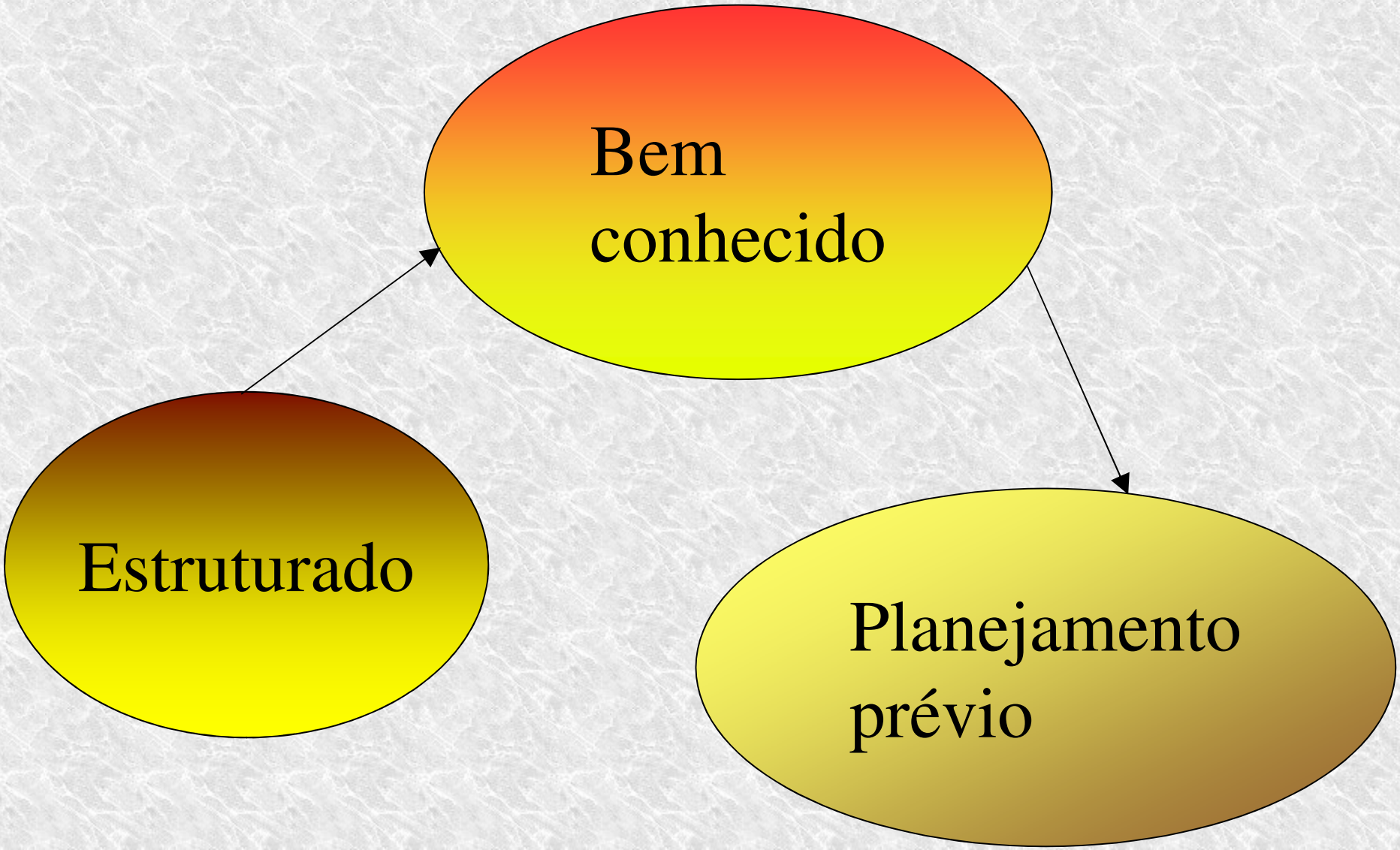
Controle de Robôs Móveis com Desvio de Obstáculos

