Direct inverse control:
Specialized training

Problems with general training

- General training is not *goal directed*. Instead, it tries to minimize the difference between the estimated and "true" control input.
- There may be large deviations between the reference and the output of the system when the controller is functioning.
- However, it would clearly be desirable that the system output followed the reference signal as closely as possible.
- A criterion based on-line training of the direct inverse controller is called *specialized training*.

The criterion

- To alleviate the problems with general training, the criterion to be minimized should address the difference between the reference and the output signals directly.
- One possible criterion:

$$J(\theta, Z^N) = \frac{1}{2N} \sum_{t=1}^{N} [r(t) - y(t)]^2.$$

- To make minimization easier, handle the criterion recursively:

$$J_t(\theta, Z^t) = J_{t-1}(\theta, Z^{t-1}) + [r(t) - y(t)]^2.$$

Implementing the criterion (1)

- We now want to minimize the criterion:

$$J_t(\theta, Z^t) = J_{t-1}(\theta, Z^{t-1}) + [r(t) - y(t)]^2.$$

- Assuming J_{t-1} has already been minimized, we adjust the weight vector θ at time t according to

$$\theta(t) = \theta(t-1) - \mu \frac{\mathrm{d}e^2(t)}{\mathrm{d}\theta},$$

  where $e(t) = r(t) - y(t)$, and

$$\frac{\mathrm{d}e^2(t)}{d\theta} = -\frac{\mathrm{d}y(t)}{\mathrm{d}\theta} e(t) = -\frac{\partial y(t)}{\partial u(t-1)} \frac{\mathrm{d}u(t-1)}{\mathrm{d}\theta} e(t).$$

- The term $\frac{\mathrm{d}u(t-1)}{\mathrm{d}\theta}$ can be calculated by applying the chain rule, and also several approximations are possible.

Implementing the criterion (2)

- To implement the criterion, we need to have Jacobians of the system, $\frac{\partial y(t)}{\partial u(t-1)}$, available.
- These are unknown as the system is unknown too.
- To apply specialized training, we therefore need a forward model of the system to estimate the Jacobians:

$$\frac{\partial y(t)}{\partial u(t-1)} \approx \frac{\partial \hat{y}(t)}{\partial u(t-1)}$$

- This is simply a system identification problem.

Jacobian approximation

- Inaccuracies in the forward model, and hence in the Jacobians, do not have large impact to the training.
- The Jacobian is a scalar factor which is used to modify the step size of the algorithm.
- Thus, as long as the Jacobians have the correct sign, the algorithm should work, as long as the step size parameter μ is sufficiently small.

