An Integrated Robotic Laser Range Sensing System for Automatic Mapping of Wide Workspaces

P. Curtis, P. Payeur
Vision, Imaging, Video and Audio Research Laboratory
School of Information Technology and Engineering
University of Ottawa
[pcurtis, ppayeur]@site.uottawa.ca

Abstract

Creating 3-D surface representation of large objects or wide working areas is a tedious and error-prone process using the currently available laser range finder technology. The primary problem comes from the fact that these range sensors allow to capture at most one line of points from a given position and orientation. When this process is not properly controlled, registration errors tend to significantly degrade the accuracy of measurements which is revealed to be critical in telerobotic operations where occupancy models are built directly from these range measurements.

This paper presents the implementation of a prototype that has been developed to automatize the process of range measurements collection by integrating a high-end one degree-of-freedom laser range finder with a seven degree-of-freedom serial robotic manipulator. The development of a user-friendly interface to control every part of the scanning process is also described as it significant improves performance and facilitates data processing and storage.

Keywords: *Range measurements; robotic sensing systems; data fusion.*

1. INTRODUCTION

The acquisition of range data for the use of building occupancy models of cluttered workspaces tends to be a complex and tedious task, since most laser range finders only allow making measurements along either a single point, or a line. Workspaces in real world telerobotics applications are three-dimensional and complex. Therefore the acquisition of range data from many different viewpoints is required to properly construct an adequate occupancy model. This requirement for a full 3-D dataset can be met by mounting a high-resolution laser range finder on a precise robotic arm to acquire data from multiple positions and orientations.

Original equipment manufacturer (OEM) solutions provided with typical robotic arms and laser range finders are separate entities. This leads to the operator of the system to maneuvering the robotic arm to the desired position using the provided robot OEM tools, acquiring the required data from the laser range finder using the other set of supplied tools, and then repeating the process for each successive position and orientation required to complete the 3-D dataset.

This iterative manual process leads to errors in registration of the data through human faults and is submitted to a lack of repeatability. Since the data acquisition process takes a significant amount of time, the acquisition environment is more susceptible to perturbations. Moreover, such a manually operated system can hardly find an application in industrial processes where efficiency is a critical issue. An automated solution is therefore desired to increase productivity, repeatability, precision, and to decrease the data acquisition time. The present work is performed in the context of a research environment aiming at the development of semi-autonomous telerobotic systems operating in complex hazardous environments.

2. SYSTEM COMPONENTS

2.1 Robotic Arm

The robotic arm employed in the system is a F3 manipulator from CRS Robotics [1] that has 6 revolute joints, and is mounted upon a CRS 2 meter track [2]. This 7-degree-of-freedom (DOF) serial robotic arm is controlled via a digital programmable controller, the CRS C500C [3]. The controller has several communications methods, of which the RS-232 asynchronous link is the most desirable, since an additional communications adaptor is not required on the external controlling computer.

The software supplied by CRS, Robcomm3, provides a compiler for the RAPL-3 language [4], so that

CCECE 2004- CCGEI 2004, Niagara Falls, May/mai 2004

customized applications can be programmed for controlling the robotic arm and track. However, the range of applications that can be developed using this software package was determined to be not general enough for the application desired, which requires a generalized set of parameters passed by the external controller. This led to the use of the built-in joint movement commands, which allows the movement of one joint at a time for this first version of the automatic scanning system.

2.2 Laser Range Finder

The laser range finder employed is a Jupiter laser line scanner manufactured by Servo-Robot Inc. [5] that exploits the well-known synchronized triangulation technology developed at NRC [6]. This range finder is able to acquire 256 or 512 points per scan on a single line. The Servo-Robot Cami-Box [7] is used to control the Jupiter laser line scanner and also offers a RS-232 asynchronous link that connects to an external interface.

This sensor has been selected for its relatively large scan range that goes up to 1 meter, its high resolution and its compactness. Very few commercial range finders offer a sufficient scan range combined with a resolution that is suitable for the application considered [8, 9, 10] while representing a light payload for the manipulator.