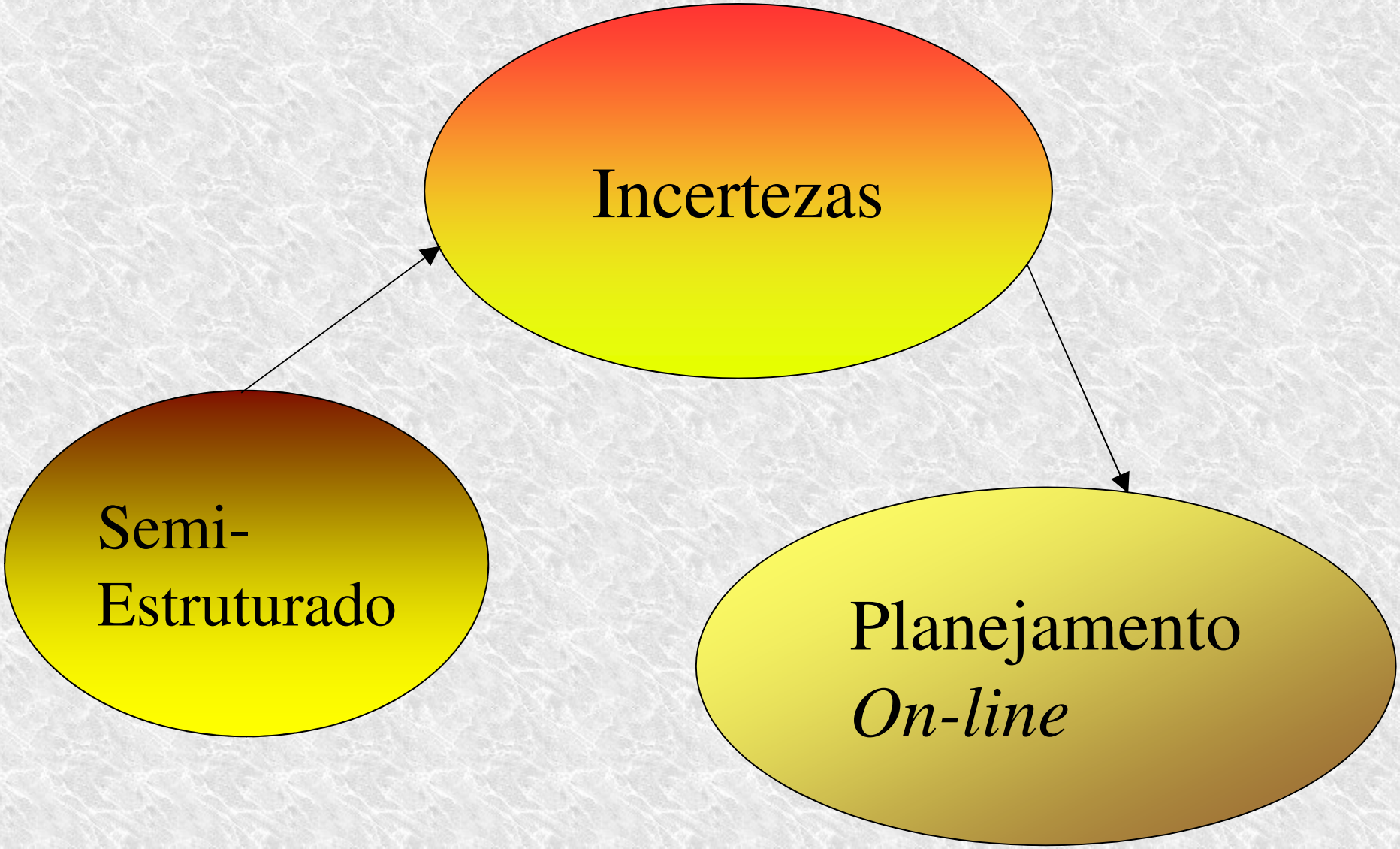
Tópicos Abordados no Trabalho

- Leis de Controle para Robôs Móveis
- Informação Sensorial de Distância
- Controle Baseado em Impedância
- Análise de Estabilidade dos Sistemas de Controle Propostos
- Testes de Performance

Ambiente de Trabalho do Robô



Ambiente de Trabalho do Robô



Equações Cinemáticas

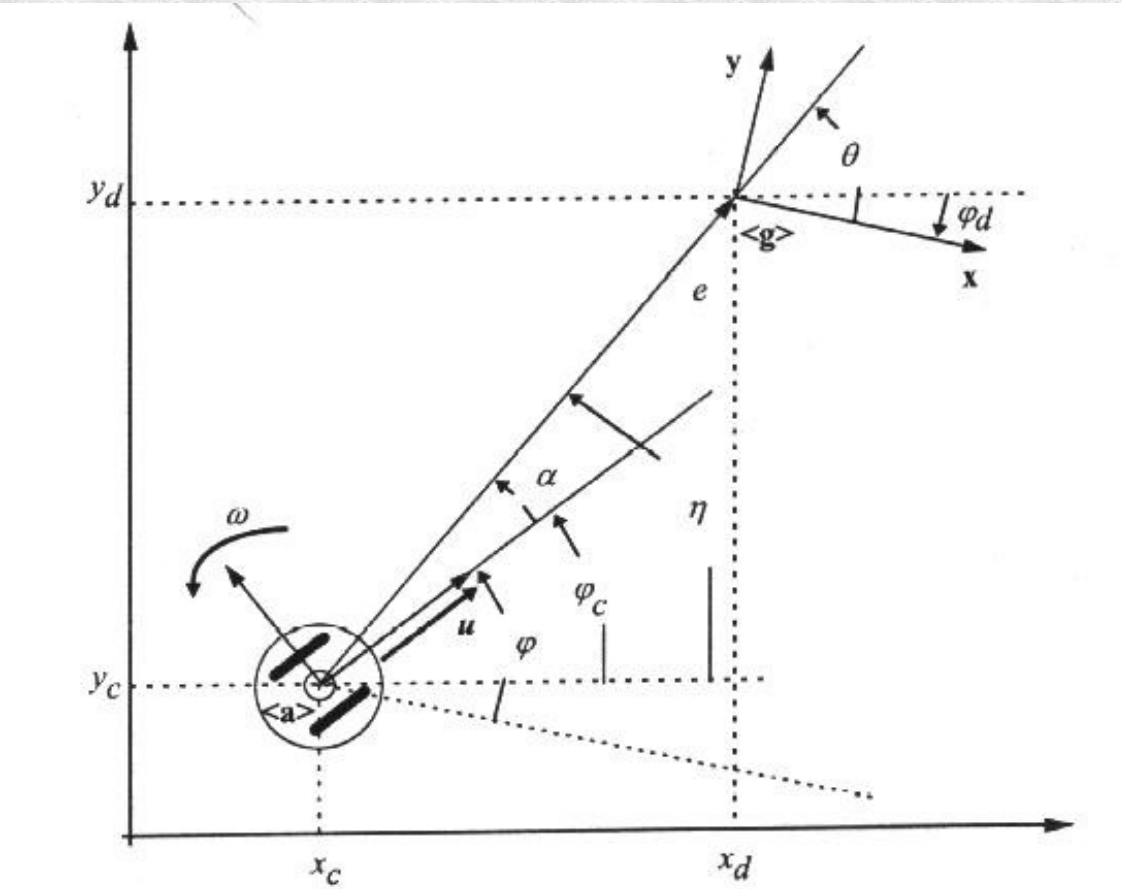


Figure 1. Position and orientation of the vehicle.

