Attractor dynamics approach to behavior generation: vehicle motion Part 2: sub-symbolic approach

Gregor Schöner Institute for Neural Computation, RUB

Behavioral dynamics



Behavioral dynamics

so far, we had a "symbolic" approach to behavioral dynamics: the "obstacles" and "targets" were objects, that have identity, are preserved over time...and are represented by contributions to the behavioral dynamics



"symbolic" approach

requires high-level knowledge about objects in the world ("obstacles", "targets", etc) and perceptual systems that extract parameters about these...

is that necessary?



Targets....

are segmented... in the foreground

=> neural fields to perform this segmentation from low-level sensory information: Dynamic Field Theory ...



Obstacles ...

obstacles need not be segmented ... does not matter if obstacles are one or multiple objects...

avoidance is about free space...



"sub-symbolic" approach



I each sensor mounted at fixed angle θ

- **that points in direction** $\psi = \Phi + \theta$ in the world
- erect a repellor at that angle



[from: Bicho, Jokeit, Schöner]

$$f_{\text{obs},i}(\phi) = \lambda_i(\phi - \psi_i) \exp\left[-\frac{(\phi - \psi_i)^2}{2\sigma_i^2}\right] \quad i = 1, 2, \dots, 7$$

Note: only Φ-ψ=-θ shows up, which is 2π constant! => force-let does not depend on Φ !



Obstacle avoidance: sub-symbolic ² vir obst

$$f_{\text{obs},i}(\phi) = \lambda_i (\phi - \psi_i) \exp\left[-\frac{(\phi - \psi_i)^2}{2\sigma_i^2}\right] \quad i = 1, 2, \dots, 7$$
$$\lambda_i = \beta_1 \cdot \exp\left[-\frac{d_i}{\beta_2}\right]$$

Repulsion strength decreases with
 ^{2π}distance, d_i
 => only close obstacles matter





=> as a result, range becomes wider as obstacle moves closer



summing contributions from all sensors

$$\frac{d\phi}{dt} = f_{\text{obs}}(\phi) = \sum_{i=1}^{7} f_{\text{obs},i}(\phi)$$



but why does it work?

shouldn't there be a problem when heading changes (e.g. from the dynamics itself)?



but why does it work?

shouldn't there be a problem when heading changes (e.g. from the dynamics itself)?



but why does it work?

shouldn't there be a problem when heading changes (e.g. from the dynamics itself)?





[from: Bicho, Schöner]

=> dynamics invariant!

Behavioral Dynamics



Bifurcations



 bifurcation as a function of the size of the opening between obstacles

Bifurcation as a function of the size of the opening between



=>tune distance dependence of repulsion so that bifurcation occurs at the right opening



S

Bifurcations



Bifurcation on approach to wall

 initially attractor dominates: weak repulsion

bifurcation

 then obstacles dominate: strong repulsion and total repulsion



Bifurcation on approach to wall

same with small opening



Bifurcation on approach to wall

at larger
opening:
repulsion
weak all the
way through:
attractor
remains stable



Tracking attractor

as robot
 moves around
 obstacles,
 tracks the
 moving
 attractor



Tracking attractor

 as robot moves in between obstacles, the dynamics changes but not the attractor



Tracking attractors







Observation:

- even though the approach is purely local, it does achieve global tasks
- based on the structure of the environment!



Observation

different solutions may emerge depending on the environment...

Other implementations

autonomous wheel-chair by Pierre Mallet, Marseille







[Pierre Mallet, Marseille]



other implementations

Estela Bicho's cooperative robots... => exercises...

Conclusion

- attractor dynamics works on the basis lowlevel sensors information
- as long at the force-lets model the sensorcharacteristics well enough to create approximate invariance of the dynamics under transformations of the coordinate frames

Second order attractor dynamics

source: Bicho, Schöner, Robotics and Autonomous Systems 21:23-35 (1997)

Second order dynamics

- idea: go to even lower level sensory-motor systems:
 - a sensor that only knows there is a target or an obstacle on the left vs. on the right...
 - but is not able to estimate the heading of either
 - a motor system that is not calibrated well enough to steer into a given heading direction in the world



behavior variable

turning rate omega rather than heading direction

- can be ``enacted'' by setting set-points for velocity servo controllers of each motor
- target: information about target being to the left, to the right, or ahead, but no calibrated bearing, psi, to target
- obstacle: turning rate
 - to the right when obstacle close and to the left
 to the left when obstacle close and to the right
 zero when obstacle far

dynamics of turning rate: obstacle avoidance

- pitch-fork normal form (to get left-right symmetry)
- but symmetry potentially broken by additive constant: biases bifurcation toward left or toward right

$$\dot{\omega} = (\alpha + \frac{1}{2}\pi)c_{\rm obs}F_{\rm obs} + \alpha\omega - \gamma\omega^3$$

obstacle avoidance

$$\dot{\omega} = (\alpha + \frac{1}{2}\pi)c_{obs}F_{obs} + \alpha\omega - \gamma\omega^3$$



obstacle avoidance

in absence of obstacle in forward direction (distance large): alpha negative, constant zero



obstacle avoidance

in presence of obstacle in forward direction, symmetric bifurcation to desired avoidance rotations: alpha positive, constant zero



obstacle avoidance

in presence of obstacle to the right of current heading: tangent bifurcation removes attractor at negative omega, alpha negative, constant negative



mathematical form

compute constant and alpha from obstacle force lets $\dot{\omega} = (\alpha + \frac{1}{2}\pi)c_{obs}F_{obs} + \alpha\omega - \gamma\omega^3$



bifurcations as an obstacle is approached





dynamics: target acquisition

- a sensor for a target on the left sets an attractor at positive turning rate, strength graded with intensity
- a sensor for a target on the right sets an attractor at negative turning rate, strength graded with intensity



mathematical formulation

force-let of each target sensor

$$g_i(\omega) = -\frac{1}{\tau_{\omega}}(\omega - \omega_i) \exp\left[-2\frac{(\omega - \omega_i)^2}{\Delta\omega^2}\right].$$

(*i* = right or left)

summed to total dynamics

 $g_{\text{left}}(\omega) + g_{\text{right}}(\omega)$

putting it to work on a simple platform

Rodinsky!

- circular platform with passive caster wheel
- two (unservoed) motors
- 5 IR sensors

2 LDR's

microcontroller
 MC68HCAIIA0
 Motorola (32 K RAM),
 8 bit



example trajectories



demonstration



why does it work?

- here the dynamics exists instantaneously while vehicle is heading in a particular direction
- while the vehicle is turning under the influence of the corresponding attractor for turning rate, the dynamics is changing!
- typically undergoing an instability as vehicle's heading turns away from an obstacle...

what is the benefit of using second order dynamics?

- ability to integrate constraints which do not specify a particular heading direction, only turning direction
- ability to impose a desired turning rate => enhances agility in turning
- ability to control the second derivative of heading direction=angular acceleration: enables taking into account vehicle dynamics

quantitative comparison



[Hernandes, Becker, Jokeit, Schöner, 2014]

Summary

- behavioral variables
- attractor states for behavior
- attractive force-let: target acquisition
- repulsive force-let: obstacle avoidance
- bistability/bifurcations: decisions
- can be implemented with minimal requirements for perception