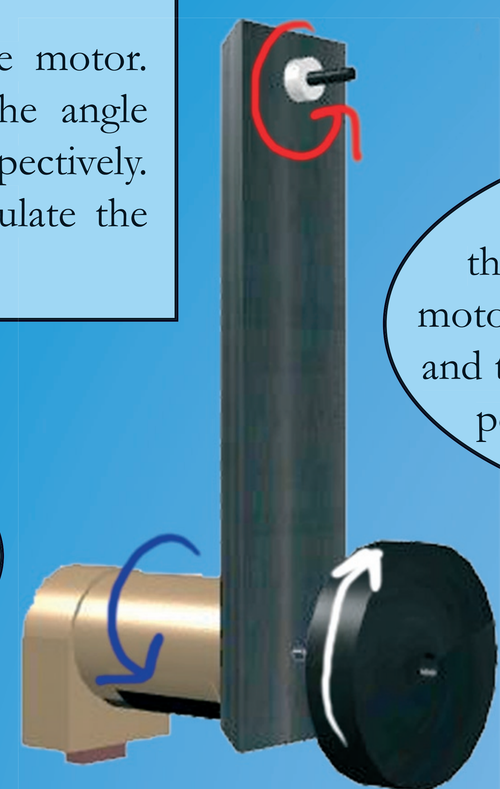
The Embedded System Project - 2003

The system to control

The system has a pendulum in which a motor with an inertia wheel is hanging. This motor with its inertia wheel is the only actuator in the system. The task is to swing the pendulum to the upright position and make it balance there. The figure to the right illustrates how we can make the pendulum move.

The output from our controller runs the motor. As inputs to the controller we measure the angle of the pendulum- and the motors haft respectively. By measuring the motor angle we can calculate the speed of the inertia wheel.



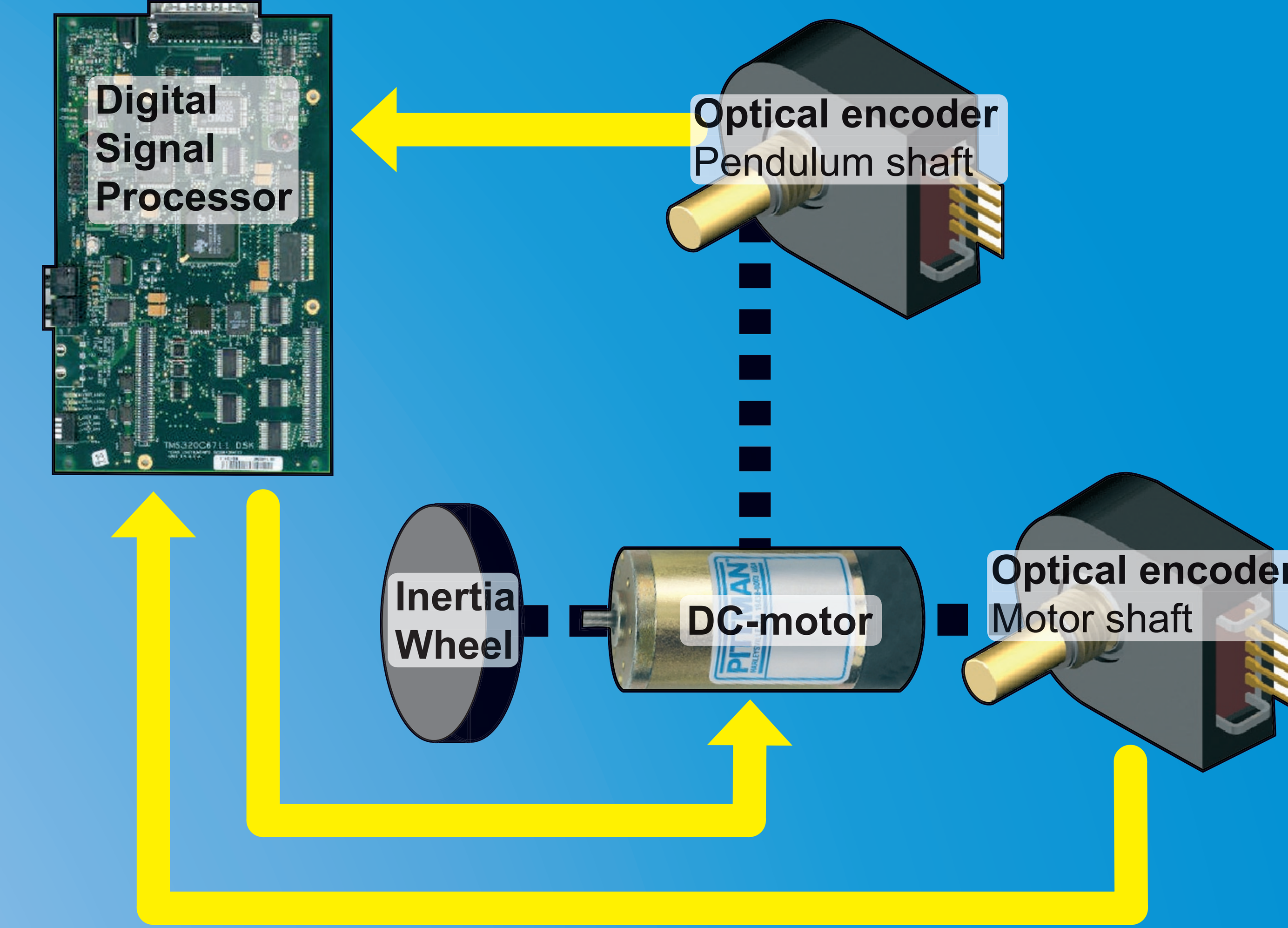
3.
The motor is fastened in the pendulum, so the torque in the motor is transferred to the whole pendulum and to the pendulums shaft. This gives the pendulum an acceleration like the red arrow indicates