$$\dot{x} = u \cdot \cos\varphi$$

$$\dot{y} = u \cdot \sin\varphi$$

$$\dot{\varphi} = \omega$$

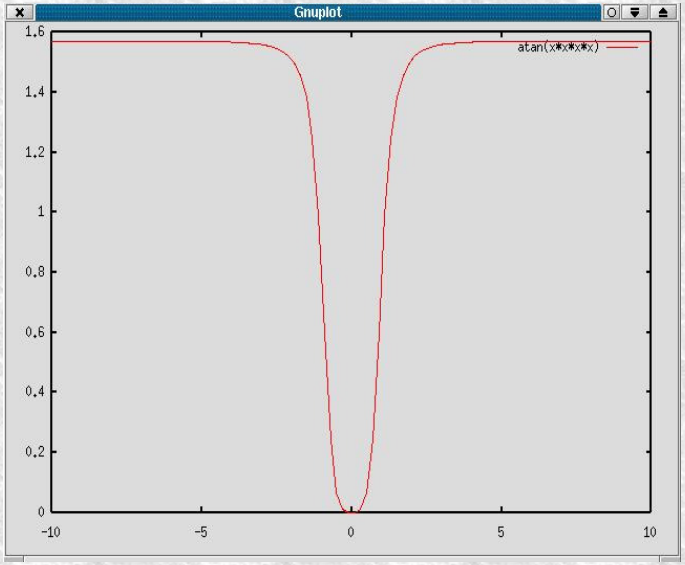
$$\dot{e} = -u \cdot \cos\alpha$$

$$\dot{\alpha} = -w + u \cdot sen\,\frac{\alpha}{e}$$

$$\dot{\theta} = u \cdot sen\,\frac{\alpha}{e}$$

Características Principais do Problema de Controle

- Chegar ao ponto destino
  - Trajetória definida
  - Ponto a ponto (origem ---> destino)
  - Orientação
- Rejeitar obstáculos
  - Controle baseado em impedância



Arquitetura de Controle

- Laço de Controle de Movimento / Posição
- Laço Externo de Controle Baseado em Impedância

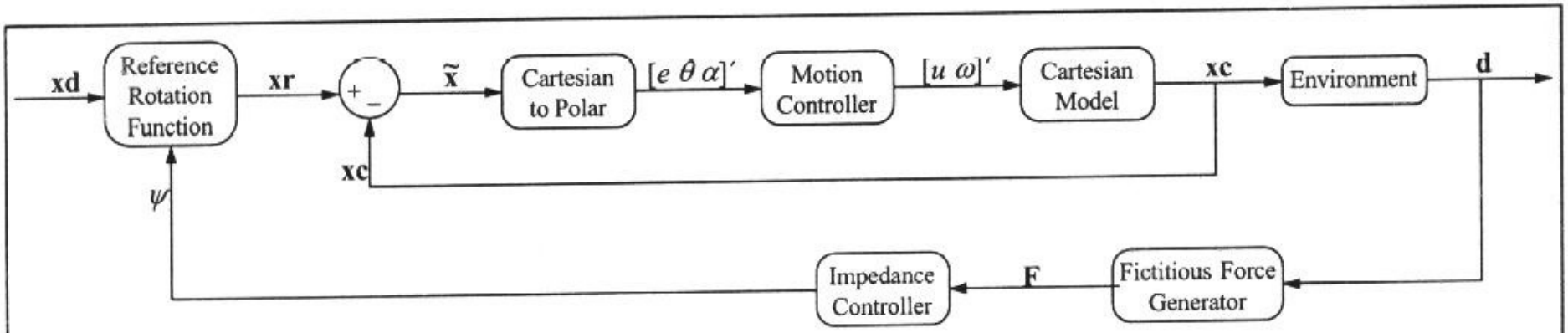


Figure 3. The block diagram of the proposed control system.

Realimentação Sensorial de Distância

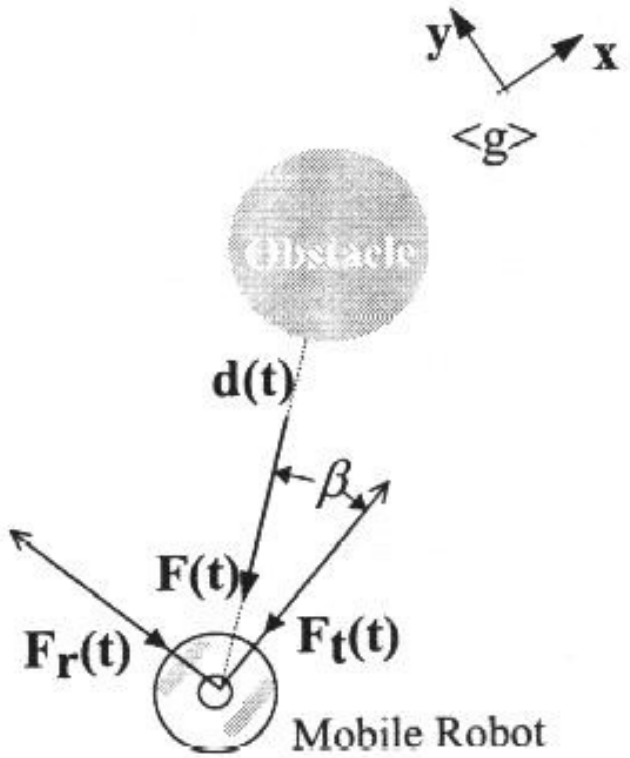


Figure 2. Action of the fictitious force **F**(t) on the mobile robot.

