

# Towards Automatic Control of Scanning Transmission Electron Microscopes: System Identification Issues

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## 1 Introduction

Scanning transmission electron microscopes (STEMs) are the tools of choice for material science research, since they provide information on the internal structure of a wide range of specimens. These complex machines are operated by skilled technicians, who execute repetitive tasks (e.g., alignment, particle counting, etc.) following long scripted manual procedures and using mainly visual feedback. Automating such procedures is a crucial step towards transforming the STEMs from qualitative tools into flexible quantitative nano-measuring tools. This is the goal of the CONDOR project, which is managed by the Embedded Systems Institute ([www.esi.nl](http://www.esi.nl)). To enable this automation, STEM dynamical models of enough fidelity are needed. Unfortunately, to the best of our knowledge, such models are not available in the literature. The first steps toward developing such dynamical models were reported in a recent publication [1]. In here, we outline our recent efforts to refine those models.

## 2 STEM Modeling

Figure 1 shows a simplified STEM dynamical model. As explained in [1], a STEM can be divided into two sections:

- **Electronics:** This represents the STEM's electronics. The value of an operator-controlled "knob",  $u(t)$ , sets the value of an optical parameter,  $p(t)$ . For instance,  $u(t)$  could represent the voltage applied to an electromagnetic lens, while  $p(t)$  could represent the corresponding focal distance
- **Optics + Algorithm:** This represents the STEM image formation process and a feature extraction algorithm. Note that the image formation process on *bright field mode* is a time independent process, while the algorithm is time dependent.

The dynamics of the electronics are given by the (possibly nonlinear) function  $f: \mathbb{R}^2 \rightarrow \mathbb{R}$ . That is,  $\dot{p}(t) = f(p(t), u(t))$ . The dynamics of the optics + algorithm block are more difficult to establish. Using bright field images (see [1]), these dynamics are given by  $I(r) = |\phi(r) * h(r, p)|^2$ , where  $\phi(r)$  is

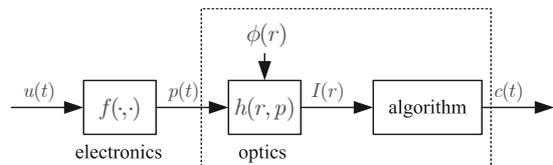


Figure 1: Simplified STEM model.

a two-dimensional complex signal that represents the sample electrical potential,  $h(r, p)$  represents the microscope's two-dimensional transfer function, which is parameterized by  $p$ , and  $*$  represents the convolution operator (over  $r$ ).

The algorithms used to measure  $p$  vary depending on the nature of  $p$ . Their outputs,  $c$ , are called the "sharpness criteria" and are considered static functions of the parameter  $p$ . That is,  $c = g(p)$ , where  $g: \mathbb{R} \rightarrow \mathbb{R}$ . Note also that  $g$  can usually be approximated by polynomials. Hence, the optics + algorithm block would be modeled as follows:  $c(t) = g(p(t - \Delta)) + \eta(t)$ , where  $\Delta$  denotes the delay introduced by the algorithm and  $\eta(t)$  represents random measurement noise and the error introduced by the algorithm. The overall system model is the

$$\begin{aligned} \dot{p}(t) &= f(p(t), u(t)) \\ c(t) &= g(p(t - \Delta)) + \eta(t), \end{aligned}$$

Thus,  $c(t)$  is understood as a nonlinear observation of the state variable  $p(t)$ . Our ongoing research consists on deriving  $g$  from simulated images and experiments with real microscopes, using system identification techniques.

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## References

- [1] A. Tejada, S. van der Hoeven, A. den Dekker, and P. van den Hof, "Towards automatic control of scanning transmission electron microscopes," in *Proc. of the 2009 American Control Conference*, St. Louis, MO, 2009, p. under review.