find circuits that perform a larger number of logic functions.

In order to be able to score fitness in this way, one must ensure that circuit output is a digital waveform at every value of the control voltage, so that the output can be classified as a particular logic function. Nevertheless, it has been observed that the circuits generated during evolutionary search typically generate analog outputs, taking values between zero volts and the power-supply voltage. In order to solve this problem, the output of an evolving circuit is digitized by use of a buffer, as illustrated in the figure. Whereas the direct output of the evolving circuit is evaluated in the unmodified method, the buffered output is evaluated in the modified method. In effect, for the purpose of evaluation, the buffer becomes part of any such evolved circuit.

This work was done by Adrian Stoica and Ricardo Zebulum of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1).*
NPO-40934

Video-Camera-Based Position-Measuring System

Coordinates of nearby targeted objects are measured quickly, easily, and safely.

John F. Kennedy Space Center, Florida

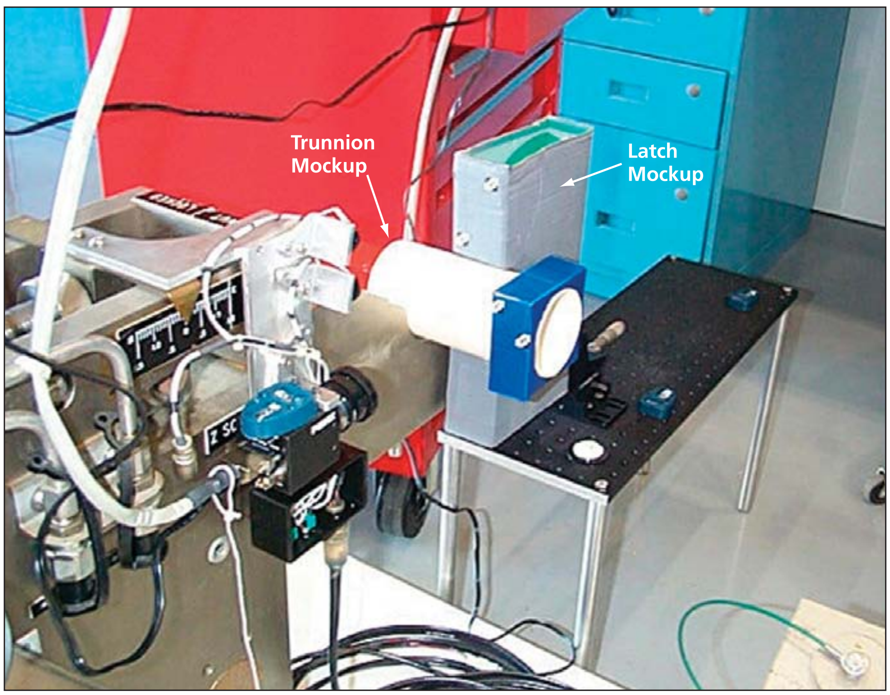

Figure 1. In this **Laboratory Setup**, the camera of the prototype system is aimed at a mockup of a latch mating with a trunnion to demonstrate the use of the system to measure the three-dimensional coordinates of the latch relative of the trunnion.

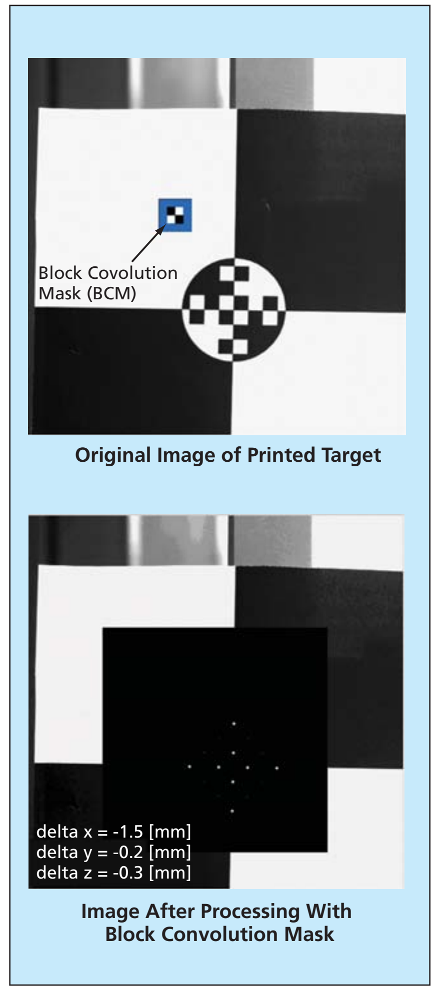

Figure 2. A **Target Pattern of Light and Dark Squares** is processed by a block convolution mask to obtain a pattern of bright dots on a dark background. The three-dimensional positions of the target can be determined from the pixel coordinates of the dots.

A prototype optoelectronic system measures the three-dimensional relative coordinates of objects of interest or of targets affixed to objects of interest in a workspace. The system includes a charge-coupled-device video camera mounted in a known position and orientation in the workspace, a frame grabber, and a personal computer running image-data-processing software. Relative to conventional optical surveying equipment, this system can be built and operated at much lower cost; however, it is less accurate. It is also much easier to operate than are conventional instrumentation systems. In addition, there is no need to establish a coordinate system through cooperative action by a team of surveyors.