Controle de Movimento Desprezando Orientação Final

Variáveis de Estado : e, α

Função candidata Lyapunov:

$$V(e,\alpha) = V_1 + V_2 = \frac{1}{2}\cdot\lambda\cdot e^2 + \frac{1}{2}\cdot\alpha^2 \; para \; \lambda > 0$$

Resultados após manipulações matemáticas:

$$\dot{V} = -\lambda\cdot\gamma\cdot e\cdot\tanh e\cdot\cos^2\alpha - k\cdot\alpha^2 < 0$$

$$V(e,\alpha) = 0 \Rightarrow \begin{matrix} e(t) \\ \alpha(t) \end{matrix} \rightarrow 0 \; quando \; t \rightarrow \infty$$

Controle de Movimento Considerando Orientação Final

Variáveis de Estado : e, α, θ

Função candidata Lyapunov:

$$V(e,\theta,\alpha) = V_1 + V_2 = \frac{1}{2}\cdot\lambda\cdot e^2 + \frac{1}{2}\cdot\alpha^2 + \frac{1}{2}\cdot\kappa\cdot\theta^2 \; para \; \lambda, \kappa > 0$$

Resultados após manipulações matemáticas:

$$\dot{V} = -\lambda\cdot\gamma\cdot e\cdot\tanh e\cdot\cos^2\alpha - k\cdot(\alpha^2 + r\cdot\theta^2) < 0$$

$$\dot{V}(e,\theta,\alpha) = 0 \Rightarrow \begin{matrix} e(t) \\ \alpha(t) \\ \theta(t) \end{matrix} \rightarrow 0 \; quando \; t \rightarrow \infty$$

Controle Baseado em Impedância

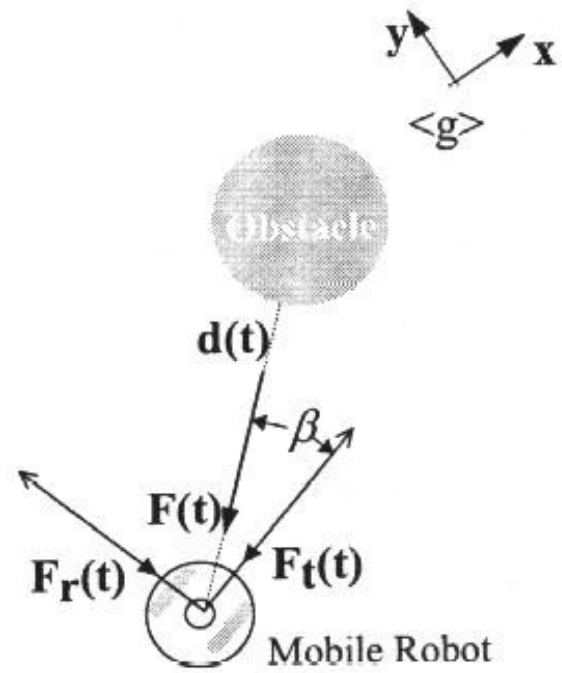
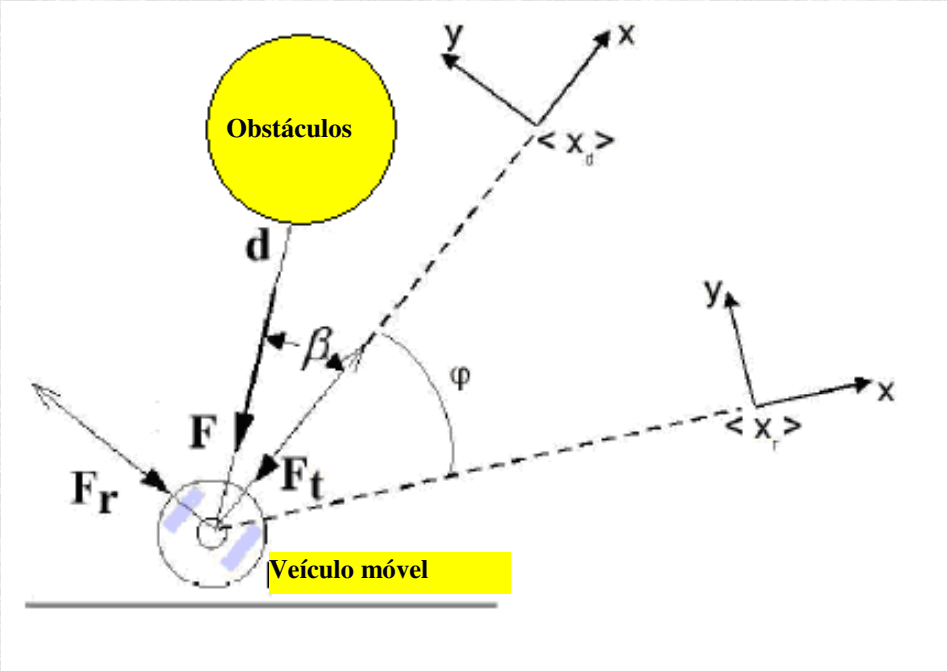


Figure 2. Action of the fictitious force **F**(t) on the mobile robot.