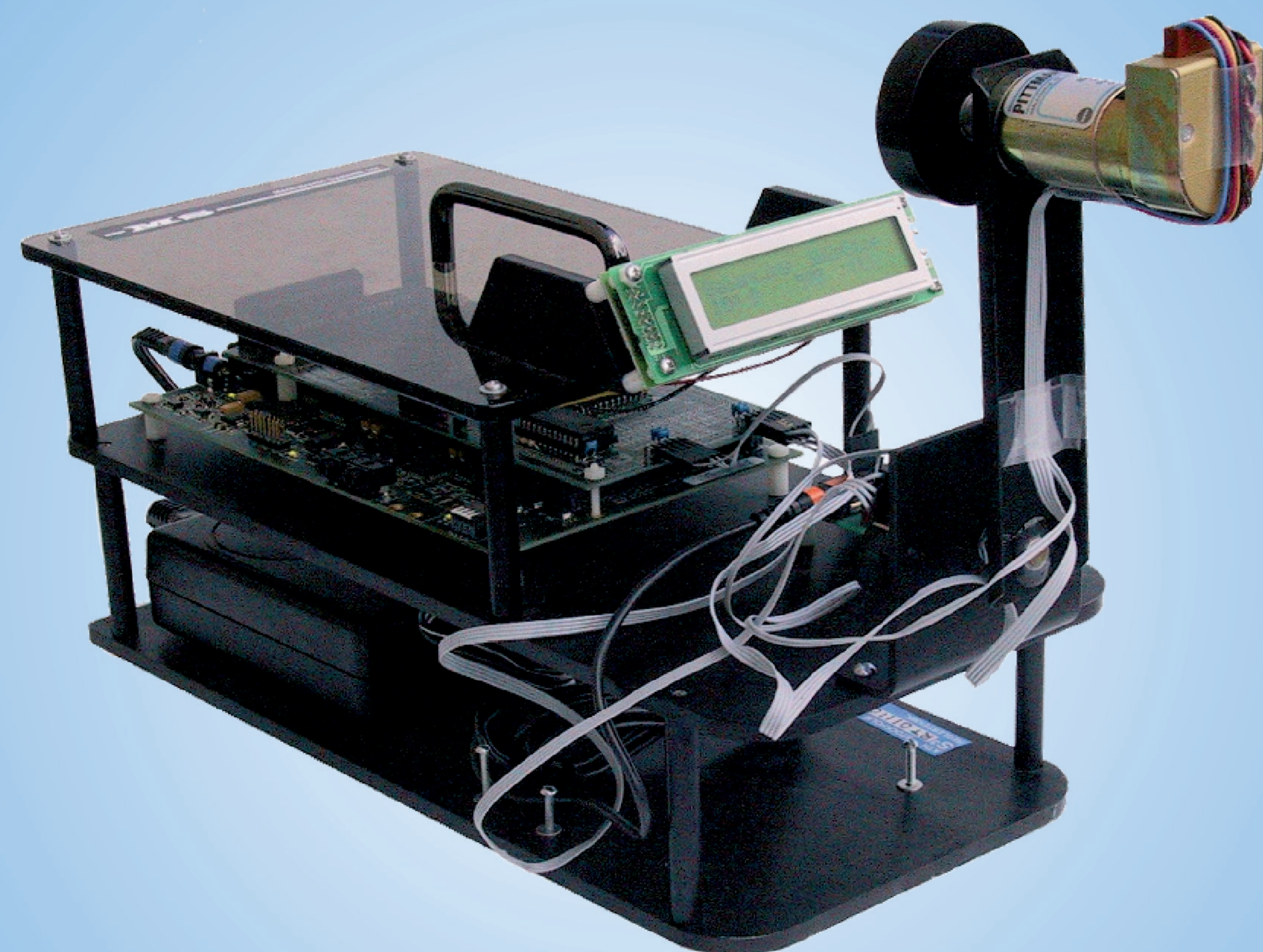
2.
Due to the mass moment of inertia the motor experiences a torque in the opposite direction, indicated by the blue arrow.

