Ute Modelling Information

Motion Model

We are using an Ackerman Model:

$$\begin{bmatrix} \dot{x}_c \\ \dot{y}_c \\ \dot{\phi} \end{bmatrix} = \begin{bmatrix} v_c \cos(\phi) \\ v_c \sin(\phi) \\ v_c \tan(\alpha) \end{bmatrix}$$

Now, if we translate our model to the gps and laser point, let us call this point (x_v, y_v).

$$\begin{bmatrix} x_v \\ y_v \end{bmatrix} = \begin{bmatrix} x_c + a\cos\phi - b\sin\phi \\ y_c + a\sin\phi + b\cos\phi \end{bmatrix}$$

The velocity v_c is measured with an encoder locate in the back left wheel. This velocity is translated to the center of the axle with the following equation:

$$v_c = \frac{v_e}{\left(1 - \tan(\alpha)\dfrac{H}{L}\right)}$$

For our vehicle:

$L = \mathbf{2.83},\ H = \mathbf{0.76},\ b = \mathbf{0.5},\ a = \mathbf{3.78}$

Finally the discrete model in global coordinates can be approximated with the following set of equations:

$$\begin{bmatrix} x(k+1) \\ y(k+1) \\ \phi(k+1) \end{bmatrix} = f(x,u) = \begin{bmatrix} x(k) + \Delta T(v_c\cos(\phi) - \dfrac{v_c}{L}\tan(\phi)(a\sin(\phi) + b\cos(\phi))) \\ y(k) + \Delta T(v_c\sin(\phi) + \dfrac{v_c}{L}\tan(\phi)(a\cos(\phi) + -b\sin(\phi))) \\ \phi(k) + \Delta T\dfrac{v_c}{L}\tan(\alpha) \end{bmatrix}$$

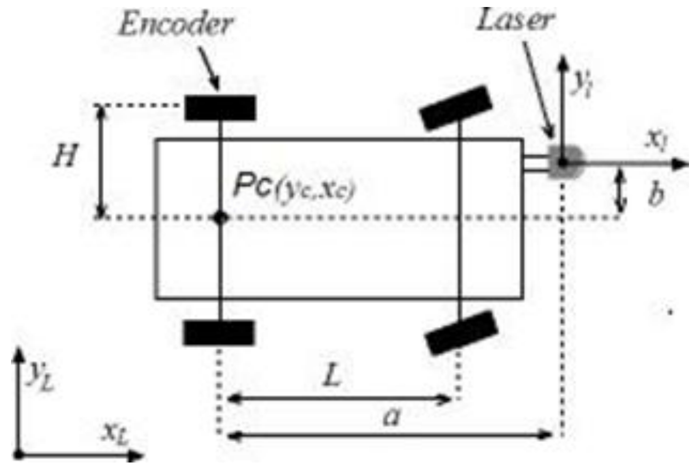

Figure 1: *Vehicle kinematics*

Observation Model

Observation model for range and bearing sensor:

$$\begin{bmatrix} z_r \\ z_\beta \end{bmatrix} = h(x) = \begin{bmatrix} \sqrt{(x_L - x_v)^2 + (y_L - y_v)^2} \\ \operatorname{atan}\left(\dfrac{(y_L - y_v)}{(x_L - x_v)}\right) - \phi + \dfrac{\pi}{2} \end{bmatrix}$$

