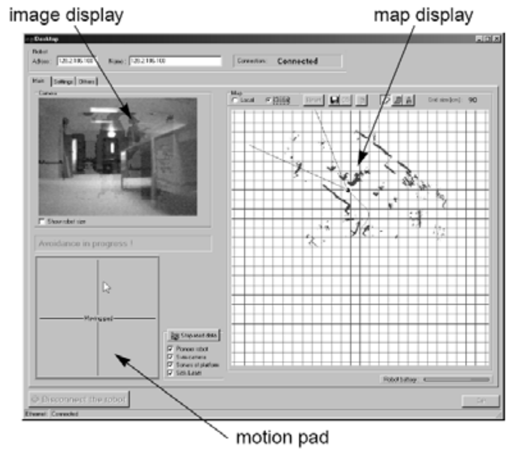


Fig. 3- Sensor fusion user interface for teleoperation

To enable the user to better understand the remote environment and to better make decisions, there are tools for mesuring distance, checking clearance, and for finding correspondences between map and image points.

a) Image Display

The image dispay contains a monocrome video image vith a color overlay to improve depth judgement and obstacle/hazard detection. Hue values encode depth information from close (yelow) to far (blue). Since close depth is more relevant (e.g. for identifying and avoiding nearby obstacles), hue is varyated exponentialy (i.e. near ranges are encoded with more values than far ranges).

b) Motion Pad

The motion pad enables the operator to directly control the robot Clicking on the vertical axis commands a forward/reverse translation rate. Cliking on the hotizontal axis commands a rotation rate. translation and rotation are independent, thus the operator can simultanously control both by clicking off-axis. The pad's border color indicates the robot's status (moving, stopped, etc.).

c)Map Display

To navigate robot, a map display gives the user with a "*bird's eye"* of the remote environment. The display is designed as the robot moves and shows sensed environment features and the robot's path. The map display provide a two kind of maps: *global map* and *local map*. For large-area navigation, global map helps maintain situational awareness by showing where the robot has bee. With the local map the user can precisely navigate through complex spaces. At any time, the user can annotate the global map by adding comments or drawing "virtual" obstacles.(e.g. if the operator finds something of interest, he can draw an artificial barrier on the map and the robot's obstacle avoidance will keep the robot from entering the region). Table 2 lists situations commonly encountered in indoor vehicle teleoperation. Although no individual sensor works in all situations, the collection on sensors provides an complete coverage.

Table2

Sensor performance in teleoperation situations

Situation	Sonar (TOF)	Ladar (laser)	2D Image (intensity)	3D Image (disparity)	Kind of fails
▪ Smooth surfaces (no visual texture)	Fails-1	OK	OK	Fails-2	1-specular reflection 2-no correlation
▪ Rough surface (little/no texture)	OK	OK	OK	Fails-2	3-echo not received 4 -no depth measurm.
▪ Far obstacle (>10m)	Fails-3	OK	Fails-4	Fails-5	5- poor resolution 6 - limited by tranceiver
▪ Close obstacle (<0.5m)	OK-6	OK-7	OK-8	Fails-9	7- limited by receiver 8- limited by focal focal length
▪ Small obstacle (on the ground)	OK	Fails-10	Fails-4	OK	9- high dispariry 10-outside of scan plane
▪ Dark environment (no ambient light)	OK	OK	Fails	Fails	

4.Senzor fusion algorithms

a) Map Display

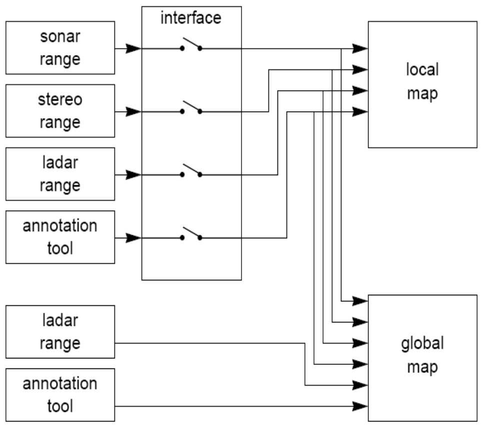
This tool use sensor data and vehicle odometry for registration. The interface allows the user to select which sensors are used for map building at any time.Fig..4 shows how the map is constructed. The local map shows only current sensor data in proximity to the robot. Past sensor readings are eliminate whenever new data is available. In contrast the global map displays sensor data over a wide area and never discards sensor data. Additionally, the global map allows the user to add annotations.

Map Building Evaluation

The robot is placed in a room with a variety of surfaces (smooth, rough, textured, nontextured). Fig. 5 shows maps constructed with different sensors combinations.

- In the first image (stereo only the we see some clearly defined corners, but some walls are not well detected due to lack of texture.
- In the second image (sonar only), the sonar’s low angular resolution and specular reflections result in poorly defined contours.
- In the third image (stereo and sonar) both corners and walls are well detected, however due to stereo’s non-linear depth accuracy, there is significant error.
- In the final image (ladar only) the map clearly shows the room.

Obviously, for an indoor environment in which the principal features are uniformly vertical(walls) the ladar produces the most useful map.



