# CONSTRUCTION METROLOGY BEYOND EARTH
# A WHITE PAPER

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Abstract: Construction metrology standardization research currently focuses on terrestrial applications. For space based applications, there is the potential for great monetary and effort savings through the creation and use of open industry standards. Current technology for construction automation in space requires either one vendor to provide an entire solution, or an organization, such as NASA, to coordinate the efforts of vendors in tightly integrated and non-competitive projects. Open standards for space based construction metrology could provide a means to promote competition in this potentially lucrative market. However, current practices in metrology, automated or manual, need to be reevaluated in this new space environment. The LiveView protocol is being designed to meet this goal.

Keywords: Automation, Construction, Metrology, Space, and Standardization.

## 1 INTRODUCTION

Having recently announced intentions to privatize the International Space Station (ISS), the United State's National Aeronautics and Space Administration (NASA) has the potential to open a new era of commercial interest in Earth orbit. With open standards in space metrology, automation of construction related tasks, maintenance and upgrades of the ISS could be handled using practices similar to terrestrial building projects. However, metrology methods and technology need to be developed and integrated before a standard approach to space based construction metrology can occur.

### *1.1Open Construction Metrology Standards*

NIST is currently investigating terrestrial automated construction metrology and supporting standards [6]. Construction metrology standards enable management of the construction project to be handled by a management company that integrates various sub-contractors to work on a project under a standard means of reporting metrology data relating to the contractor's work to the construction management.

The implications of quicker, automated metrology data on construction projects are lower overhead and more efficient construction project management. Construction visualization systems, teleoperation, and computer assisted task planning all could enable more effective management by offering more timely information.

In orbit, automated means of metrology provide the first step to enabling automation of construction projects, remote visualization of construction progress, and remote direction of construction agents. And even though construction metrology methods are readily understood in terrestrial applications, the implications for automation in space need to be addressed.

## 2 CURRENT PRACTICE

Terrestrial based construction metrology is focused on surveying and inventory control. Automation is limited in both these fields at this time, primarily taking the form of hand-held computers for field operatives.

Surveying [1] is the science of taking spatial measurements on or near the Earth's surface. These measurements are used for planning and quality control throughout the life of a construction project. In surveying, one or more field workers use various tools (such as total stations) to measure distance, angles, and elevation. In even the most automated of these systems, a lone worker is required to move the system about and to determine which measurements to take [2].

Current research in automated surveying for excavation [8] shows some promise as integrated solutions for the automated collection of metrology data. Additionally, sensor systems have been designed to capture large amounts of survey-usable data. Examples include GPS and LIDAR (LIght Detection And Ranging). These technologies have shown promise to furthering integrated construction metrology and automation in general.

While there are a variety of methods of performing the ancient task of inventory control, methods for automation in construction domains are scarce. Some initial research between NIST and the Construction Industry Institute research team for RFId (Radio Frequency Identification) is attempting to develop methods for the tracking of discrete components on a site.

Many companies are also trying to develop automated inventory control systems to reduce overhead and increase the efficiency and accuracy of inventory control. Even these proprietary systems will benefit from standardized protocol to communicate results with integrated visualizers and construction management applications.

## 3 ISSUES FOR SPACE APPLICATION

Even today, proposed projects in space call for robotic automation in projects such as the International Space Station [3]. If we anticipate the ability to interchange different robots from different vendors to accomplish similar tasks, in addition to a framework for the physical integration of robots on the station, currently being done at NASA [3], but also an open and common metrology standard. This standard would enable these robots to report their operational status and any metrology they sense related to the station.

Information for construction robots in space will be construction metrology information. Information about the state of the construction site, location and quantities of components, and the status of activities of other robots (especially if the information reported by other robots is unreliable) are all included as part of the metrology that needs to be measured. Terrestrially, surveying and inventory control provide the basic tasks that generate metrology information.

Most terrestrial surveying is done on a 2-D plane, with leveling done to add elevation separately [1]. In orbit or free-space, a total 3-D methodology of surveying and positioning would need to be developed.

An old Newtonian rule states "objects in motion, stay in motion unless acted upon by an outside force; objects at rest, stay at rest". Terrestrially, this translates to most components in a construction site being "at rest" on the ground and stationary. In orbit, however, objects are rarely at rest, even if addressed in a local frame tied to a common base reference within work site. Addressing the location of a group of components as a trajectory in relation to the site may be important to ensure that the components do not leave the vicinity of the orbital construction site. Thus, the trajectory information for the site and components, as well as the robots, is necessary for a complete picture of the dynamic state of an orbital construction site.

Humans do most terrestrial surveying; in space there is a need to automate as much as possible, as human time for extra-vehicular activity is a limited and expensive resource. As well, extra-vehicular activity is a dangerous for the humans. Although teleoperation may solve some of the need for direct human action, research suggests performance penalties for teleoperation, even in experienced operators [12]. Additionally, researchers are beginning to investigate the nature of semi-autonomous teleoperation, in initiatives such as Carnegie Mellon's Lunar Rover Initiative [13]. In both cases, a standardized means of collecting metrology data is needed to present the most information possible.

