DATA INTERPRETATION FROM LEUZE ROTOSCAN SENSOR FOR ROBOT LOCALISATION AND ENVIRONMENT MAPPING.

by

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ABSTRACT: Two applications for the use of a laser-scanning device are currently under investigation at Lancaster University. Lancaster University Computerised Intelligent Excavator (LUCIE) is an autonomous excavator which navigates using GPS and compass readings. Work is currently concentrating on navigational safety, for which the rotoscan sensor is employed for obstacle detection, and for possible self-localisation and environment comprehension in ambiguous operational states. Starlifter is a robotic arm built by Construction Robotics Ltd. The rotoscan sensor in this instance is to be mounted on the tool head and used as a final positioning navigation tool. Both these applications rely heavily on the interpretation of the received data, and the ability to filter out any interference. This paper initially outlines the mode of utilisation of the laser range finder within such applications and then proceeds to investigate the implications and potential limitations of such a sensor following the analysis of the sensory data from external field trials.

KEYWORDS: collision detection; navigation; robotics; sensors; surface estimation.

1.0 INTRODUCTION

Construction robots have been under development for many years, although in the field they have not yet fulfilled their potential [1]. Although it is relatively straightforward to get the robot to achieve its coarse objectives, it is considerably more difficult to ensure that the task is completed safely and accurately. One of the ways for handling safety is to fence the robot off away from human beings, and other disturbances, however this will often remove the gains of using a robot in the first place. The alternative approach is to have the robot respond predictably to its changing external environment. To do this effectively the robot needs to accurately sense its surroundings. Accurate sensing is also critical for tasks requiring accurate positioning and operations.

With regards to safety, there are numerous safety concerns that need to be catered for in the safety validation of such a system. Apart from internal operational integrity, of fundamental importance in such systems is the need to ensure correct interaction between the autonomous system and the environment. The correctness of such interaction will be dependent on the autonomous system's perception of its surroundings, these being dependent in turn on the exteroceptive sensory suite of the system, of which the laser scanner is a critical element.

Correct interpretation of the range sensing data is also critical for accurate positioning operations. In this case, accuracy becomes a critical parameter.

However, the operation of the laser scanner as a range sensing device gives rise to substantial

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ambiguity in the interpretation of the data, partly because of the limited information provided by scanning only in one plane at a time and mainly due to inherent limitations of the sensory system, such as dependency on object reflectivity and other physical parameters, which gives rise to uncertainty in the interpretation of the sensory information.

Knowledge of such limitations in the information quality from such a sensor is a fundamental necessity in developing a system that is capable of managing and utilising the information adequately for the task at hand. The focus therefore in such an application is to better comprehend;

1. the application of the rotoscan itself as an additional verification tool for other exteroceptive sensory data.
2. The inherent limitations in the interpretation of the rotoscan data for obstacle recognition, localisation, and accurate measurement.

This paper thus looks at aspects of concern in the use of such a sensing device for the underlying applications, given test runs that were performed for the sensor.

2.0 APPLICATION AREAS

The Rotoscan RS3 range sensor under test is a twin laser beam unit, with each beam scanning 90^o leading to a 180^o flat plane of view. The range of detection is up to 25m with obstacles as small as 70mm being detectable. Two protection boundaries can be programmed into the sensor, an object boundary and personal boundary. Both boundaries trigger relays once broken. Alternatively a serial data string is available.

Two application areas are being considered for the sensor. The first is Starlifter which aims to combine the laser scanner data with a camera view to enable accurate final positioning, the second is Lancaster University's Computerised Intelligent Excavator (LUCIE) which uses the sensor for navigation and operational safety.

2.1 Starlifter robot

Starlifter is a hydraulically powered portable robot with six revolute joints. The joints can be simultaneously locked in any position with power and control shut down to provide a stable platform to deploy heavy tools up to 200 kg at any orientation. Starlifter is currently configured to carry diamond core drilling tools and concrete saws for construction applications - for further details see reference [2].

One of the uses of Starlifter is working in hazardous environments in which human involvement is eliminated. In this case the robot is located in a remote position from the operator. Consequently information about the position of the robot base relative to the working area is required to enable the operator to position the robot accurately and safely.

An important use of the range scanner with Starlifter is to assist in the positioning of the robot base relative to the working area so that the robot can operate correctly within its working envelope. In this case the laser scanner is attached to the robot base, which is kept level by using balancing rams. The scanner's object safe field can then be adjusted for collision avoidance. Working area perception is improved via the use of a vision system.

2.2 LUCIE

LUCIE is a JCB801 retrofitted with Danfoss electro-hydraulic valves and three individual PC104 units to act as Low Level Controller, Activities Manager and Safety Manager [1]. The range sensor is mounted approximately 0.5m high on the excavator cab. This allows a full field of vision around the side of the excavator for slewing operations, as well as the area immediately around the arm and bucket. For final implementation a second range sensor would be placed on the opposite corner of the vehicle giving a swept coverage of approximately 300^o. The area directly behind the excavator is of lesser importance and can be protected by other sensing means, whilst the application of the frontal overlap removes blind spots due to operation of the arm.