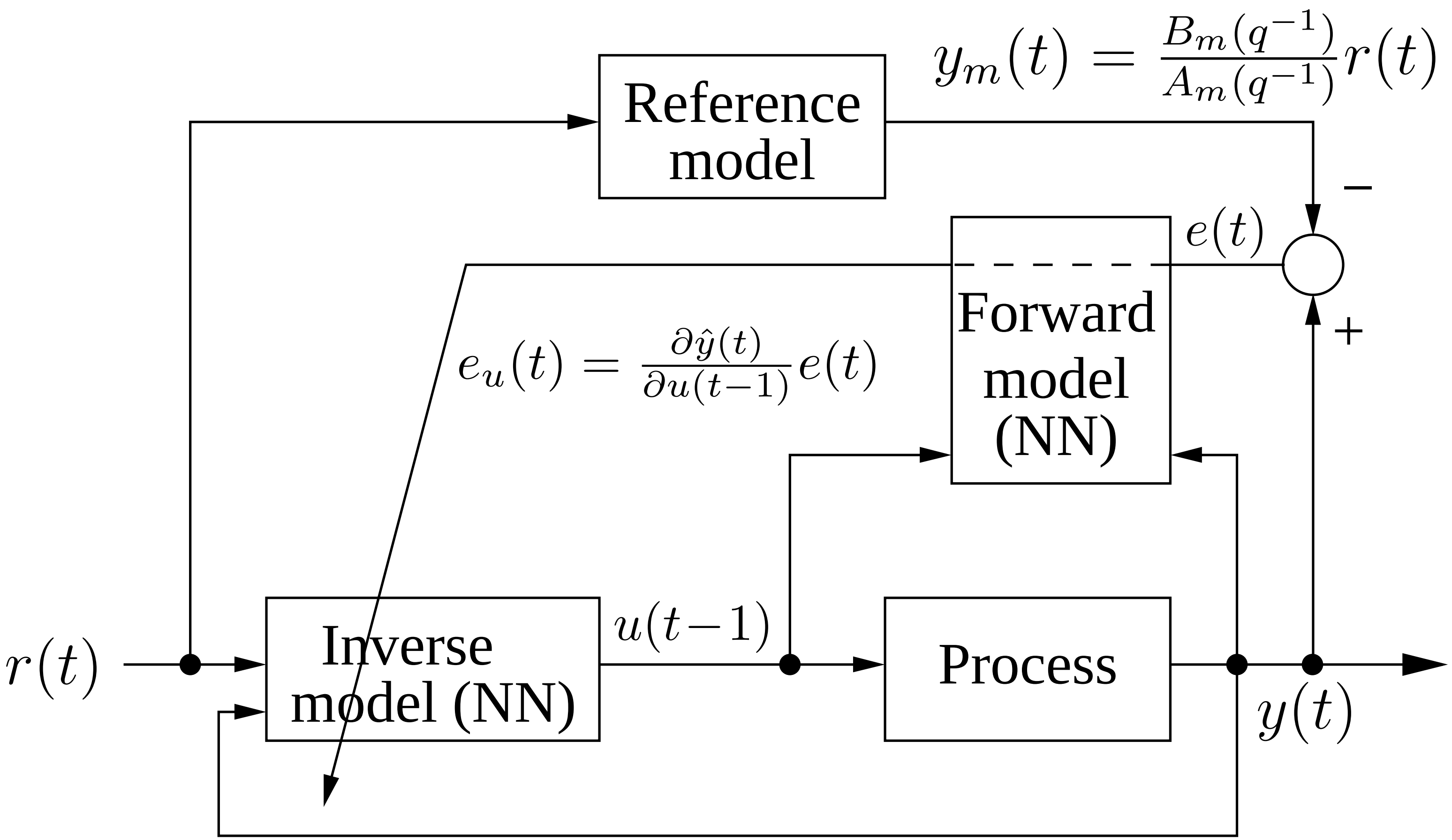
Control signal activity

- Using inverse models directly as controllers often result in unnecessarily fast response to reference changes, and hence a very active control signal.
- This might be undesirable as too quickly changing control signal may even harm the system.
- The network can be trained to follow a filtered reference signal to avoid too fast responses:

$$y_m(t) = \frac{B_m(q^{-1})}{A_m(q^{-1})} r(t).$$

- This can be obtained by using the error signal $e(t) = y_m(t) - y(t)$.

Specialized training: a scheme



On-line requirements for training

- Special training is an on-line approach, meaning the training occurs while already controlling the actual system.
- The control network therefore needs to have rather good initial performance, and the network convergence needs to be fast.
- General training can be used to initialize the network.
- Special training can first be done “off-line”, simulating the process by a forward model.
- The training should be terminated when an acceptable behaviour has been achieved.

Specialized training and adaptation

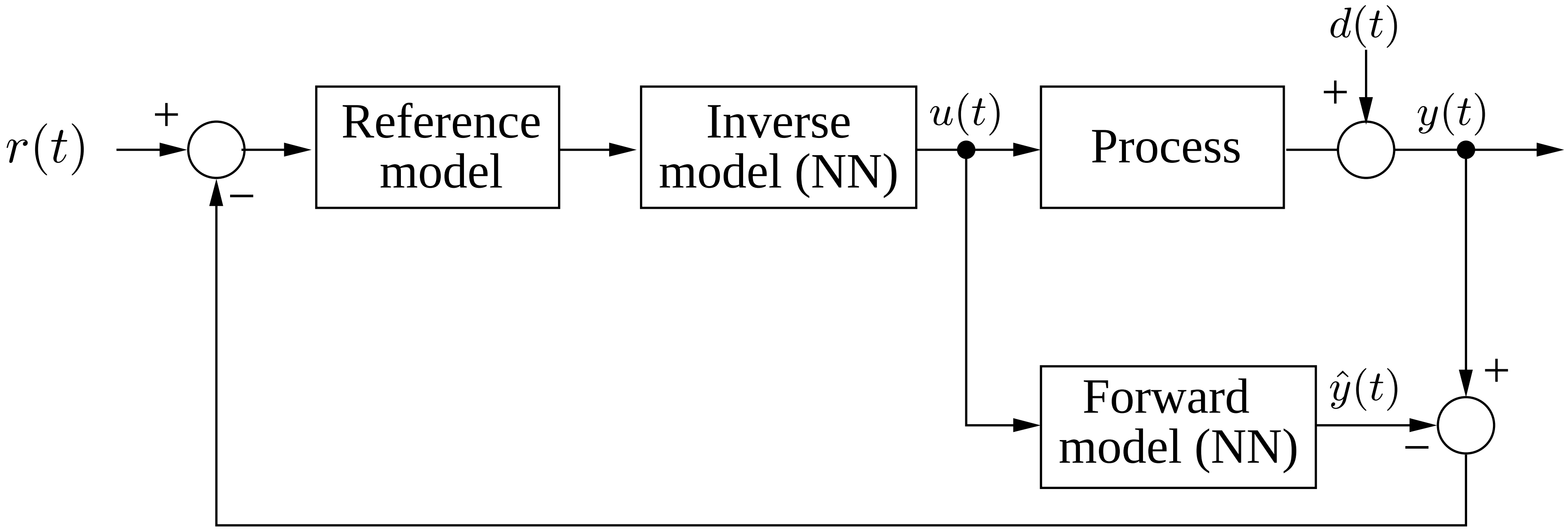
- In principle specialized training can be used to adapt the controller if the system has time-varying dynamics.
- The specialized training adapts the inverse model, so the forward model needs to be adapted as well.
- In practice the on-line adaptation is difficult and it has limited practical relevance.
- Can only be expected to work for systems with very slow variations in the dynamics.

Direct inverse control: a summary

- Advantages:
  - Intuitively simple.
  - With specialized training the controller can be optimized for a specific reference trajectory.
- Disadvantages:
  - Problems if the inverse is not stable or does not exist uniquely (not a one-to-one system).
  - Lack of tunable parameters.
  - Sensitive to disturbances and noise.
  - Active control signal.

Internal model control (IMC)

Internal model control: the principle



Basics of the internal model control

- As with the special training case of direct inverse control, IMC requires both a forward and an inverse model of the system.
- These are trained as with direct inverse control.
- Unlike direct inverse control, feedback is the error between the system output and the model output.
- If the forward model is perfect and there are no disturbances, the feedback is zero and the controller is a pure feedforward from the reference.

Properties of IMC

- The only design parameter in IMC is the reference model filter.
- IMC requires that the system as well as its inverse are stable.
- Control signal can be large and oscillating.
- If the requirements of the IMC are met, it can be designed to give off-set free response under a constant disturbance.
- However, constant disturbance makes training of the networks difficult.