In the past, single companies, provided proprietary solutions for space application. Proprietary total solutions would tend lock in a single corporate total solution provider. In a more openly competitive model, an overriding standard for data exchange could enable separate vendor robots to provide each portion of the solution.

## 4 PROPOSED SOLUTION

In our group at NIST, we are developing a new protocol LiveView. LiveView is a proposed protocol based on IEEE standard 1278, Distributed Interaction Simulation (DIS) – Application Protocols [4]. It adds standard methods of reporting sensory input into an IEEE 1278 based distributed system. This system may include several worker robots, teleoperators, remote viewers, and more. The main premise is that the protocol is designed to enable autonomy of agents in a Distributed System (DS) while providing a common means of sharing metrology and agent-state information.

DIS protocols are a well-accepted method for representing spatial and temporal information about dynamic, physical entities in a simulated world. The standard has extensions for reliable management and integration of live participants into a simulation. The Web3D consortium is addressing the issue of integrating DIS protocols with 3D graphical (VRML) browsers [5].

LiveView concentrates on adding extensions for the transmission of raw sensory data in generic formats for processing and updating models of the world. In a reference exercise underdevelopment, two field agents observe changes to the world and communicate the raw data to the DS for processing and eventual display to a construction manager's display and a database.

One field agent is an all-terrain vehicle mounting a turret LIDAR. The LIDAR produces range point and angle to point information, which can be viewed as a range map. Combined with the ATV's GPS, this provides a set of globally registered points. The vehicle takes surface scans of the construction site (e.g. of the terrain). The vehicle then passes the raw sensory data points over a wireless connection [7] to the DS, which eventually processes the points into a surface through one or more of the participating applications [Figure 1 below].

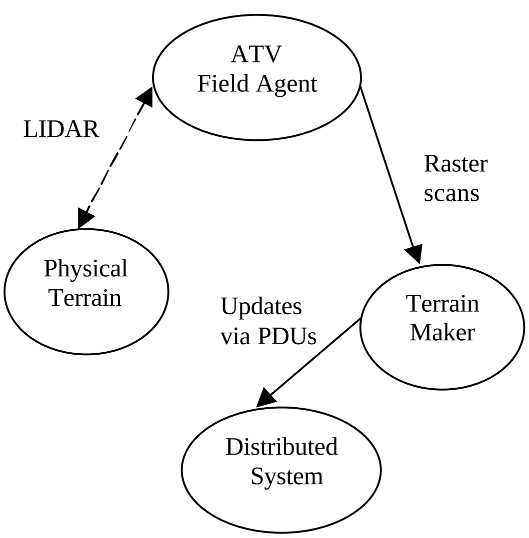


Figure 1. Diagram of Communication between a field agent and the DS.

The second field agent performs inventory control. Currently a person does this with a portable computer with a bar-code reader for part identification and a GPS antenna for position. The person scans the bar code of a component in the field. If needed, the person also acquires three or more fiducial points on the component, using the GPS antenna for locating the component in three-space. This information is then broadcast to the DIS, which updates the position of the component in a world model.

At the same time these field agents are providing updates to the world model, in this reference exercise a visualization application is displaying the updated information as soon as the application receives the new information, displaying a moved component and the movement of the ATV. The database archives the observed change(s) in position of a component. Another user of this information could be an autonomous construction agent awaiting a component for installation.

The basic units of communications between the agents are protocol data units (PDUs) similar in format to those already defined in IEEE 1278. LiveView, featuring standardized sensory PDUs, enables the sensory data to be sent to multiple separately designed applications, the manager's 3D display and the database. PDUs contain information in standard form, referenced to an agreed upon coordinate frame.

In our example, though the two agents appeared to be performing very different tasks, they were both essentially producing the same type of data – point clouds. LiveView uses the same representation for both types of data sets. The first point cloud set, of the ground, is handled by an application with authority to modify the global model of the ground, which it then rebroadcasts to the other applications in the system. The second point cloud, the three fiducial points, are handled by the simulated entity representing the component, which updates its location to the rest of the system after receiving the points.

Additionally, other applications could be predicting changes to the ground or the component based on the raw data.

Although our scenario uses humans to assist data collection, the ATV could have been autonomous [11], or the person could be replaced with a robot following a coverage pattern over the construction lay down yard.

This short example, when implemented, demonstrates potential in two key areas of construction metrology, surveying and tracking of components.

## 5 FUTURE WORK

We plan to release, a set of extensions to the DIS-Java-VRML [5] package to demonstrate some of the potential of LiveView. These extensions will demonstrate the point cloud sensory data, as well as a few other generic data types. LiveView, as part of a larger metrology system, is to be field tested on a real construction site.

To further prepare LiveView for possible use in space applications, LiveView will need to move away from the Earth-centric position data standard used in IEEE 1278. Potential solutions include referencing position to several local position beacon “corner stones” of the project (e.g. a central causeway of the station), or to the nearest celestial body and include detailed trajectory information. Further investigation of universal positioning beyond a narrow belt around the Earth’s surface is needed.

Security issues, such as authority and safety will need to be addressed.

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