The system operates in real time at around 30 frames per second (limited mostly by the frame rate of the camera). It continuously tracks targets as long as they remain in the field of the camera. In this respect, it emulates more expensive, elaborate laser tracking equipment that costs of the order of 100 times as much. Unlike laser tracking equipment, this system does not pose a hazard of laser exposure.

Images acquired by the camera are digitized and processed to extract all valid targets in the field of view. The three-dimensional coordinates (x, y, and z) of each target are computed from the pixel coordinates of the targets in the images to accuracy of the order of millimeters over distances of the orders of meters. The system was originally intended specifically for real-time position measurement of payload transfers from payload canisters into the payload bay of the Space Shuttle Orbiters (see Figure 1). The system may be easily adapted to other applications that involve similar coordinate-measuring requirements. Examples of such applications include manufacturing, construction, preliminary approximate land surveying, and aerial surveying.

For some applications with rectangular symmetry, it is feasible and desirable to attach a target composed of black and white squares to an object of interest (see Figure 2). For other situations, where circular symmetry is more desirable, circular targets also can be created. Such a target can readily be generated and modified by use of commercially available software and printed by use of a standard office printer. All three relative coordinates (x, y, and z) of each target can be determined by processing the video image of the target. Because of the unique design of corresponding image-processing filters and targets, the vision-based position-measurement system is extremely robust and tolerant of widely varying fields of view, lighting conditions, and varying background imagery.

This work was done by John Lane, Christopher Immer, Jeffrey Brink, and Robert Youngquist of Dynacs, Inc. for **Kennedy Space Center**. *For further information, contact:*

Christopher Immer
ASRC Aerospace
Kennedy Space Center, FL 32899
Phone No. (321) 867-6752
KSC-12397/67/68/442

N-Type δ Doping of High-Purity Silicon Imaging Arrays

Success depends on details of a low-temperature MBE process.

NASA's Jet Propulsion Laboratory, Pasadena, California

A process for n-type (electron-donor) delta (δ) doping has shown promise as a means of modifying back-illuminated image detectors made from n-doped high-purity silicon to enable them to detect high-energy photons (ultraviolet and x-rays) and low-energy charged particles (electrons and ions). This process is applicable to imaging detectors of several types, including charge-coupled devices, hybrid devices, and complementary metal oxide/semiconductor detector arrays.

Delta doping is so named because its density-vs.-depth characteristic is reminiscent of the Dirac δ function (impulse function): the dopant is highly concentrated in a very thin layer. Preferably, the dopant is concentrated in one or at most two atomic layers in a crystal plane and, therefore, δ doping is also known as atomic-plane doping. The use of δ doping to enable detection of high-energy photons and low-energy particles was reported in several prior *NASA Tech Briefs* articles. As described in more detail in those articles, the main benefit afforded by δ doping of a back-illuminated silicon detector is to eliminate a "dead" layer at the back surface of the silicon wherein high-energy photons and low-energy particles are absorbed without detection. An additional benefit is that the delta-doped layer can serve as a back-side electrical contact.

Delta doping of p-type silicon detectors is well established. The development of the present process addresses concerns specific to the δ doping of high-purity silicon detectors, which are typically n-type. The present process involves relatively low temperatures, is fully compatible with other processes used to fabricate the detectors, and does not entail interruption of those processes. Indeed, this process can be the last stage in the fabrication of an imaging detector that has, in all other respects, already been fully processed, including metallized.

This process includes molecular-beam epitaxy (MBE) for deposition of three layers, including metallization. The success of the process depends on accurate temperature control, surface treatment, growth of high-quality crystalline silicon, and precise control of thicknesses of layers. MBE affords the necessary nanometer-scale control of the placement of atoms for delta doping.

More specifically, the process consists of MBE deposition of a thin silicon buffer layer, the n-type δ doping layer, and a thin silicon cap layer. The n dopant selected for initial experiments was antimony, but other n dopants as (phosphorus or arsenic) could be used. All n-type dopants in silicon tend to surface-segregate during growth, leading to a broadened dopant-concentration-versus-depth profile. In order to keep the profile as narrow as possible, the substrate temperature is held below 300 °C during deposition of the silicon cap layer onto the antimony delta layer. The deposition of silicon includes a silicon-surface-preparation step, involving H-termination, that enables the growth of high-quality crystalline silicon at the relatively low temperature with close to full electrical activation of donors in the surface layer.

This work was done by Jordana Blacksberg, Michael Hoenk, and Shouleh Nikzad of Caltech for **NASA's Jet Propulsion Laboratory**. *Further information is contained in a TSP (see page 1).*

In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:

Innovative Technology Assets Management
JPL
Mail Stop 202-233
4800 Oak Grove Drive
Pasadena, CA 91109-8099
(818) 354-2240
E-mail: iaoffice@jpl.nasa.gov

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