FEED-FORWARD CONTROL IN AN EXPERIMENTAL CHANNEL FLOW

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Abstract
Feed-forward control of natural disturbances in a plane channel flow at $Re = 840$ is considered. The experimental facility consists of air flow through an open return channel. Two hot-film sensors are placed at the wall and a blowing and suction device is used for the actuation. In a first step, the flow dynamics between input and output devices is identified using a least squares technique based on a Finite Impulse Response (FIR) model. This identified model then forms the basis for the design of a feed-forward controller. When applied to the channel flow, the measurement signal at the downstream objective sensor could be reduced, in its standard deviation, by 45%.

EXPERIMENTAL SET-UP

The experiments were carried out in an open return tunnel at GALCIT, Caltech. The tunnel has a total length of 2.60 meters and an inside width and height of 15.6 cm and 1.2 cm, respectively. The air, driven by a simple computer fan of diameter 8 cm, is passed through a small grid of mesh size 1.5 mm followed by a smooth contracting nozzle of inlet-to-outlet ratio 8.3. Downstream of the nozzle, the flow exits into an invariant duct of length 186 cm. Two hot film sensors were placed on the wall of the channel at locations $x = 0$ cm and $x = 29$ cm. The upstream sensor will provide information about the incoming disturbance field, while the second downstream sensor will be used to evaluate the control objective. A blowing and suction device is composed of a syringe pump controlled by a computer via a stepper motor. The 20cl syringe is connected to a small hole (of diameter 0.8 mm) in the lower channel wall located at $x = 16.5$ cm. The full set-up is sketched in figure 1. The sensors are operated by a AN-1005 Wheatstone bridge which in turn is connected to the data acquisition card of a computer. The control signal (within a voltage range from 0 to 10 V) is generated by the computer, converted by a Voltage/Frequency Converter (BK Precision 4011A, 5MHz Function Generator) and passed via a Motor Controller (Integrated Circuit L297 and L298) to the stepper motor of the syringe pump.

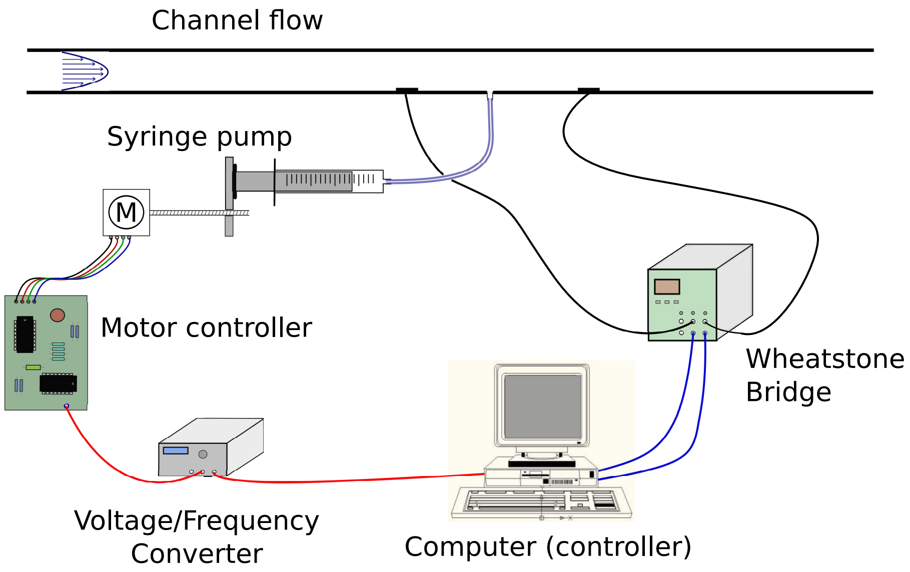

Figure 1. Sketch of the full experimental set-up including the air tunnel, all actuation and measurement devices, and data acquisition and processing units.

CONTROL DESIGN AND RESULTS

The convective nature of our flow configuration suggests the use of a feed-forward control design [2]. More specifically, a Model Predictive Control (MPC) framework [1, 4] was employed to reduced the standard deviation of naturally occurring disturbances, as measured by the downstream sensor. The full control design proceeds in two steps. First, a linear model, linking upstream sensor information and control input to the downstream sensor output, has to be postulated. In our case, we used a simple Finite Impulse Response (FIR) model [3] whose coefficients have been determined directly from the observed data by a least-squares fitting technique. The final result of the identification phase consists of two transfer functions: from the actuator to the downstream sensor, and from the upstream to the downstream sensor. The second step consists of using these two transfer functions to design a control law such that the signal at the downstream (objective) sensor is minimized. More intuitively, the actuator counteracts the incoming perturbations, as measured by the upstream sensor, in order to accomplish a minimal signal at the downstream sensor, which represents the essence of feed-forward control.

This control strategy has been implemented in our experimental set-up described above. Representative results of the controlled and uncontrolled flow are shown in figure 2, visualized by a time trace of the downstream objective sensor output. The control experiment has been repeated more than 25 times to gather statistics on the controller's performance. For the specific realization shown in figure 2, the uncontrolled signal shows a standard deviation of $\sigma = 0.0625$ which has been reduced by 44%, to a value of $\sigma = 0.0348$, once the control has been activated. Averaged over all sample runs, a robust reduction in standard deviation by 45% could be established. Despite the fact that only a reduction of the downstream objective sensor signal has been targeted by our control, a reduction in standard deviation of still 30% could be measured by an additional sensor placed 14 cm further downstream from the objective sensor. Our results support the use of a combined system identification and feed-forward framework; within an experimental setting, these techniques have proven effective and robust in controlling disturbances arising in a natural noise environment.

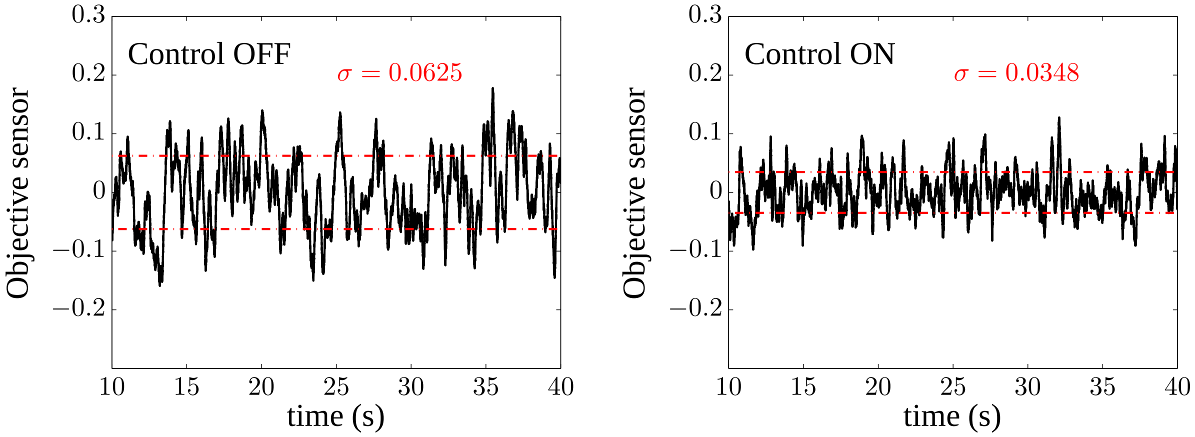

Figure 2. Representative time trace of the downstream (objective) sensor signal. On the left: uncontrolled case. On the right: controlled case. A reduction in standard deviation of 44% can be observed.

References

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