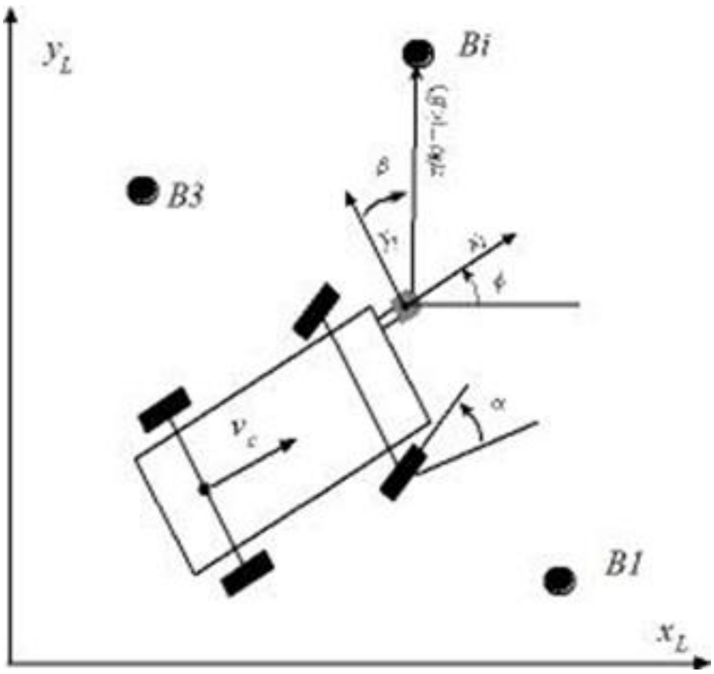

Figure 2: *Vehicle and Laser sensor*

Appendix A

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A.1 Motion Model Jacobians:

$$\frac{\partial f}{\partial X} = \begin{bmatrix} 1 & 0 & -\Delta T(v_c \sin(\phi) + \frac{v_c}{L}\tan\alpha(a\cos(\phi) - b\sin(\phi))) \\ 0 & 1 & \Delta T(v_c \cos(\phi) - \frac{v_c}{L}\tan\alpha(a\sin(\phi) + b\cos(\phi))) \\ 0 & 0 & 1 \end{bmatrix}$$

A.2 Observation Model Jacobians:

$$\frac{\partial h}{\partial X} = \begin{bmatrix} \frac{\partial h_r}{\partial x} \\ \frac{\partial h_\beta}{\partial x} \end{bmatrix} = \begin{bmatrix} \frac{\partial z_r}{\partial(x_v, y_v, \phi_v)} \\ \frac{\partial z_\beta}{\partial(x_v, y_v, \phi_v)} \end{bmatrix}$$

with

$$\frac{\partial h_r}{\partial X} = \frac{1}{\Delta}[-\Delta x, -\Delta y, 0]$$

$$\frac{\partial h_\beta}{\partial X} = \left[\frac{\Delta y}{\Delta^2}, -\frac{\Delta x}{\Delta^2}, -1\right]$$

$$\Delta x = (x_L - x_v) \qquad \Delta y = (y_L - y_v)$$

$$\Delta = \sqrt{\Delta x^2 + \Delta y^2}$$

Where

$\{x_v, y_v, \phi_v\}$ are the vehicles state variables.

$\{x_L, y_L\}$ is the landmark position.

For the Slam case, where the state vector is the vehicle posse and beacons position:

$$\frac{\partial h}{\partial X} = \begin{bmatrix} \frac{\partial h_r}{\partial x} \\ \frac{\partial h_\beta}{\partial x} \end{bmatrix} = \begin{bmatrix} \frac{\partial z_r}{\partial(x_v, y_v, \phi_v, \{x_L, y_L\})} \\ \frac{\partial z_\beta}{\partial(x_v, y_v, \phi_v, \{x_L, y_L\})} \end{bmatrix}$$

with

$$\frac{\partial h_r}{\partial X} = \frac{1}{\Delta}[-\Delta x, -\Delta y, 0, 0, 0, \ldots \Delta x, \Delta y, 0, 0 \ldots 0]$$

$$\frac{\partial h_\beta}{\partial X} = \left[\frac{\Delta y}{\Delta^2}, -\frac{\Delta x}{\Delta^2}, -1, 0, 0, \ldots, -\frac{\Delta y}{\Delta^2}, \frac{\Delta x}{\Delta^2}, 0, 0 \ldots 0\right]$$