Even though this sensor is originally developed for applications in the welding industry and not for 3D modeling, the software supplied by Servo-Robot, Winuser, has a functionality that allows the acquisition of raw range profiles, as well as the setting of the various parameters of the Jupiter to suit specific applications. Range data is normally saved to a proprietary file format (.3dx).

However, our previous experiments with this software revealed to be inefficient as the operator had to intervene after each scan to manually save the data acquired. This motivated the development of a new interface based on the RS-232 link to directly and automatically control the sensor, transfer the range data from the internal controller memory and save this information to a more suitable format.

3. SYSTEM DESIGN

3.1 Hardware

The new system uses an Intel-based computer running Windows 2000 that is interfaced with both the F3 manipulator controller and the Jupiter scanner controller via two RS-232 asynchronous links as shown in Figure 1. The laser range finder being mounted on the end effector of the robotic arm with a home-made bracket as shown in Figure 2, this configuration allows to synchronize and track with high precision the displacement of the sensor, to request a scan of a profile when the desired pose is reached and to download, display and save the range measurements in the desired format and location for further processing by modeling software.

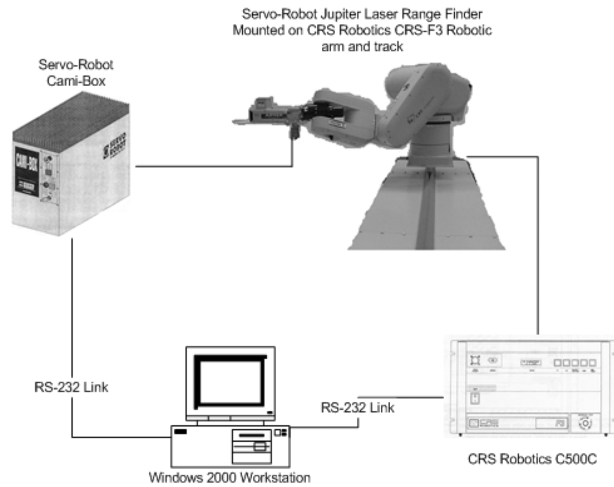

Fig. 1. Diagram of the integrated system.

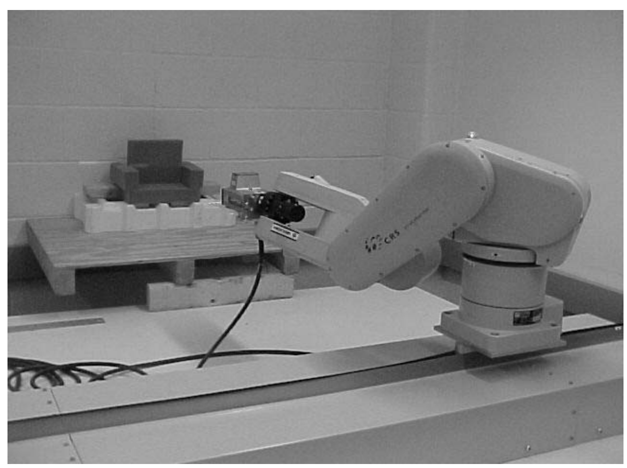

Fig. 2. The robotic arm and laser range finder scanning a mockup chair.

3.2 Software

Using the OEM supplied software, the robot had to be moved to the desired location through the use of the robot's software interface, and then using the laser range finder's software, the range data was acquired and saved to a separate file. This meant that for a scan of N lines, N different positions were manually calculated by the operator, and N different files were produced following operator's intervention. Additionally to this time consuming process, the files containing the laser line range data were in a proprietary format, unsuitable for direct fusion into a 3-D occupancy model using other software developed in our laboratory.

To overcome these limitations, a custom interface was designed to integrate the functionalities of the robot arm and the laser range finder. Using the command line instructions of the robotic arm controller [3] to control the movement of specific joints, as well as a modified inverse kinematics solution inspired from [11] for this specific 7-DOFs manipulator, the robot controlling module of the application was developed.

The module to control the laser range finder relies on low level internal commands provided by the manufacturer to interact with the Cami-box controller [12]. Of particular interest for this application was the implementation of the commands to enable and disable the laser, to activate the acquisition of the data using the scan command and to download the information stored in the sensor's controller memory.

