Measurement 75 (2015) 1–4

Contents lists available at ScienceDirect

Measurement

journal homepage: www.elsevier.com/locate/measurement

Technical note

Rapid design and implementation of semi-automated research-grade test systems

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ARTICLE INFO

Article history:
Received 5 July 2015
Accepted 3 August 2015
Available online 7 August 2015

Keywords:
System integration
Materials science
Engineering automation
Test systems

ABSTRACT

As opposed to industrial automation and test equipment, typically requiring teams of engineers to design and operating over multi-year/decade lifetimes; in academic-based materials science labs there often exists a time-sensitive short-term need to (1) implement some level of automation in lieu of brute force testing techniques; (2) enhance or introduce added functionality into existing tools and equipment; or (3) develop completely customized systems to investigate new types of material phenomenon. Herein lies the challenge, as many research teams lack the expertise for rapid prototyping/development of such novel material testing systems. Therefore, here we present a methodology to rapidly create systems that can be quickly designed and fabricated, utilized as needed, and then whose constituent components can be modified for further experimentation or incorporated into future systems.

Implemented correctly, a semi-automated system can help improve data quality; reduce systematic errors; standardize experimental protocols; enable multiple people to work on a single system; and reduce time to publication – all hallmarks of successful research teams. Therefore, we present a basic set of steps for rapid development and implementation of a reliable, repeatable, and accurate test systems in a minimal timeframe. The method presented herein has been successfully demonstrated in numerous test systems developed by the author [1–7]. Furthermore, obtaining research funding is becoming increasingly competitive [8]; therefore, *innovation is essential* for researchers to both first discover new material phenomena, as well as modify existing material properties to exceed previous best-known values. For example, the success rate for securing National Science Foundation (NSF) funding dropped from 31% in 2001 to 24% in 2012 due mainly to increased proposal numbers [9]. Therefore, scientists need ability to quickly modify existing capital equipment, or if required, rapidly develop and prototype equipment to feature new testing capabilities. Although not expected to be test engineers, a basic understanding of these skills are nonetheless essential for materials researchers.

Numerous well-written publications exist covering various approaches to test systems design, ranging from short web-based resources [10,11] to full-length textbooks [12,13]. However, these resources tend to be geared towards promoting a single product line [10,11] or towards full-time test engineers, and perhaps are too detailed for small resource-limited academic research groups [12,13]. Therefore, researchers and materials scientists (who may not have the resources of a large corporate infrastructure or dedicated engineers to assist with development) may benefit from a concise test system design methodology.

Generally, three stages are required to quickly implement a material test system – determining *what* you want to do (brainstorming); figuring out *how* to do it (design and integration); and then *doing* it (implementation) Fig. 1. The vast majority of testing systems can be built by implementing these steps through use of some sort of design

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http://dx.doi.org/10.1016/j.measurement.2015.08.002
0263-2241/

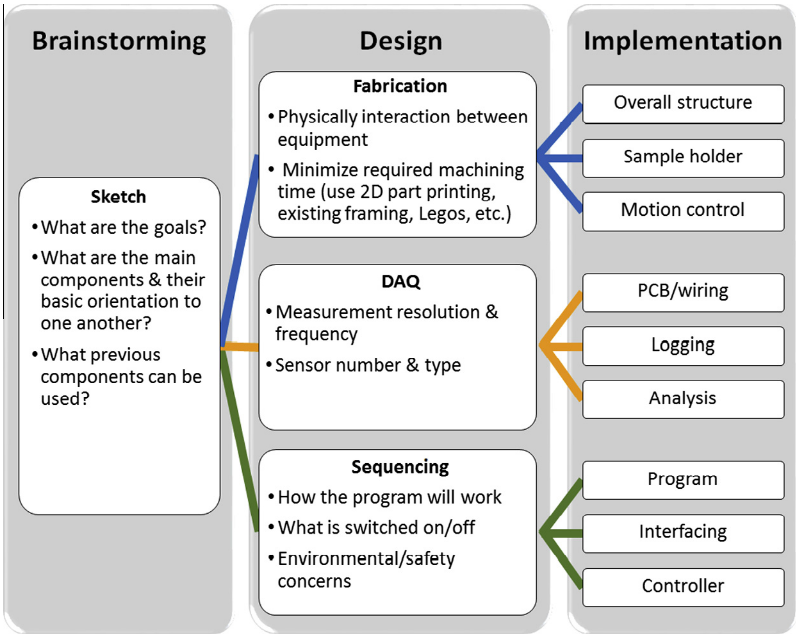

Fig. 1. Block diagram detailing basic steps in system development, including *brainstorming* (initial system layouts); *design* (developing plans to accomplish experimental tasks); and *implementation* (building and running the system).

method (ranging from pen and paper to SolidWorks), sequencing/control/data logging software (LabVIEW or similar), and data analysis method (Excel, MATLAB, etc.). This approach, combined with a high level of ingenuity, can help level the playing field for Principal Investigators (PIs) regardless of research group size or institution.

Test system development. A research-grade test system is a coherent combination of physical components (frame, structure, sensors, etc.), experimental data acquisition, and follow-on analysis – which aids a materials researcher to (1) provide some level of automation in lieu of brute force testing; (2) enhance or introduce added functionality into existing equipment; or (3) develop completely customized equipment required to investigate new phenomenon. There usually exists some (project specific) optimal investment in terms of system design (implementation) time and reduction in dedicated operator time (and introduction of new experimental capabilities).

The block diagram and 'back of the napkin' drawings. A well laid-out block diagram is the most basic representation of the test system – where overall goals are first defined and then refined. Start by brainstorming with a two-column list: in column *a*, enumerate all properties you hope to obtain or system goals; in column *b*, list all potential equipment, components, or supplies required to achieve the goals from column *a*. Draw a square representing each component (such as a balance, laser, camera, etc.). Next, draw (and label) lines connecting these squares to indicate interactions or relationships with each other – *i.e.*, information exchange. Add/Remove components as needed. Then rearrange the squares based on these (communication and testing) relationships such that they start to resemble physical orientations relative to one other. Iterate this process, each time adding small bits of information – such as lines indicating supply power, introducing test sample orientation/configuration, and indicating fabricated versus existing components.

These simple sketches are the first step towards planning the task at hand, and will help guide the rest of the work. When designing the block diagram, continuously ask – How do capabilities of individual components complement each other; Are the components listed adequate to take all measurements (including range, resolution, sampling rate, etc.), or are additional sensors required; How difficult will it be to adapt the system to evolving and perhaps unforeseen testing requirements; What will be the physical format of the system; Is the form factor realistic given real-world workspace constraints; What are the test sample handling requirements; Regarding motion control – Does anything need to move; and ultimately, Is the design sufficient to achieve stated objectives? Most importantly, get feedback. The key is not how much time is spent in initial development, but rather – generating a well thought-out, executable plan.

Fabrication. Fabrication encompasses all items purpose-built for use in the specific test – consisting of some combination of *framing* (system's skeleton for mounting, wiring, etc.); any modifications to *components/sensors* (to interact with or measure the sample); *sample holders* (enables testing standardization); and *motion control* (sample changers, moving testing apparatus, etc.) intermixed to introduce added functionality or investigate new types of material phenomenon altogether. Of all these elements, the *frame* should be the most adaptable towards future expansion or changing goals. Ideal candidates range from ready-made kits to T-slotted aluminum extrusions. These