Blanche: Position Estimation for an Autonomous Robot Vehicle

Ingemar J. Cox

AT&T Bell Laboratories
Murray Hill, New Jersey 07974

ABSTRACT

This paper describes the position estimation system for an autonomous robot vehicle called Blanche, which is designed for use in structured office or factory environments. Blanche is intended to be low cost, depending on only two sensors, an optical rangefinder and odometry. Briefly, the position estimation system consists of odometry supplemented with a fast, robust matching algorithm which determines the congruence between the range data and a 2D map of its environment. This is used to correct any errors existing in the odometry estimate. The integration of odometry with fast, robust matching allows for accurate estimates of the robot's position and accurate estimates of the robot's position allow for fast, robust matching. That is, the system is self sustaining.

The vehicle and associated algorithms have all been implemented and tested within a structured office environment. There is no recourse to passive or active beacons placed in the environment. The entire autonomous vehicle is self contained, all processing being performed on board. We believe this vehicle is significant not just because of the sensing and algorithms to be described, but also because its implementation represents a high level of performance at very low cost.

1. INTRODUCTION

A key to autonomy is navigation, i.e. an accurate knowledge of position. By position, we mean the vehicle's (x, y, θ) configuration with respect to either a global or local coordinate frame, *not* topological position, e.g. to the left of the wall. Dead reckoning using inertial guidance and odometry sensors drift with time so that the estimated position of the vehicle becomes increasingly poor. This complicates the process of position estimation. In order to correct for these cumulative errors, the vehicle must sense its environment and at least recognize key landmarks. Using sensory information to locate the robot in its environment is the most fundamental problem to providing a mobile robot with autonomous capabilities.

This paper describes the position estimation system employed by the vehicle. Section (2) begins with a brief overview of the vehicle and its guidance system. Section (3) then discusses in detail the navigation (position estimation) subsystem employed by the vehicle. Included in this is a description of the robot's map representation, Section (3.1), the algorithm used to match the range data to this map, Section (3.3), as well as some implementation details. Section (3.4) discusses how the odometry position estimate is combined with the correction estimated by the matcher. The system has been implemented on the vehicle and experimental results are included in Section (4).

2. OVERVIEW OF BLANCHE

Blanche [3] is an experimental vehicle intended to operate autonomously within a structured office or factory environment. It is designed to be low cost, depending on only two sensors, an optical rangefinder and odometry. Blanche, shown in Figure (1), has a tricycle configuration consisting of a single steerable drive wheel at the front and two passive rear wheels. The vehicle is powered by two sealed 12V 55Ah batteries which, in the current configuration, provide a useful lifetime of approximately seven hours. Control of the cart is based on a Multibus system consisting of a MC68020 microprocessor with MC68881 math coprocessor, 2 Mbyte of memory, an ethernet controller, a custom two-axis motor controller and an analogue-to-digital convertor. The Motorola 68020 runs a real-time UNIX® derived executive called NRTX [10].

The cart is equipped with two primary sensors: odometry on each of the two rear wheels and an optical rangefinder. Both sensors are extremely low cost (under $1000 each for components), and together provide all the navigational sensing information available to the cart. The advantage of odometry is, of course, that it is both simple and inexpensive. However it is prone to several sources of errors. First, surface roughness and undulations may cause the distance to be over estimated. Second, wheel slippage can cause distance to be under estimated. Finally, variations in load can distort the odometer wheels and introduce additional errors. If the load can be measured, then the distortion can be modelled and corrected for [17]. Where appropriate, a simple and more accurate alternative is to provide a pair of knife edge, non-load bearing wheels solely for odometry. Blanche uses this approach. In addition, even very small errors in the vehicle's initial position can lead to gross errors over a long enough path. Consequently, it is imperative that the vehicle's environment be sensed.

