The Mars 2020 Lander Vision System
IPPW 2016

Jet Propulsion Laboratory
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Mars

TRN required to access best science sites and land near pre-deployed assets

Europa

TRN required to land safely on science site

Enceladus

TRN required to land near water plumes

Comets

TRN required to safely acquire a sample

Asteroids

TRN required to pick up boulder

The Moon

TRN required to access permanently lit terrain
Map Relative Localization (MRL)

Inputs

Initial State
- pos h: ±3.2km
- alt: ±150m
- vel: ±1.5 m/s
- att: ±0.5°

Camera

Map

IMU

Batch Initialization

Residuals

Extended Kalman Filter

coarse landmark matching

fine landmark matching

Complete in 10 seconds

Propagate

Batch update

Propagate

EKF update

Propagate

EKF update

Remove Initial Position Error (3km 3-) Final Position Accuracy (40m 3- @ 2km)
The Vision Compute Element (VCE) is a 3 slot 6U processor with a RAD750 general purpose processor, a power conditioning card (CEPCU1) and a new Virtex5 enabled Computer Vision Accelerator Card (CVAC).
LVS Camera (LCAM)

- Mass: ~1000 g
- Volume: ~150 mm x ~100 mm x ~100 mm (HxWxD)
- Power: ~4W idle, ~8W average, ~11W peak
- Image format: 1024x1024 pixels, 8-bits / pixel
- Spectral range: 480 nm to 720 nm, monochrome
- Field-of-View: 90°x90°, f-tan-theta projection
- Nominal exposure time: ~400µs, global shutter
- Nominal frame rate: 1Hz
MRO CTX imaging is used to generate the LVS map
- CTX images are 6m/pixel and about 30km across
- MRO images the landing site around the time of landing (telecom constraint)
- stereo pairs are needed for elevation map generation while one of the stereo images is used for the appearance map

- 2 stereo pairs are needed to cover the map area
- an additional 2 stereo pairs will be used for V&V of the map
- these CTX images are being collected as part of M2020 landing site assessment
MRL Processing Phases

Spacecraft Initialization State
(position error < 3.2 km)

- altitude < 3700m

Coarse Match
(position error < 200m at 4.5s)

- LVS State Estimate
- 3 images processed

Fine Match
(position error < 54m at 6s)
(position error < 40m at 10s)

- LVS State Estimate and Validity
- altitude < 2km or BSS
VCEFSWE and MRL Algorithms Data Flow

Radial Distortion Correction
Homography Warp
Image Normalization
Interest Operator
FFT Correlation
Spatial Correlation

Hardware

Sensor

Device Driver/Library Module

Task Module

Event w/ data

RCE FSW

VCEFSW

VCEFSW Driver

MRL

RCE RAD750

VCE RAD750

LVS

HO

BCMGR

BCDRV

MCICDRV

IML

ICCITCDR

MSIADRV

VCE

MGR

DIMU

CVAC

VP

FPGA

MCIC

1553

BC

1553

MCIC

FPGA

CVAC

HK

HSS

MSIA

ICCI

TC

LVS

Main

IP

MGR

LCAM

MGR

DIMU

MGR

1553

MGR

seqlib

filtlib

iplib

imu_pkt

LVS_meas_pkt

camera_pose

rhnifs_invoke

rhnifs_result

rhnifs_prep

img_available

ML_pkt

batch_estimate

ML_update

img_exposed_time

imu_pkt

img_exposed_time

init_pkt

xfer

expose

sRTI

ML_pkt

filter_done

imu_pkt

init_pkt

sRTI

ML_pkt

filterbtp

camera_pose

sRTI

hss

HSS

MCICDRV

IML

BCDRV

BCMGR

LVS

HO

LVS

HO

DIMU

CVAC

VP

FPGA

MCIC

1553

BC

FPGA

CVAC

HK

HSS

MSIA

ICCI

TC

RCE FSW

VCEFSW

VCEFSW Driver

MRL

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LVS Operations Timeline

LVS is powered on at E-8m30s

Map Relative Localization with MSL Data (MARDI, DIMU and CTX Map)

MARDI Image

CTX Map

Radar Data Collection

~800s before nav filter converges

LVS Start (3.7km)

~20s in LVS operational altitude window

LVS End (Backshell Separation or 2km)

Safe Target Selection Divert

Divert Maneuver

Powered Descent

Flyaway

Sky Crane
5 Landmark Movie: CZ02.1.6 Movie

- Significant terrain relief
- 20 degree elevation angle with terrain relief
Horizontal Position Error Scatter Plot
After Fine Match and EKF (8 images total)

Error (Est - Truth) p_M2B_in_M

meets 40m requirement
BACKUP
LVS Architecture

LVS operates during parachute descent when descent stage and rover are attached and inside backshell.

Descent Stage

LVS uses the Descent IMU (DIMU) on the descent stage.

Rover

The VCE is inside the rover.

LVS camera (LCAM) is on rover, 90° FOV.