$$Z = Bs + K \qquad x_a = Z^{-1} \cdot F_t$$

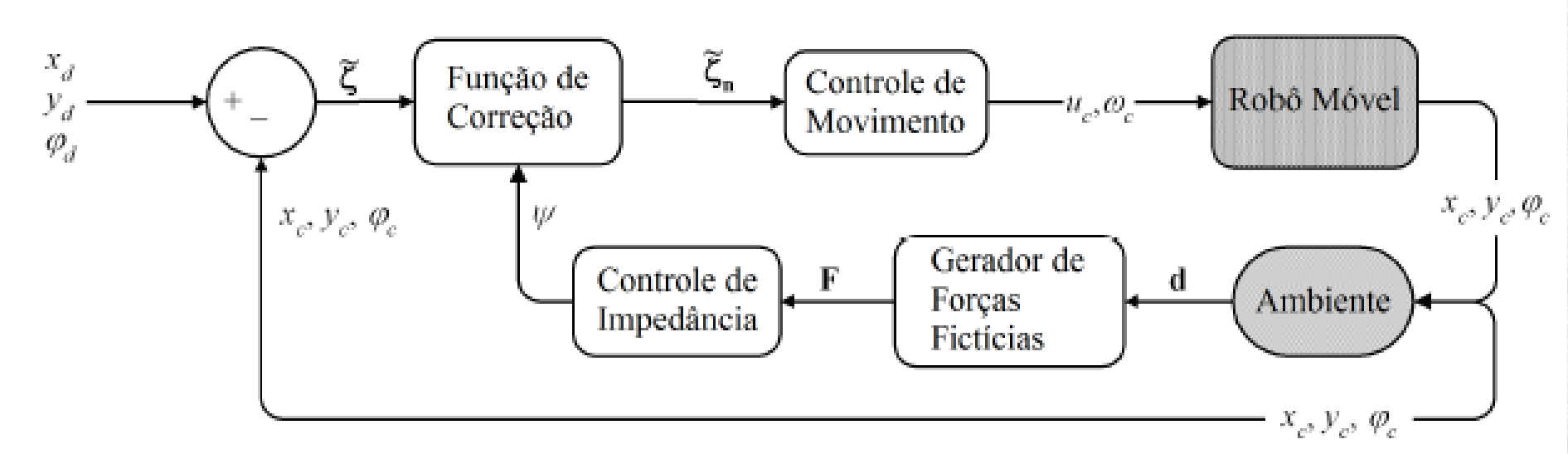
Controle Baseado em Impedância

- Impedância Generalizada
- Módulo da Força de Repulsão
  - $F = a - b[d - d_{min}]^2$, onde
  - $a = b.[d_{max} - d_{min}]^2$.
  - a e b constantes.
- Impedância
  - $Z(s) = Bs + K$
- Erro da Impedância
  - $x_a = Z(s)^{-1} F_t$
- Ângulo de Rotação
  - $\varphi = x_a.sign(F_r)$



$$\varphi = \left(\frac{\pi}{2} - |\beta|\right) reverseSign(\beta) - \alpha$$

Voltando ao Sistema de Controle...



$$e = \sqrt{(x_d - x_c)^2 + (y_d - y_c)^2}$$

$$\eta = atan3\left[(y_d - y_c), (x_d - x_c)\right]$$

$$\theta = \eta - \varphi_d$$

$$\alpha = \eta - \varphi_c$$

$$x_r = \begin{bmatrix} \cos\psi & \sin\psi & 0 \\ -\sin\psi & \cos\psi & 0 \\ 0 & 0 & 1 \end{bmatrix} x_d$$

$$\psi = x_a \cdot sign(Fr)$$

- Destino temporário
  - $x_r = \begin{bmatrix} cos\varphi & sen\varphi & 0 \\ -sen\varphi & cos\varphi & 0 \\ 0 & 0 & 1 \end{bmatrix} x_d$
- Ângulo de desvio inversamente proporcional à distância robô-obstáculo e ao ângulo β.
- Na ausência de obstáculos, φ é nulo e a matriz de rotação é igual a matriz identidade.
- Estável no sentido de Lyanpunov.

Ensaio 01: Controle de Posição Desprezando Orientação Final

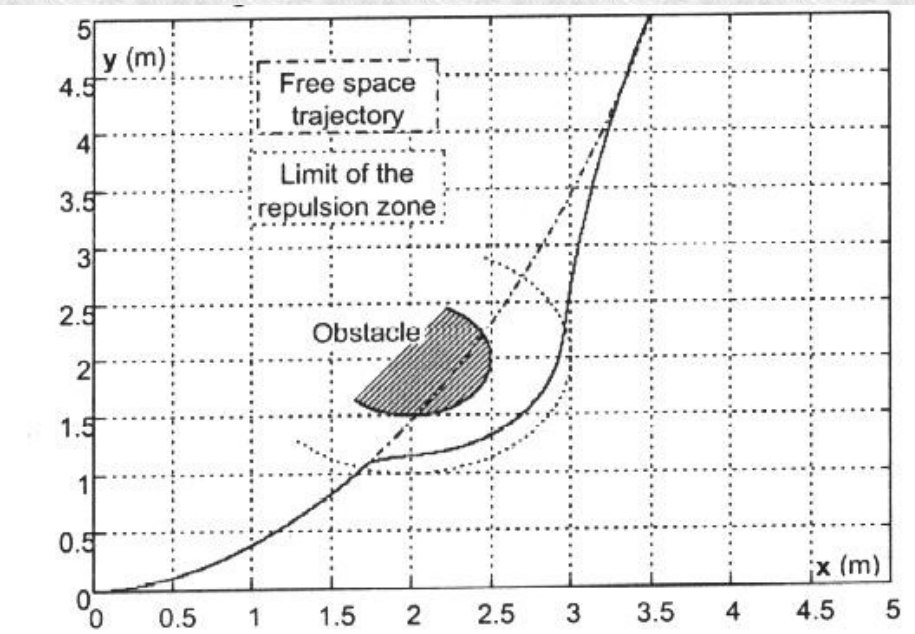


Figure 4. Trajectory described by the mobile robot to avoid an obstacle on its path.