The investigation in the case of LUCIE focuses on the evaluation of safety aspects and the underlying causes of operational risks for an autonomous excavator in a construction site environment [3].

2.3 Sensor Data Processing

The serial data from the laser range sensor is extracted and processed using a user interface specially developed using the LabVIEW graphical programming environment. Figure 1 shows the front panel of the user interface. The serial data includes start and end identifiers, the scanner status bits and the user data. The user data represent the measured distances in mm per 2 degrees of the 180-degree range. A successive matrix manipulation of the serial data is employed to separate the user data and the status bits in the data processing section of the code diagram. Further processing of the user data is performed to visualise the measured distances in a Cartesian or polar co-ordinate graph.

The processed data can then be stored for further off-line evaluation. The data obtained represents the co-ordinates of a horizontal plane passing through the laser scanner known as a segment. Moving the laser scanner up and down at different levels, or by tilting the scanner, and by feeding back the vertical or tilt position of the scanner a three-dimensional graph of the working area can be constructed. Figure 1 illustrates a Cartesian map creation by stacking a number of scans taken by shifting the scanner in a vertical plane.

The data is also stored for post processing purposes for further analytical work. The processing and post-processing of the data and the visual representation provide the necessary tools to determine the operational characteristics as seen in the experimental tests and conclusions that follow.

3.0 EXPERIMENTATION

A series of tests were carried out with the range sensor to determine the performance characteristics in external environments and under the likely operational conditions to which the sensor will be subjected.

The objective of the tests was to determine the reading reliability in external environments, particularly:

i. when the scanner is utilised for the detection of surfaces that are irregular and with poor reflective properties

ii. When the scanner is attached to a moving platform and driven over rough terrain, and is therefore subject to machine vibrations and sudden displacement changes.

From the results obtained the level of accuracy of the data, given the specific operating conditions, was to be determined. In this manner, the interpretation of the data during operation could be adapted according to the sensor characteristics.

Experimental runs consisted of both static and dynamic tests, with 180^o scans being recorded every 0.75sec, The total number of scans per test ranged from 50 to 80. The distance measurements were extracted through the sensor data processing program and then post-processed to extract statistical characteristics of the data.

Final tests were performed on the plotted data for surface extraction via the Iterative End Point Fit algorithm [4], to determine the portability of such a routine, given the quality of the readings obtained in external environments.

Figure 2 illustrates a typical test run for the laser scanner, where the scanner is placed on a mobile platform and with the motion of the scanner as indicated.

3.1 Static Testing

Static tests were carried out with the laser scanner stationary and pointing to a static or partly static environment (i.e. with random object presence). Figure 3 illustrates the scanned data for a completely static test with figure 4 illustrating the mean and standard deviation values for the test. The number of scans recorded for this test was 50.

From the graph it is immediately appreciated that as distances from the scanner increase the standard deviation for the readings taken over the total number of scans increases. Given the prior measurements from the scanner of the detected surfaces, the readings give a zero mean error for the vast majority of the readings. Non-zero mean errors tend to occur mostly on poor reflective surfaces, since the surface is not adequately detectable.

The rate of change of standard deviation though, is relatively irregular and depends greatly on the type of surface being detected. This can be immediately noted from the detection of vehicles that cause unexpected fluctuations in readings due to the type of surfaces (including glass) on which the laser beam impinges. Yet still, an exponential relationship between distance and reading variance has been found to suitably fit the vast majority of readings, as would be expected from the general class of range sensor models described by Elfes [5].

Spurious readings have also been noted to cause unexpected increases in standard deviation readings, particularly at edges of surfaces and mostly at relatively distant surfaces. This is likely to be caused due to the possible repeatability errors in the range sensor output.

In the case of tests involving partial dynamic features in the environment, where an object was placed within the identified zone for a relatively short period of time at random, it was noted that the temporary presence of the object mainly causes a substantial increase in standard deviation in the sensory readings with a minor effect on mean value. The mean is found to only drop slightly in value as expected due to the presence of shorter distance measurements within the time interval where obstacles are present. Similar results were obtained when simulating rain conditions with standard deviation readings increasing whilst still maintaining relatively constant mean values.

3.2 Dynamic Testing

Dynamic tests were principally carried out with the laser scanner attached to a mobile platform and moved over relatively rough terrain, inducing minor vibrations to the sensor. Figure 5 outlines the results from such a dynamic test for the example illustrated in figure 2. In this specific test, the laser scanner is brought close to the objects at a relatively linear and constant speed.

