Mars Science Laboratory
Technology Functional Design Document
Extended Kalman Filter (EKF)

Revision: 1

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MSL Technology Functional Design Document –EKF

Signature Sheet

Approval

Eric Baumgartner – Technology Provider Date

Dan Haines – CLARAty POC Date

Platforms:

☐	Rocky 7	X	Rocky 8
☐	FIDO	☐	K9
☐	Other		

Terry Huntsberger – Task Manager, Test & Validation: Long Range Traverse Date

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Revision History

Revision	Date	Description	Author
DRAFT	12/15/02	draft	Terry Huntsberger
Initial Release	01/15/03	Initial document without system figure	Eric Baumgartner
Rev 1	03/20/03	Added system figure and commands from CLARAty website	Terry Huntsberger

1 Introduction

This document contains the Functional Design Description (FDD) for the EKF software functionality. EKF includes the two-tiered algorithm for estimation of rover heading and position based on inputs from wheel encoders and the IMU. This document covers both the nominal and off-nominal (fault protection) functionality of EKF.

2 Related Documents

The documents related to EKF are given in Table 1

Table 1 – Related Documents

Document Title
T. Huntsberger, H. Aghazarian, Y. Cheng, E.T. Baumgartner, E. Tunstel, C. Leger, A. Trebi-Ollennu and P.S. Schenker, "Rover Autonomy for Long Range Navigation and Science Data Acquisition on Planetary Surfaces," *Proc. IEEE International Conf. on Robotics and Automation (ICRA2002)*, Washington, DC, 3161-3168, May 2002.
E. T. Baumgartner, H. Aghazarian, and A. Trebi-Ollennu, "Rover Localization Results for the FIDO Rover," *Sensor Fusion and Decentralized Control in Autonomous Robotic Systems IV* , SPIE Proc. Vol. 4571, Newton, MA, 34-44, Oct 2001.
E.T. Baumgartner, H. Aghazarian, A. Trebi-Ollennu, T.L. Huntsberger, and M.S. Garrett, "State estimation and vehicle localization for the FIDO rover," *Proc. SPIE Symposium on Sensor Fusion and Decentralized Control in Robotic Systems III,* 4196, Boston, MA, 329-336, Nov 2000.
T.L. Huntsberger, E.T. Baumgartner, H. Aghazarian, Y. Cheng, P.S. Schenker, P.C. Leger, K.D. Iagnemma, and S. Dubowsky, "Sensor fused autonomous guidance of a mobile robot and applications to Mars sample return operations," *Proc. SPIE Symposium on Sensor Fusion and Decentralized Control in Robotic Systems II*, 3839, Boston, MA, 2-8, 1999.
B. H. Hoffman, E. T. Baumgartner, T. A. Huntsberger, and P. S. Schenker, "Improved State Estimation in Challenging Terrain," *Autonomous Robots*, Vol. 6, No. 2, pp. 113-130, April 1999.
E.T. Baumgartner, P.S. Schenker, C. Leger, and T.L. Huntsberger, "Sensor-fused navigation and manipulation from a planetary rover," *Proc. SPIE Symposium on Sensor Fusion and Decentralized Control in Robotic Systems*, Vol. 3523, Boston, MA, 58-66, 1998.

3 Requirements

The baseline localization accuracy requirement from the current MSL reference mission is 3% of the total distance traveled. There is currently no requirement for heading accuracy based on EKF.

4 Hardware Interfaces and functionality

The EKF interfaces to H/W include:

- Wheel encoders
- IMU

5 Basic Software Functionality

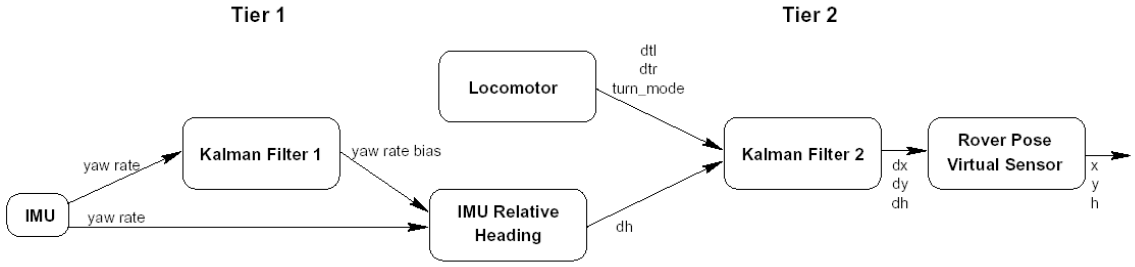

Figure 1 – EKF SW Context

This section describes the nominal and off-nominal SW functionality required for EKF. Figure 1 provides the SW context for EKF in the rover system. The primary use of EKF is for stabilization of the IMU bias drift and estimation of vehicle heading and position based on the fusion of IMU and wheel encoder data. For EKF, the IMU bias is estimated while the vehicle is stopped using a linear Kalman filter (Tier 1 in Figure 1) and is then fixed during vehicle movement. The second stage of the EKF (Tier 2 in Figure 1) uses a non-linear Kalman filter to fuse the IMU yaw and wheel encoder data for vehicle heading and position. This can be done continuously or updated during the next rover stop.

5.1 Set Rover Position (float X, float Y, float Heading)

Description: set rover position to <X>, <Y> with a heading of

<Heading> degrees, where X, Y and Heading are relative to the initial starting position of the rover.

Units:

X: meters

Y: meters

Heading: degrees float

5.2 Move (float Length, float Heading)

Description: move rover <Length> meters with a heading change of

<Heading> degrees.

Units:

Length : meters

Heading: degrees

Note: This command can be used to do:

straight-line-drive: set heading to 0

turn-in-place: set length to 0

5.3 Go To (float X, float Y)

Description: move rover to absolute position <X>, <Y> relative to the initial starting position of the rover.

Units:

X: meters

Y: meters

5.4 Enable Estimation (void)

Description: Turn on EKF position estimation

5.5 Disable Estimation (void)

Description: Turn off EKF position estimation

5.6 Set Collection Rate (int Frequency)

Description: collect data at a rate of <Frequency> Hertz.

Units:

Frequency: Hertz

5.7 Open Data File (int d)

Description: write collected data to file named psefile<d>.txt.

The logged data format will be:

System Time

Output Estimated X - float, in meters relative to rover start position

Output Estimated Y - float, in meters relative to rover start position

Output Estimated Heading - float, in degrees relative to rover start position

Output Covariance for X, Y, H (3x3 matrix of floats)

Input: IMU yaw rate - float, radians per second

Input: Encoders from two center wheels - float, rotations since previous data

Internal: MOVE TYPE - string (arc, straight-line, turn-in-place)

5.8 Close Data File ()

Description: close a currently open data file.

5.9 Exit (void)

Description: exit the system. This will close an open data file, if there is one. Move (

5.10 Engineering Data Products

The details of the data products generated during EKF commands are primarily the internal inputs to the EKF algorithm, the EKF outputs in terms of the estimated position, heading and covariance matrix, and the rover command. Conceptually there are two data products:

- EKF Data Product
    - Starting conditions
    - Time history during operation at 200Hz rate
    - Output: Estimated X - float, in meters relative to rover start position
    - Output: Estimated Y - float, in meters relative to rover start position
    - Output: Estimated Heading - float, in degrees relative to rover start position
    - Output: Covariance for X, Y, H (3x3 matrix of floats)
    - Input: IMU yaw rate - float, radians per second
    - Input: Encoders from two center wheels - float, rotations since previous data
    - Internal: MOVE TYPE - string (arc, straight-line, turn-in-place)
    - Ending conditions

- EKF Error Data Product
    - Includes specific fault condition and recent detailed history of relevant data.

6 Fault Protection Software Details

The fault monitors or safety checks for EKF are detailed in following sections. The limits and persistences for the fault monitors are ground-settable. The responses to these faults can be disabled.

6.1 EKF Fault Monitors

None in the current release.

6.2 EKF Fault Response

None

6.3 EKF Fault Monitors not in current release

6.3.1 Loss of IMU

Data feed from IMU is unavailable due to loss of power to unit or loss of serial line.

7 Operational Constraints

1. IMU should be allowed to stabilize prior to measurements for at least 15 seconds during power up sequence.