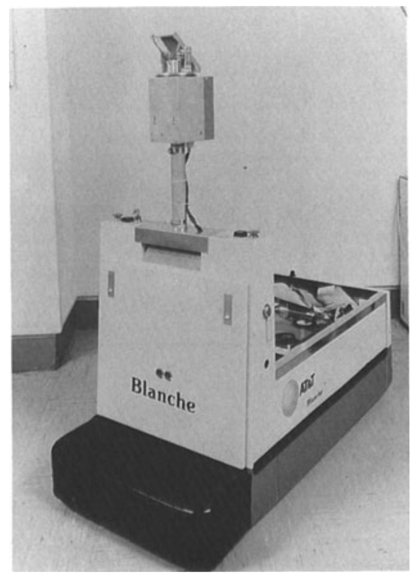

Figure 1: Blanche, an autonomous robot vehicle.

A simple low cost time-of-flight optical rangefinder has been developed specifically for cart navigation [12]. The rangefinder uses an approximately 1″ diameter beam and a rotating mirror to provide 360° polar coordinate coverage of both distance and reflectance out to about 15 feet. Both radial and range resolution correspond to about 1 inch at a ranging distance of 5 feet, with an overall bandwidth of approximately 1 kHz. Figure (2) shows a typical range map of a room obtained from a single scan of the rangefinder. A scan typically takes about one second. Each point is represented by its corresponding region of uncertainty, denoted by a circle of radius twice the standard deviation in the measurement. It should be pointed out that the error due to assuming that the range output is linear with distance, may sometimes exceed the error due to noise in the rangefinder. This systematic error can be removed by using a table look up technique to accurately map range output into distance.

The control of Blanche can be classified into three main components; path planning, guidance (trajectory generation and low level control) and navigation (position estimation). These components are illustrated in Figure (3).

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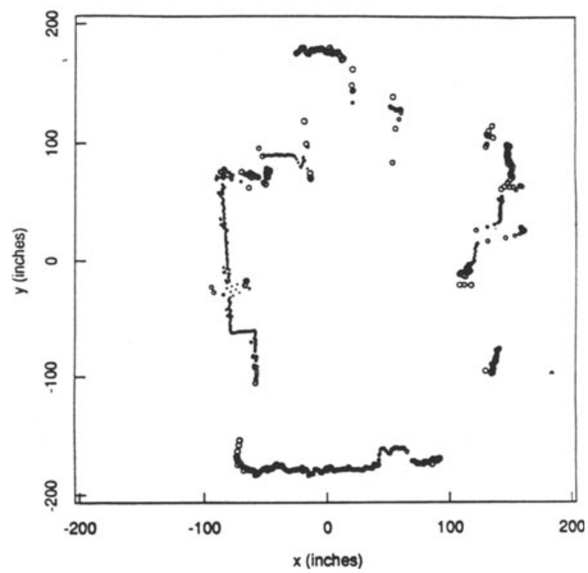

Figure 2: A range data scan obtained in a typical room. (Each point is denoted by twice its standard deviation).

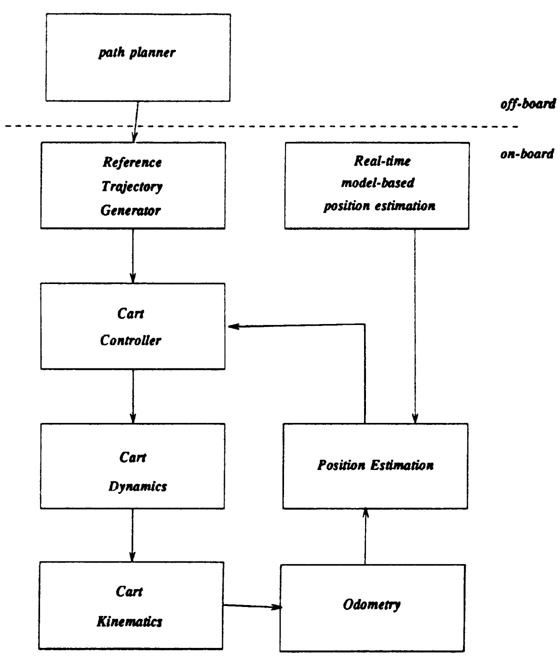

Figure 3: Block diagram of the overall control system.