$$\Delta x = (x_L - x_v) \qquad \Delta y = (y_L - y_v)$$

$$\Delta = \sqrt{\Delta x^2 + \Delta y^2}$$

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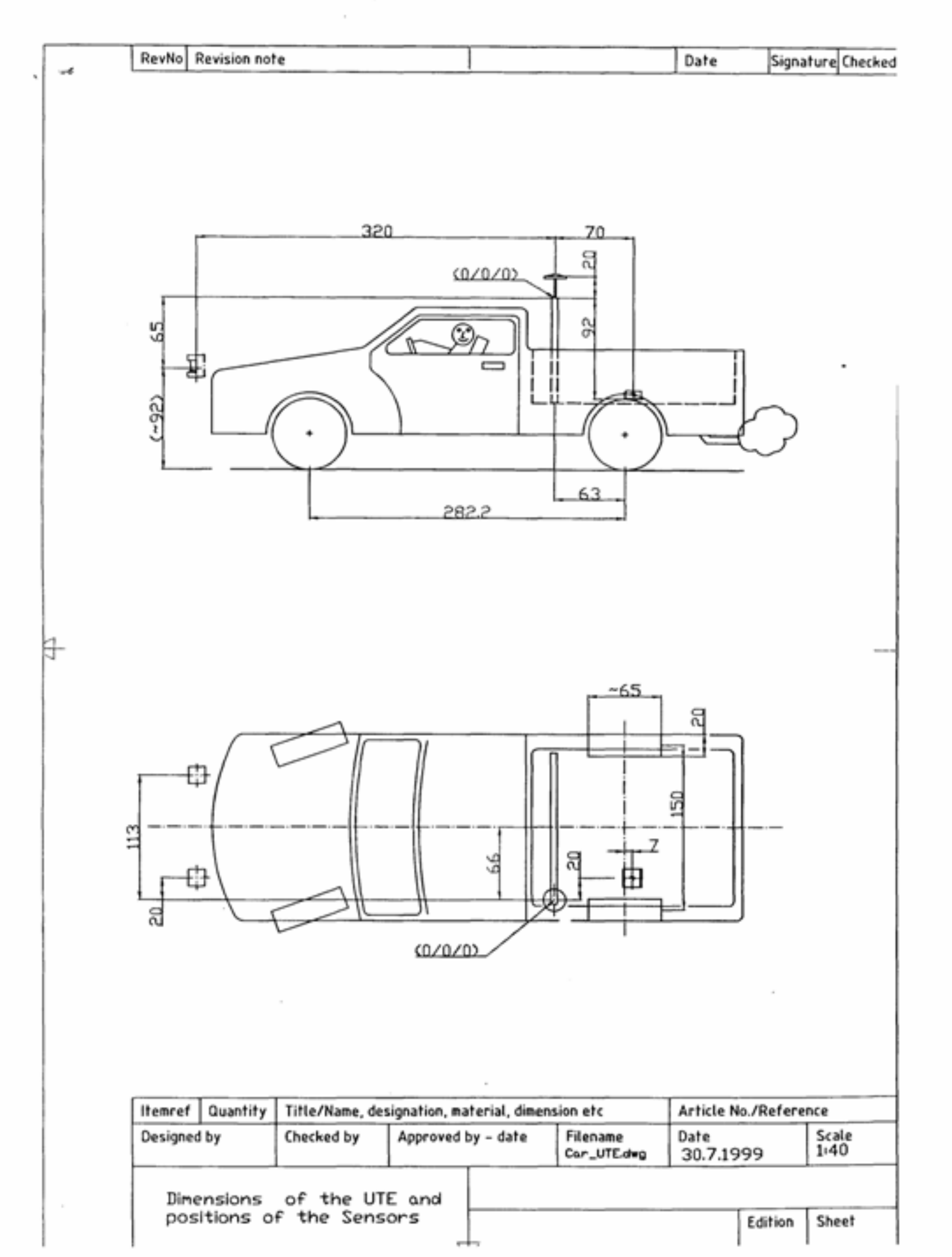
Appendix B

<u>Ute Dimensions:</u>



2 Sensors

2.1 Sensors available in the Ute

Dead Reckoning:

Velocity Encoder and Steering angle

Inertial Measument Unit: 3 accel / 3 gyros / 2 inclinometers (Watson Unit)

External Sensors:

GPS

Laser

Vision

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