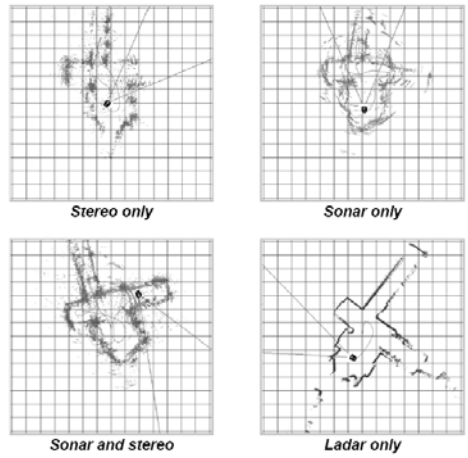
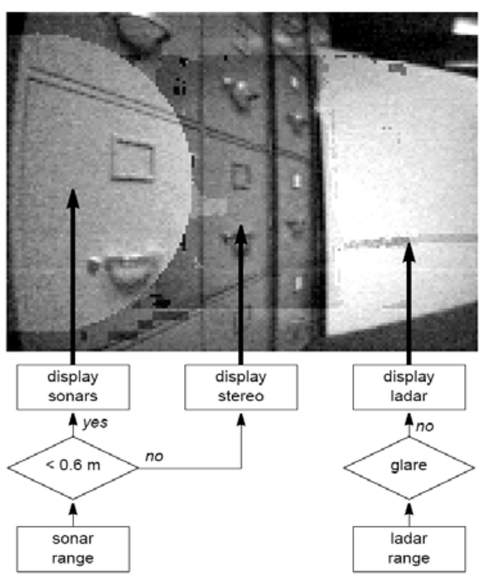


Fig. 4 –Map display processing

Fig. 5- Map display

b) Image Display

Fig. 6 shows how the image display is constructed. For each overlay pixel the sonar range is used to decide whether to display sonar or stereo data. When the sonar range is low, sonar data is used because stereo correlation fails when objects are too close. Otherwise, if the sonar range is high, stereo is displayed. In addition, because the ladar is precise and reliable in an office environment, is useful always overlay ladar range when available (i.e. unless the ladar detects glare.)



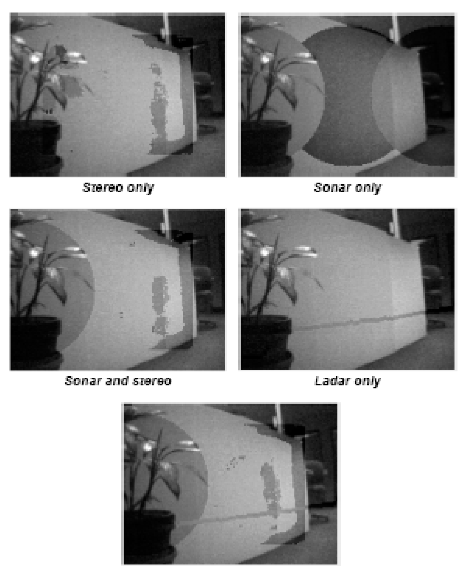


Fig. 6- Image display processing

Fig. 7- sensor fusion based image display

Image Display Evaluation

To evaluate the image display the robot is placed in a setting which has difficult to sense characteristics: in front of the robot is a smooth, untextured wall. Close to the robot is a large office plant. Fig.7 shows the image display for this scene with various overlay. Each range sensor individually has problems, but collectively provides robust sensing of the environment.

- In the top left image (*stereo only*) the wall edges are clearly detected and the plant partially detected(the left side is too close for stereo correlation).However, the center of the wall (untextured) is completely missed.
- In the top right image (*sonar only*) the plant is detected well, but the wall is shown at incorrect depths due to specular reflection.
- In the middle left image (*fused sonar and stereo*)both the wall edge and plant are detected, but the center remains undetected.
- In the middle right image (*ladar only*) we see that the wall is well defined, but that the planar scan fails to see the plant.
- In the bottom image (*all sensors*) we see that all features are properly detected. The sonar detect the plant, the ladar folows the wall and stereo find wall edge.

5.Obstacle detection

The most challenging tasks in vehicle teleoperation is obstacle avoidance. By exploiting complementary sensor characteristics, it is possible to avoid individual sensor failures and improve obstacle detection. Fig. 8 shows a scene with a box on the floor. Because the box is too small, it is not detected by the ladar (it is too short to intersect the scanning plane), nor by the sonar (it is located outside the sonar cones). However, it is properly detected by stereo as both display shows.

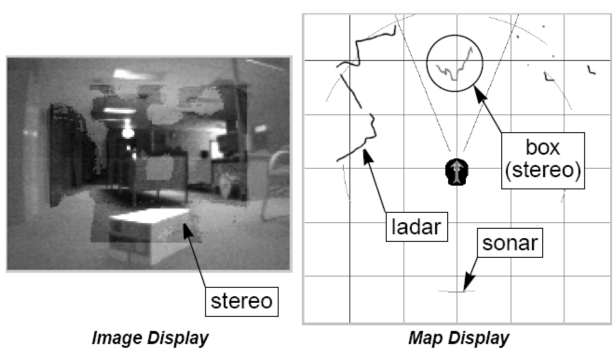


Fig. 8- Detection of small obstacle

Fig. 9 shows a situation in which the robot is approaching a chair. We can see that the chair is well detected by the stereo camera and the sonars. The ladar has problems with chair because only the supporting post intersects the scanning plane.

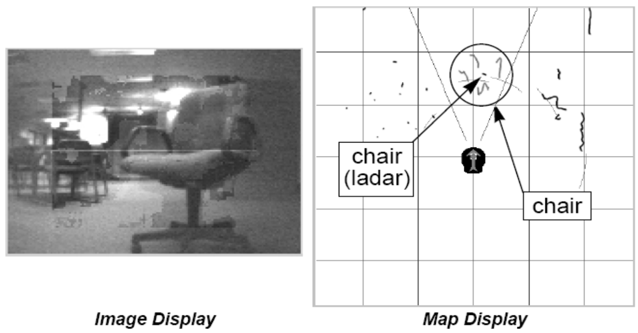


Fig. 9- detection of a chair

6.Conclusion

We have found that with an appropriate sensor suite and user interface, sensor fusion is a powerful method for improving vehicle teleoperation.

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