The path planner [19] is an off-line program which generates a series of collision free maneuvers, consisting of line and arc segments, to move the vehicle from a current to a desired position. Since the cart has a minimum turning radius (approximately 2 feet), it is not possible to simply turn on the spot and vector to the desired position as is the case for differentially driven vehicles.

This path is downloaded to the vehicle, which then navigates along the commanded route. The line and arc segments specifications are sent to control software consisting of low level trajectory generation and closed-loop motion control [13]. Briefly, the reference state generator takes each segment specification from which it generates a reference vector at each control update cycle (every 0.1 secs). The cart controller controls the front steering angle and drive velocity using conventional feedback compensation to maintain small errors between the reference and measured states.

3. NAVIGATION (POSITION ESTIMATION)

Navigation can be broadly separated into two distinct phases, reference and dead reckoning, as discussed in [6]. Reference guidance refers to navigation with respect to a coordinate frame based on visible external landmarks. Dead reckoning refers to navigation with respect to a coordinate frame that is an integral part of the guidance equipment. Dead reckoning has the advantage that it is totally self contained. Consequently, it is always capable of providing the vehicle with an estimate of its position. Its disadvantage is that the position error grows without bound unless an independent reference is used to periodically reduce the error. Reference guidance has the advantage that the position errors are bounded, but detection of external references or landmarks and real-time position fixing may not always be possible. Clearly inertial and external reference navigation are complementary and combinations of the two approaches can provide very accurate positioning systems.

Position estimation based on the *simultaneous* measurement of the range or bearing to three or more known landmarks is well understood [15]. However, recognizing naturally occurring reference points within a robot's environment is not always easy due to noise and/or difficulties in interpreting the sensory information. Placing easy to recognize beacons in the robots workspace is one way to alleviate this problem. Many different types of beacons have been investigated including (i) corner cubes and laser scanning system, (ii) bar-code, spot mark or infra-red diodes [16] and associated vision recognition systems [9] and (iii) sonic or laser beacon systems. We chose not to rely on beacons, believing that the ability to operate in an unmodified environment was preferable from a user standpoint.

There have been many efforts to use high level vision to navigate by, particularly stereo vision [1], [8]. However, conventional vision systems were ruled out because of the large computational and associated hardware costs: We want the vehicle to be economic.

Figure (4) is an overview of Blanche's position estimation system. It consists of:

1. An *a priori* map of its environment.
2. A combination of odometry and optical range sensing to sense its environment.
3. An algorithm for matching the sensory data to the map [4].
4. An algorithm to estimate the precision of the corresponding match/correction [5] which allows the correction to be optimally (in a maximum likelihood sense) combined with the current odometric position to provide an improved estimate of the vehicle's position.

Provided the error models are accurate, the combined position estimate is less noisy than any one of the sets of individual measurements. The sensor integration process can, of course, be routinely mechanized by use of the Kalman filter [11]. The Kalman filter is not explicitly used in this system, but equivalent results are obtained.

3.1 Map Representation

Many spatial representations have been proposed. However, it is worth reflecting on the purpose of a map representation. Our purpose is to compare sensed range data to a map in order to refine our position estimate. The map is *not* intended to be used for path planning, it is not even necessarily intended to be updated by sensory data. It's sole purpose is for position estimation in an absolute coordinate frame. While many spatial representations have been proposed few appear to have been tested on a real vehicle. One major exception is occupancy grids [7]. Occupancy grids represent space as a 2– or 3D array of cells, each cell hold an estimate of the confidence that it is occupied. A major reason given for not using a more geometric representation is that sensor data is very noisy making geometric interpretation difficult.