To determine the repeatability of the sensory data given such operating conditions, successive readings were mapped onto each other following an angular and linear translation, so as to give the least mean square error between successive readings. The least mean square error is given in figure 5(i) as the test proceeds for each scan taken (a total of 55 scans were taken in this test). Figure 5(ii) and (iii) outline the estimated linear and angular translations to obtain the least mean square error.

From the graphs it is easily noticeable that the root mean square error is much greater than the standard deviation readings obtained for the static readings. Most of this increase in the readings' variance can be said to be due to the motion of the sensor and the induced vibrations. Indeed towards the end of the test with the sensor's velocity almost zero, root mean square error values drop down to values close to those obtained for standard deviation in the static tests. This clearly indicates a substantial limitation of the laser scanner for accurate distance readings during motion, where sensor variance increases as expected due to the errors induced from the motion vibrations.

It can also be noted that as distance measurements increase a higher mean square error is observed with the range sensor in motion, as would be expected given the results of the static tests. This can be noticed from figure 5(i) where there is a gradual drop in root mean square error values as the laser scanner is brought closer to the obstacles. This drop is roughly exponential in nature, as would be expected.

The root mean square error has also been noted to increase with speed for the same distance measurements. Again, this would be expected partly because of the increased 'disturbance' between two successive scans.

3.3 Surface Estimation

The Iterative End Point Fit algorithm was applied to each and every set of test scans to determine the performance of the algorithm given the characteristics of the tests. The algorithm was found to perform poorly when applying the plotted readings directly, particularly under conditions where the variance between successive readings was large. This resulted in totally different surface profiles being generated between successive scans. Better results were obtained for tests with reduced variance in the readings, although spurious readings did cause sudden changes in the estimated surface profile.

Improvements to the algorithm were obtained by introducing a filtering algorithm to eliminate spurious readings between successive scans and by averaging multiple readings to smooth out any ambiguities within single scans.

However, due to the nature of the surfaces being scanned, the algorithm still gave erroneous interpretations when not scanning large flat surfaces, and therefore was not found to be adequate in its simple form for external environment surface recognition.

4.0 CONCLUSIONS:

The tests outline a number of interesting aspects with regards to the use of the Rotoscan range sensor in the outlined applications.

Primarily it is seen that the reliability and accuracy of the rotoscan readings degrades with the motion of the range sensor, mostly as a result of the induced irregular motion from the terrain characteristics. However, this does not diminish to any major extent the applicability of the sensor given that the measurements are made beyond the immediate vicinity of the autonomous system. Measurements made close to the autonomous system, requiring high accuracy, , cannot be made while the scanner is in motion. Accurate close-up measurements therefore require a stationary platform, which results in a drastic reduction in variance. This reduction in variance has also been found to be related exponentially with distance, and this exponential behaviour has been found to occur both during stationary and dynamic scans.

The range sensor has been noted to be ideal for detecting uniform surfaces perpendicular to the scanning plane. Slopes and other obstacles with uneven surfaces though detectable are much more difficult to identify, and distinguish from sensor errors. Indeed, the detection of such surfaces also induces larger variance values than for flat surfaces. In addition the ability to distinguish features as distance increase drops drastically, particularly if such features are of an irregular nature (i.e. not a flat perpendicular surface). It was also noted that transparent materials such as glass and water (rain) are not detectable to any significant extent, resulting mostly in spurious readings. However spurious readings seem to occur even in the absence of such surfaces and at a rate greater than for internal environments.

With regards to the iterative end-point fit algorithm for feature extraction, as stated earlier on, the algorithm was found to act poorly and was only useful in identifying large flat, perpendicular surfaces. The nature of the readings and the irregularity of the surfaces tend to inhibit the correct identification of the readings given the relatively high variance that occurs in external environments.

The above outline the main limitations for the use of the laser range finder in external environments. The sensor has been found to perform suitably particularly if relatively rough estimates of distance measurements are required, particularly when the scanner is in motion. The relatively high variance in the readings may not be too much of a hindrance if the data is only required to roughly estimate the distance from obstacles. In addition, the variance tends to drop as obstacles get closer to the autonomous system.

However, the nature of the readings, inhibits proper identification of environmental features unless, the sensor is stationary and multiple readings can be taken. In addition, feature identification and consequently self-localisation requires the presence of regular surfaces that are distinguishable for the relative clutter in the data caused by other irregular and poorly reflective surfaces. The absence of such type of surfaces and adequate operating conditions is highly likely to inhibit the correct application of the sensor for more accurate identification tasks.