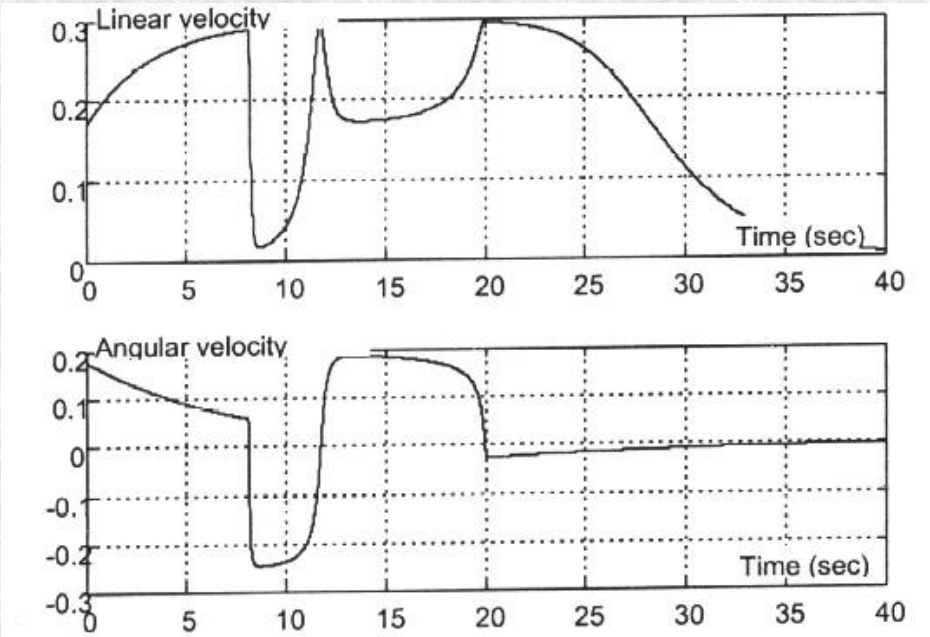


Figure 5. Linear and angular velocities of the mobile robot when avoiding obstacles.

Ensaio 01: Controle de Posição Desprezando Orientação Final

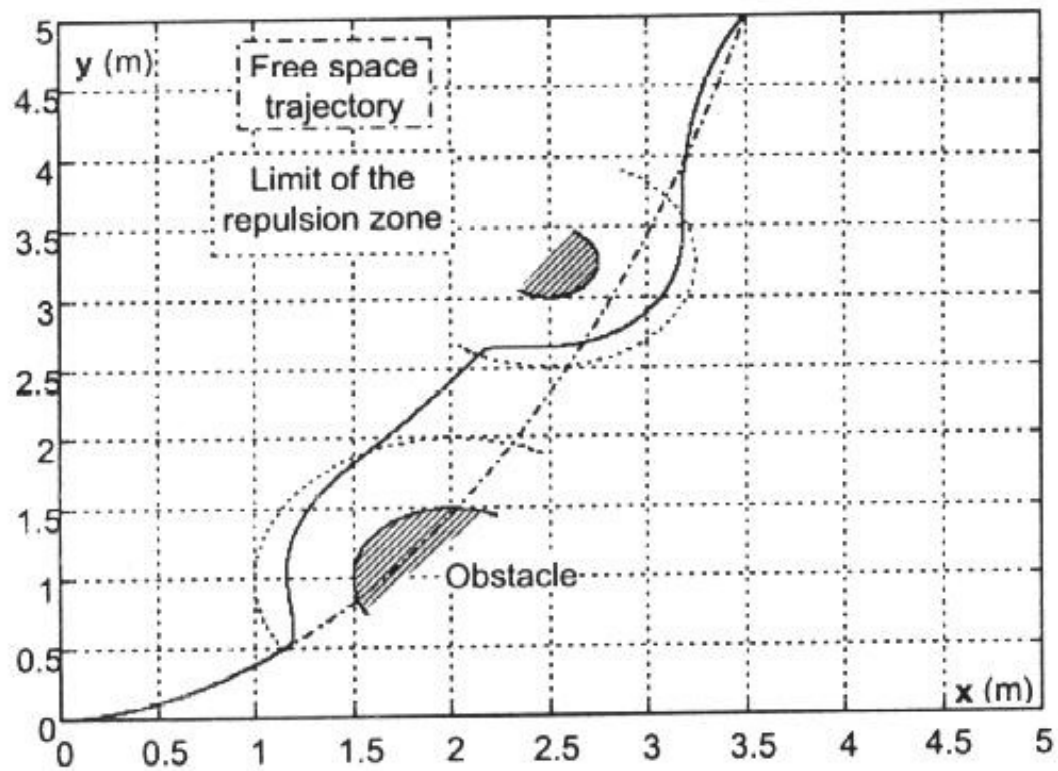


Figure 6. Trajectory described by the mobile robot to avoid two obstacles on its path.