The RS-232 serial protocol that is used to exchange information with both the laser range finder and the robotic arm is based on the Microsoft's WIN32 serial communications application programming interface (API) [13].

A user-friendly graphical interface was designed to manage the operation of the robot arm and the laser range finder as shown in Figure 3. It was developed using Microsoft Visual C++ 6 with the Microsoft Foundation Classes and Win32 APIs.

Using this interface, the operator now only has to specify the main parameters for the scan that include the starting position and orientation encoded in a homogenous transformation matrix (S), a vector defining the magnitude of the steps of the sensor along each direction that is encoded in a homogeneous transformation matrix (D), and the number of steps for the acquisition of the data (N). Using this limited set of parameters, the operator can select the desired resolution and size of the workspace to be measured. The data collected from all positions and orientations visited along the scanning trajectory is then saved to a single file to facilitate further processing and minimize errors.

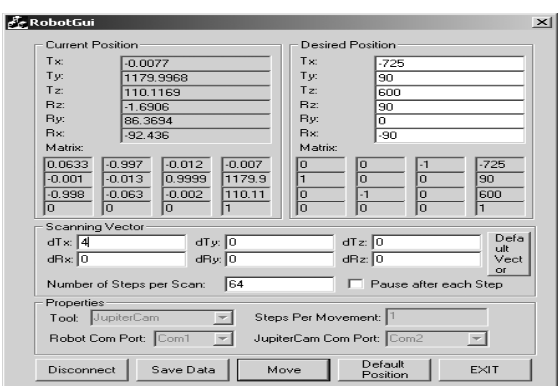

Fig. 3. Operator's graphical interface.

3.3 Integrated system's operation

To ensure the safety of the operator and equipment, as well as to minimize development time, it was decided for this first prototype to move the robotic arm one joint at a time, as well as to turn the laser on only when required to acquire data. A typical acquisition sequence using the parameters set by the operator then results in the following steps:

1. The current scan position (P) is determined by the starting transformation matrix (S), and the step transformation matrix (D) multiplied by itself n times, where n represents the current step number and is between 0 and N, such as:

$$P=SD^n$$

2. Once the scan position is computed, the robot inverse kinematics solution is used to generate the 7 joint values.
3. The robot control module then moves each of the joints to their respective angular position.
4. Once the robot is finished moving, the laser is turned on, the line of data is acquired, and the laser is turned off. The range data is kept in a temporary memory with the corresponding pose of the sensor.
5. Steps 1 to 4 are repeated until n=N.
6. Once the scanning trajectory is complete, the operator clicks on a button on the graphical interface to automatically save the acquired data to a specified file.

4. EXPERIMENTAL RESULTS

Originally, the time to acquire 64 lines of data from a series of 3 different viewing areas using the OEM provided set of tools, excluding merging the data into one viable set of data points, was on the order of a day [14]. Repeatability was low, due to the manual driving of the robotic arm by using the supplied command line interface, or the pendant tool. Important loss of precision in the registration of the position and orientation parameters was occurring as a consequence of numerous manipulations.

With the new integrated acquisition setup, the time to acquire 64 lines of data from 3 different viewing areas is currently about 2 hours. Precision of the fusion of the multiple lines of range data is ensured by using maximal precision in the registration parameters of the system as provided by the robotic arm. Repeatability is also much improved due to the fact that sensor displacements are now fully programmed and take advantage of the precision of the integrated computer controlled solution. These performances have been achieved without optimization of the control strategy as robot joints are moved one at a time and the laser is turned on and off for each scan line, forcing it to run a complete internal recalibration procedure each time. It is expected that acquisition time can still be very significantly reduced after these aspects will have been refined.

Data visualization is currently accomplished via a Matlab script to present the 3D distribution of raw measurements. A sample of range data points collected on the scene shown in Figure 2 is presented in Figure 4. We can observe the quality of the mapping and the limited number of outliers that are collected. This fact is critical in ensuring a proper modeling of complex surfaces on which a telemanipulator will have to interact.