1.
The motor is accelerated, for example in the direction of the white arrow.

Background

This project is part of the project course in automatic control at the department of Signals, Sensors and Systems at KTH. There are five different project groups and each get an order for a control system for one of five different control processes. The order describes some given specifications and features and the project has approximately ten weeks to develop and deliver a system that satisfies these requirements.





Mathematical model

By using mechanical knowledge we analyzed the system and came up with a non-linear state-space model with three states: angle of the pendulum, speed of the pendulum and the speed of the inertia wheel. To design the controllers the model was linearized around the controllers working point.

Implementation

The heart of the system is the embedded DSP-card that makes all the measurements, calculations and also controls the motor. The control law is written in C, then compiled and flashed into the memory of the DSP. After that the system can run totally stand alone without any other computers.

The controllers are designed in continuous time and then discretized. The sampling frequency for normal operation is 500 Hz.

Low sampling frequency

We have implemented a possibility to choose the sampling frequency for the system. This way we can demonstrate how the performance is affected by lower sampling frequencies.

The swing controller works with frequencies down to 20 Hz, where it start enter the balance area with too high speed. At 10 Hz the balance controller stop to work, it can not hold the pendulum within the balance area any more. We also designed a discrete controller for 10 Hz sampling frequency and that one managed to balance! Not a stable one but it kept the pendulum within the balancing area.

Three controller modes

We have made controllers for the three operational modes: swing, balance and stop. The swing controller takes the pendulum to the upright position as fast as possible, where the balance controller takes over. The balance controller is used as long as the pendulum stays within 15 degrees from the upright position. If the pendulum falls out of this area, the swing takes the pendulum back up again. The third, stop controller takes the pendulum down to the safe, hanging position as fast as possible. This controller is used by the operator when the system shuts down and by the safety features when the system has detected an unsafe condition.

Balance
For the balance controller the most important thing is to keep the angle deviation as small as possible. The second thing is to keep the speed of the inertia wheel down, or we will soon loose the possibility to add torque in some direction. This made us choose an LQ-controller with the possibility to punish these factors.

Stop
We have chosen the LQ-controller here too, since we never got the PID-controller to settle to rest with the inertia wheel stopped.

Swing
The swing is energy controlled. The controller know the energy needed to get to the upright position and it keeps track of the actual energy of the pendulum. At every sampling instant, energy is added or taken from the pendulum to reach the desired value.

The project group

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Modelling
Documentation

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Documentation
Web

Safety features

We have identified the following two dangerous situations that the system can get into, and we have designed safety features to take care of them.

Wire breakage

The motor and the encoder on the pendulum are connected to the rest of the system with wires. When the pendulum rotates the wires wind up around the shaft. To prevent the wires from being torn off, the pendulum is only allowed to rotate two revolutions in either direction from the starting point. If this limit is exceeded, the stop controller is activated to stop the system.

Too high pendulum speed

If the pendulum moves too fast, the stop controller is activated to stop system. This unsafe speed can not be reached by the system itself, only by external disturbances, like a hit on the pendulum.

Visit the project web pages: http://www.e.kth.se/~mikalek/embedded

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