The role of satellite laser ranging in space geodesy: developments, applications and Indian perspective

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Satellite laser ranging (SLR) has been a key geodetic technique for over 60 years, contributing to reference frame realisation, Earth orientation monitoring, orbit determination, and gravity field modelling. The International Laser Ranging Service (ILRS) operates a global network of 50 tracking stations, ensuring millimetre-precision measurements for the International Terrestrial Reference Frame (ITRF). However, challenges such as uneven station distribution, atmospheric effects, and retroreflector degradation impact data accuracy. The United Nations (UN) adopted the Global Geodetic Reference Frame (GGRF) resolution in 2015, aiming for 1 mm accuracy and 0.1 mm/year stability; however, the current precision stands at 5 mm and 0.5 mm/year. Advancements such as MiniSLR technology, automation, and high-power kHz lasers enhance precision. India is expanding its SLR capabilities with ISRO-tracked stations at Mount Abu and Ponmudi, alongside co-located geodetic sites at IIT Kanpur's Geodesy Village. The National Geospatial Policy 2022 (NGP 2022) supports the Continuously Operating Reference Stations (CORS) network for horizontal datum definition, strengthening India's self-reliance in space geodesy and terrestrial reference frame realisation. The objective of the present article is to consolidate global and Indian developments in SLR, highlighting its applications in geodesy and India's geodetic future.

Keywords: ILRS, National Geospatial Mission, National Geospatial Policy 2022, satellite laser ranging, space geodesy

SATELLITE laser ranging (SLR) is the only geodetic technique operating in optical wavelengths, crucial for reference frame realisation[1–3]. It plays a key role in the Global Geodetic Observing System (GGOS) by directly measuring the Earth's center of mass (CM)[3], unlike Global Navigation Satellite System (GNSS) and Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS), which rely on ground station distributions. SLR enables precise geocenter motion estimation[4,5] and Earth Orientation Parameter (EOP) monitoring, achieving sub-milliarcsecond[6,7]. accuracy in polar motion and length-of-day (LOD). It also supports precise orbit determination (POD), validating satellite orbits[8,9] with 1–2 cm accuracy for LAser GEOdynamic Satellite (LAGEOS)[10], 3–5 cm for GNSS satellites[11–13] and 1–3 cm for Low Earth Orbit (LEO) missions like Jason-3 and Sentinel-3 (refs 6,14,15). Additionally, SLR contributes to time-varying gravity field modelling and mass transport studies[16,17], offering mm-level accuracy and long-term data continuity since the 1970s. Its unique capabilities make it indispensable in space geodesy and geophysical research[10,18,19]. The present review article provides a comprehensive overview of global developments in SLR, outlines its diverse geodetic applications, and presents India's recent initiatives, including the Geodesy Village, that aim to strengthen national geodetic infrastructure.

Global SLR developments

SLR has evolved through decades of international collaboration. National Aeronautics and Space Administration's (NASA) Goddard Space Flight Center achieved the first successful satellite laser ranging in 1964, launching SLR as a geodetic technique[20]. During the 1970s–80s, the network expanded with fixed stations in the U.S., Europe, and the Soviet Union, along with mobile units for global geodetic campaigns. Agencies like NASA, the space agency of the Union of Soviet Socialist Republics (USSR), and the European Space Agency (ESA) spearheaded developments, deploying transportable systems like French Transportable Laser Ranging Station (FTLRS) and MOBile LASer Ranger (MOBLAS)[10,21–24]. By the 2000s, the International Laser Ranging Service (ILRS) had integrated regional networks into a unified global system, standardising data for geodesy, space navigation and Earth monitoring[2,10].

SLR technique and measurement principles

SLR measures the distance between ground-based reference stations and orbiting satellites using short-pulse lasers, optical receivers, and advanced timing systems. The technique works by transmitting a laser pulse from an SLR station to a satellite equipped with a retroreflector array, which reflects the signal back to the ground[25,26]. The

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