Ensaio 02: Controle de Posição Considerando Orientação Final

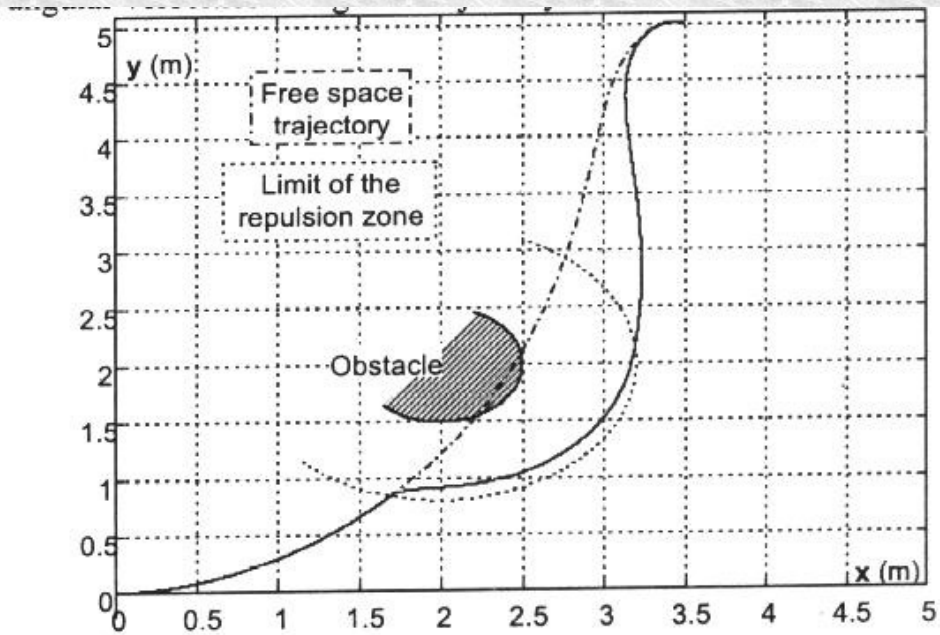


Figure 7. Trajectory described by the mobile robot to avoid an obstacle on its path.

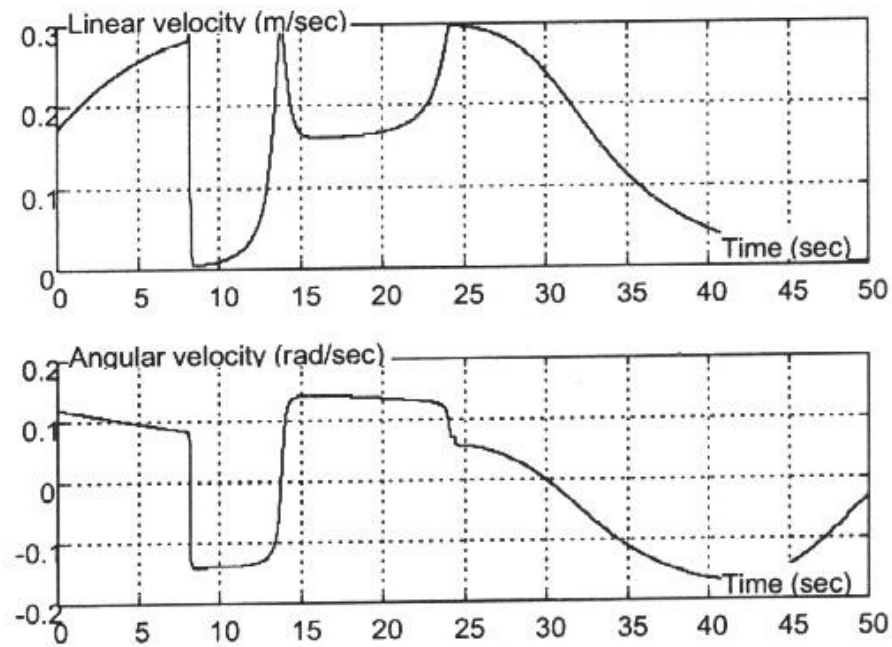


Figure 8. Linear and angular velocities of the mobile robot when avoiding obstacles.