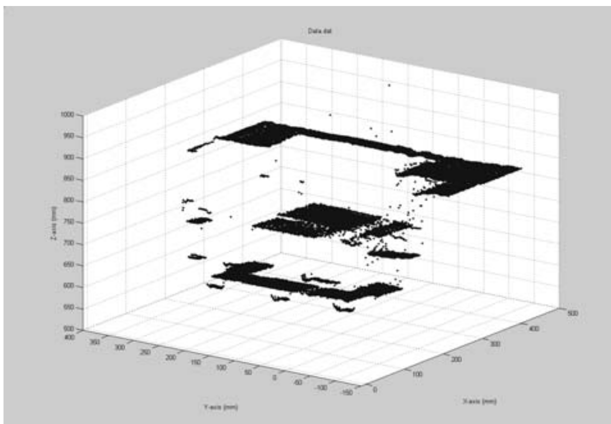

Fig. 4. 64 range profiles collected on the mockup chair.

5. CONCLUSIONS AND FUTURE WORK

The worth of an automated laser range data acquisition system consisting of a integrated robotic arm with a laser range finder has been demonstrated primarily through the improvement of the acquisition time (approximately 5 times faster without optimization being completed). Additionally, since there is no intervention of a human operator between the acquisition of each profile in the data set, repeatability is inherently improved, as well as the precision in the fusion of each line acquired to produce a 3-D data set. The used-friendly interface allows any untrained operator to define a multiple viewpoints scanning trajectory that will be automatically scanned with full registration of the data collected without any external intervention required.

Further refinements of the integrated scanning system are currently underway. Among other things, to further decrease the scanning time while making displacement smoother, the simultaneous movement of the manipulator's joints is being enabled. As the main goal is to allow a scan of full surfaces with a single line range sensor using a minimal displacement of the sensor, various scanning patterns are being tested and compared. The operator interface is also being refined to integrate visualization functionalities of the range profiles to allow the operator to quickly evaluate the quality of the scans obtained. Finally, supplementary saving file formats are going to be available to better match with 3D modeling tools.

Acknowledgements

The authors wish to acknowledge the support of the Canadian Foundation for Innovation and the Ontario Innovation Trust as well as the Faculty of Engineering of the University of Ottawa for their support that made this research work possible.

References

[1] CRS Robotics Corp., *F3 Robot System User Guide,* Burlington, ON, 2000.

[2] CRS Robotics Corp., *Track User Guide,* Burlington, ON, 1999.

[3] CRS Robotics Corp., *C500C Controller User Guide*, Burlington, ON, 2000.

[4] CRS Robotics Corp., *RAPL-3 Language Reference Guide,* Burlington, ON, 1999.

[5] Servo-Robot Inc, *Jupiter 3-D Laser Vision Camera Installation and Operation Manual,* St-Bruno, QC, 1996.

[6] M. Rioux, "Laser Rangefinder Based on Synchronized Scanning", in *Applied Optics*, vol. 23, pp. 3837-3844, 1985.

[7] Servo-Robot Inc, *Cami-Box Vision System Control Unit User's Manual,* St-Bruno, QC, 2000.

[8] 3D Scanners, *ModelMaker range sensors technology*, http://www.3dscanners.com, UK, 2004.

[9] Inspeck,*3D Capturator digitizer*, http://www.inspeck.com, Québec, QC, 2004.

[10] 3dcgi.com, *3D cameras and digitizers*, http://www.3dcgi.com/cooltech/cameras/cameras.htm, 2004.

[11] W.M. Keck Virtual Factory Lab, *Virtual Robot System version 2,* Technical report, School of Industrial and Systems Engineering, Georgia Institute of Technology, pp. 25-39, 2002.

[12] Servo-Robot Inc, *Data-3000 System Commands and Parameters,* St-Bruno, QC, 1997.

[13] A. Denver, "Serial Communication in Win32", in *Microsoft Windows Developer Support*, http://msdn.microsoft.com/library/default.asp?url=/library/en-us/dnfiles/html/msdn_serial.asp, 1995.

[14] C. Chen, *Registration of Range Measurements With Compact Surface Representation,* Master thesis, University of Ottawa, Ottawa, ON, 2002.