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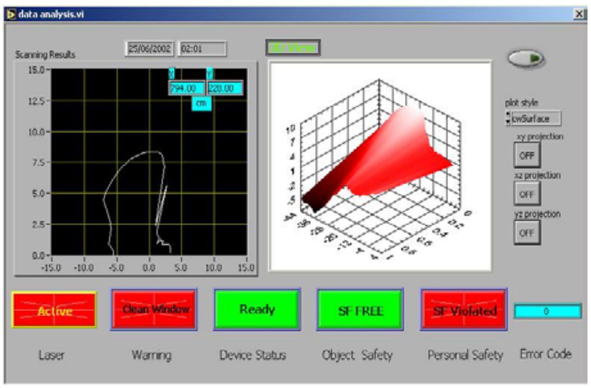

Figure 1. The front panel of the graphical user interface of the laser scanner

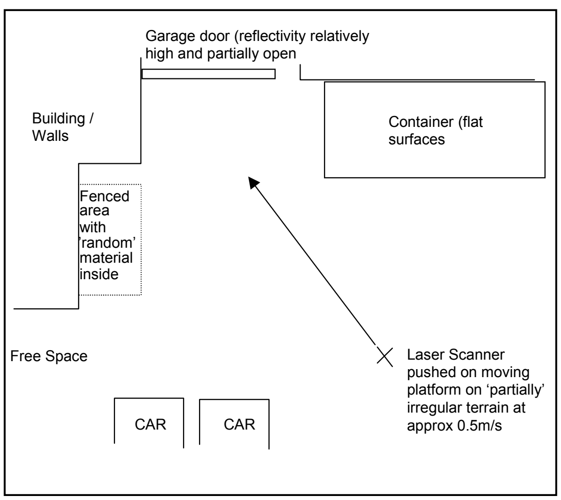

Figure 2. Typical test layout for Laser Range Sensor

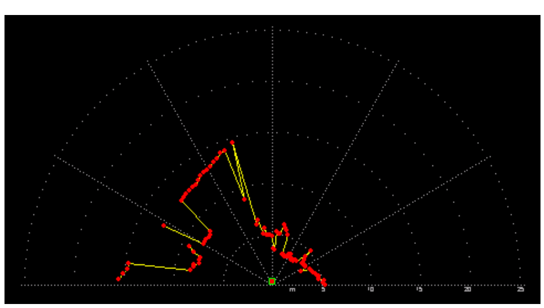

Figure 3. Static sample scan test in polar coordinates

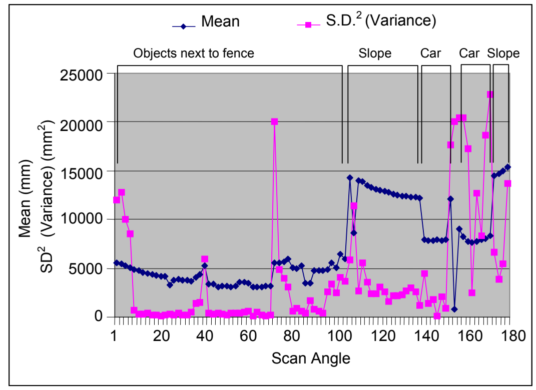

Figure 4. Statistical data (mean and standard deviation) for static test of figure 3.

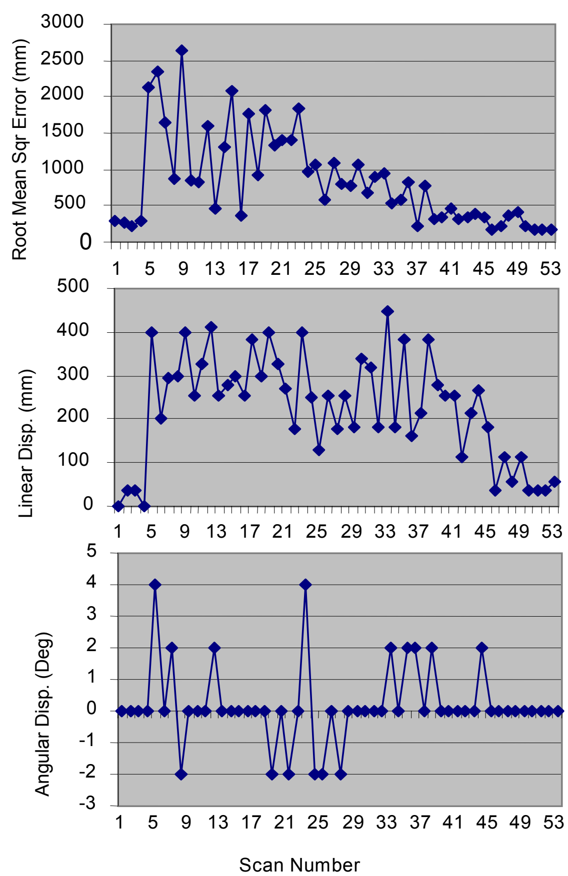

Figure 5. Results for dynamic test in figure D. (i) Root mean square error for every scan sample, (ii) estimated incremental linear displacement, (iii) estimated incremental angular displacement