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Title: No Access, No Data, No Problem: Toward Autonomous Robotic Inspections of Nuclear Facilities

Abstract

Whether safeguarding Iranian uranium enrichment facilities, denuclearizing North Korea, or verifying limits on U.S. and Russian arsenals, nuclear safeguards and arms-control traditionally require intrusive on-site inspections to perform verification tasks. In such applications, the ability to localize a radioactive source is imperative for identifying anomalies when no significant neutron emitters are expected or declared to be present, such as for confirming the feedstock composition in a gas-centrifuge enrichment plant or the absence of clandestine warheads. We investigate the role of machine learning and autonomous mobile robots, which, if designed properly, may be more effective and less intrusive than their human counterpart. Towards developing such a capability, we characterize and demonstrate an “inspector bot,” comprised of three equally-distributed boron-coated straw detectors encased in high-density polyethylene, mounted on an omni-directional robotic platform. While many reported methods use only the total detected counts, our inspector bot is specifically designed to provide directional and spectral sensitivity, in addition to gross counts, in a single measurement. The detection system has been extensively characterized by MCNP modeling, which has been benchmarked to experiments conducted at the Princeton Plasma Physics Laboratory. For source localization using our inspector bot, we utilize a simple system of equations which, with the three detectors, is solved online to estimate the direction to the source. We apply the result of the online model in the framework of a particle filter. Each “particle” represents a hypothesized source intensity and planar location, and is assigned a weight according to a logarithmic-likelihood function. By leveraging the directional sensitivity of our inspector bot, we correctly estimate the location and intensity of a source with fewer measurements as compared to particle filtering based only on gross counts. Our efforts in advancing this methodology are ongoing as we consider the effects of background noise and obstacles.