Ensaio 02: Controle de Posição Considerando Orientação Final

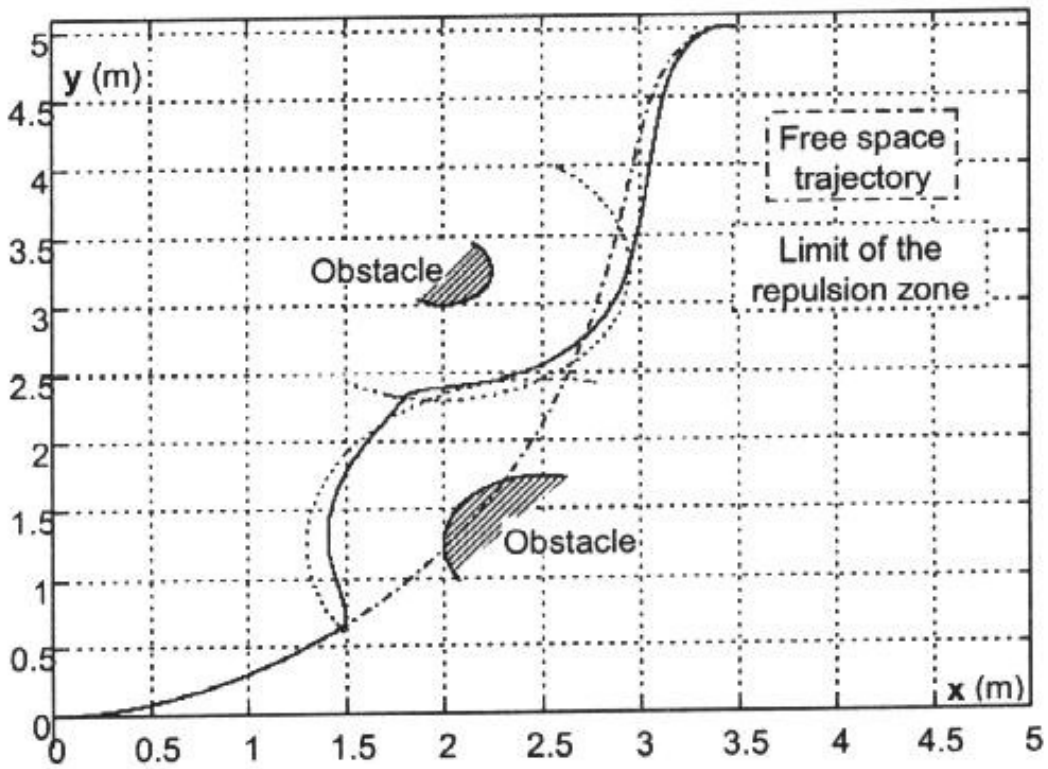
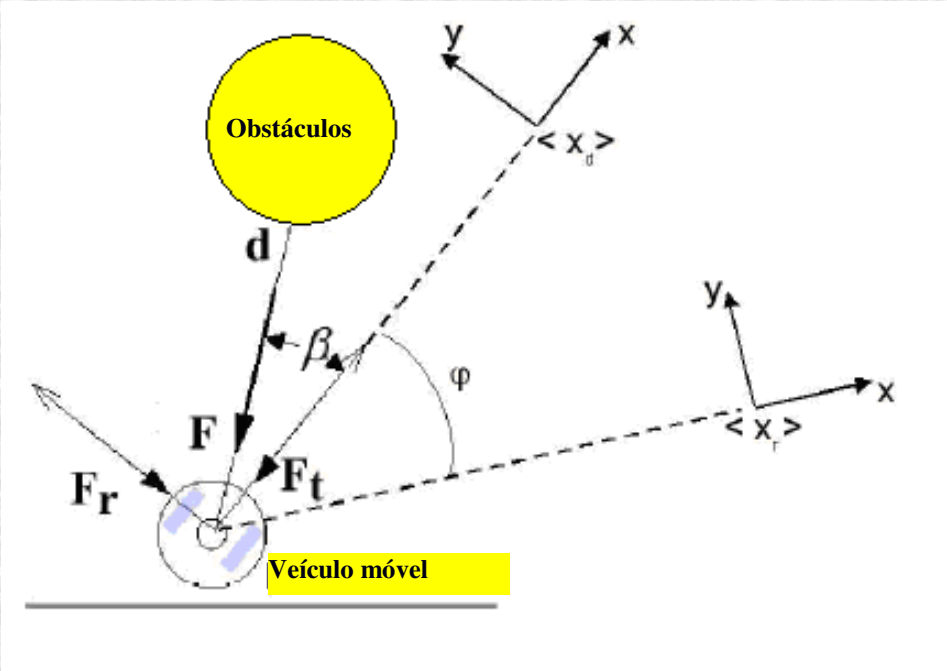
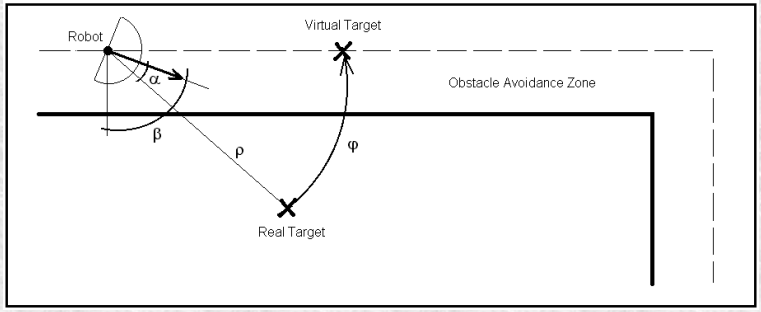
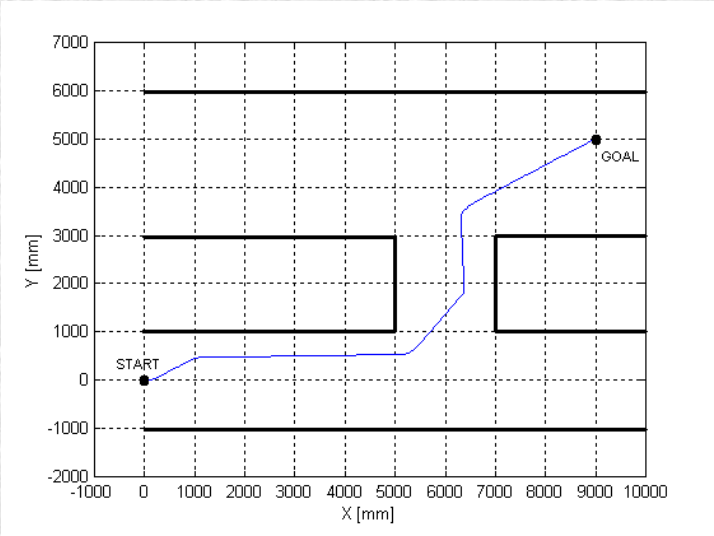


Figure 9. Trajectory described by the mobile robot to avoid two obstacles on its way.

Exemplo: Desviando de Paredes e Atingindo Alvo



Método de Impedância Modificado



$$\varphi = \left(\frac{\pi}{2} - |\beta|\right) reverseSign(\beta) - \alpha$$