

WELL-POSED LINEAR SYSTEMS IN L^1 AND L^∞ ARE REGULAR

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Abstract. We study well-posed linear system with locally L^p inputs and outputs, where $1 \leq p \leq \infty$, and whose input, state and output spaces are Banach spaces. Like in the usual Hilbert space theory, we call such a system regular if each of its step responses has a right Cesaro limit at zero. In this case, the system has a feedthrough operator; the Cesaro limit is given by the feed-through operator applied to the constant value of the input step. Regular systems have a simple representation. We show that the system is regular if $p = \infty$, or if $p = 1$ and the state space is reflexive. We also present an application to a quadratic cost minimization problem for a parabolic equation.

Key Words. Well-posed linear system, regular linear system, feedthrough operator, parabolic equation, LQ-problem, spectral factorization.

1. Introduction

Many infinite-dimensional systems can be described by the equations

$$\begin{aligned}x'(t) &= Ax(t) + Bu(t), \\y(t) &= Cx(t) + Du(t), \quad t \geq 0, \\x(0) &= x_0,\end{aligned}\tag{1}$$

on a triple of Banach spaces, namely, the input space U , the state space X , and the output space Y . We have $u(t) \in U$, $x(t) \in X$ and $y(t) \in Y$. The operators A, B and C are usually unbounded. It is often convenient to use the “integral” representation of the system, which consists of the four operators from the initial state x_0 and the input function u to the final state $x(t)$ and the output function y :

$$\begin{aligned}x(t) &= \mathcal{A}^t x_0 + \mathcal{B} \pi^t \pi_+ u, \\y &= C x_0 + \mathcal{D} \pi_+ u.\end{aligned}\tag{2}$$

Here, \mathcal{A}^t is the semigroup generated by A (which maps the initial state x_0 into the final state $x(t)$), $\mathcal{B} \pi^t \pi_+$ is the map from the input u to the final state $x(t)$, C is the map from the initial state x_0 to the output y , and $\mathcal{D} \pi_+$ is the input-output map from u to y (see the notation in Section 2).

The *well-posedness* assumption is that (2) behaves well in an L^p -setting, i.e., $x(t) \in X$ and $y \in L_{loc}^p(\mathbf{R}^+; Y)$ depend continuously on $x_0 \in X$ and on $u \in L_{loc}^p(\mathbf{R}^+; U)$. If this is the case, we call the operators $(\mathcal{A}, \mathcal{B}, C, \mathcal{D})$ a *well-posed linear*

system. There is an almost one-to-one correspondence between (1) and (2): most well-posed linear systems can be represented as in (1). These systems are called *regular*. They are characterized by the fact that their transfer function has a strong limit at $+\infty$ (along the real axis), see Weiss [22]. However, there do exist irregular well-posed systems, and this may happen, for example, in the most commonly studied case where $p = 2$ and U, X, Y are Hilbert spaces. For example, any realization of the transfer function

$$G(s) = \cos(\log s)$$

is irregular (this example is due to Kirsten Morris). Such realizations exist with $p = 2$. We show that in the case $p = \infty$, every well-posed linear system has a representation of the form (1) (for a restricted class of inputs u). A similar statement is true when $p = 1$ (in this case, there is no extra limitation on the input function, but the state space should be reflexive). In particular, the transfer function G defined above has no realizations with $p = 1$ or $p = \infty$.

A simple example to which this theory applies is a system whose semigroup \mathcal{A}^t is analytic on a reflexive state space and whose control operator B and observation operator C are not too unbounded, i.e., there exists some $\alpha < 1$ such that $C(\gamma I - A)^{-\alpha} B$ is a bounded linear operator for some (hence for every) γ in the resolvent set of A . In this case it is possible to use any value of p , $1 \leq p \leq \infty$, as long as the state space X is adapted to the value of p . The values $p = 1$ and $p = \infty$

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